FortisBC Inc Advanced Metering Infrastructure CPCN
Exhibit C17-8

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November 23, 2012

VIA ELECTRONIC MAIL

British Columbia Utilities Commission
6th Floor, 900 Howe Street
Vancouver, B.C.
V6Z 2N3

Attention: Erica M. Hamilton, Commission Secretary

Dear Sirs/Mesdames:

Re: FortisBC Inc. Application for a Certificate of Public Convenience and Necessity for the Advanced Metering Infrastructure Project ~ Project No. 3698682

We are counsel for the Commercial Energy Consumers Association of British Columbia (CEC). Attached please find the CEC's second set of Information Requests pertaining to the above-noted matter.

A copy of this letter and attached Information Requests has also been forwarded to FortisBC and registered interveners by e-mail.

If you have any questions regarding the foregoing, please do not hesitate to contact the undersigned.

Yours truly,

OWEN BIRD LAW CORPORATION

Christopher P. Weafer
CPW/jlb
cc: CEC
cc: FortisBC Inc.
cc: Registered Interveners

COMMERCIAL ENERGY CONSUMERS ASSOCIATION OF BRITISH COLUMBIA ("CEC")

INFORMATION REQUEST #2

FortisBC Inc. Application for a Certificate of Public Convenience and Necessity for the Advanced Metering Infrastructure Project Project No. 3698682

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1. Reference: Exhibit B-11, CEC 1.1 and Exhibit B-1-1, Application Errata Updated, Page 69

FortisBC confirms that the outcomes noted above will be achieved by the proposed AMI Project. Further, it should be noted that these outcomes are inextricably linked to the significant financial and non-financial benefits (outcomes) that result from the proposed Project. It is these benefits, as identified in the Application, which drive the need for the implementation of AMI at this time.

The summary table below displays the total savings to FortisBC customers between 2015 and 2030 and calculates the net present value of these savings in 2012 dollars.

Table 5.0 - AMI Cost and Benefit Summary

Benefits		2012 NPV ($000s)
	Meter Reading	(23,785)
	Theft Reduction	(38,386)
	Remote Disconnect/Reconnect	(5,466)
	Meter Exchanges	(1,478)
	Contact Centre	(441)
Costs		
	Operating Costs	14,320
	Depreciation Costs	16,464
	Carrying Costs	17,163
	Income Tax	3,982
Total		(17,629)

QUANTIFIED BENEFITS INCLUDED IN THE APPLICATION

Functionality (A)	*Means (B)*	*Benefit(C)*	*Financial - NPV (D)*	*Reference (E)*	*Duration (F)Note 1.*
Transition from analogue to digital meters	Installation of 115,000 new digital meters throughout FortisBC territory	1.Cost avoidance related to meter exchanges	1. $1.478 million	1. B-1-1 Appl Errata Updated p.69	1.*
Energy balancing and loss management; Increased	Feeder, transformer and portable meters; Customer	1. Theft loss detection and deterrence	1.Theft benefit $38.386 million	1.B-1-1 Appl Errata Updated p.69	1. **

granularity and synchronicity of customer electricity consumption ; multiple attribute sensing	meters with near real-time information recording; additional sensors				
Two way communication between the customer and utility	Radio signal	1.Reduced manual meter reading expenses 2.Reduced Contact Centre costs 3.Remote disconnect/reconnect	1.$23.785 million 2.$.441 million 3.$5.466 million	1.B-1-1 Appl. Errata Updated p.69 2.B-1-1 Appl Errata Updated p.69 3.B-1-1 Appl Errata Updated p. 69	1.*** 2.*** 3.***
TOTAL			$69,556,000		
COSTS			$51,929,000		
NET Quantified Ben.			**$17,629,000**	B-1-1 Appl Errata updated p.69	
Add'l Benefits Note 2.					
Meas. Canada Cust.Inf.Portal In-Home Display			$9,800,000 $3,800,000 $9,800,000	B-1 Appl p.94 B-11 CEC IR1 1.61.1 B-11 CEC IR1 1.61.1	1.* 2.*** 3.***

Note 1: *One time reduction; ** Reduction over project life *** Enduring benefit

Note 2: Additional benefits are those that have been Quantified by FortisBC but not incorporated into the NPV customer benefit calculation.

1.1. The above table categorizes the FortisBC AMI project Financial benefits into three classifications (by functionality) as follows: Functionality (Column A); the Means by which the functionality is achieved (Column B); the types of Benefit that will be derived(Column C); the financial value of each benefit (Column D); source reference (Column E) and the duration for which the benefits can be expected accrue.(Column F). Duration is characterized as being a one-time saving; saving over the project life or an enduring benefit which can be expected to last beyond 20 years providing sustaining capital replacements are made as necessary. Please complete and/or adjust the table to include all the quantified Financial Benefits, the Total Benefits and Total Costs in the event anything is missing or misrepresented.

2. Reference: Exhibit B-6, BCUC 1.14.1 and Exhibit B-11, CEC 1.61.1

Non-financial customer service benefits are detailed in Exhibit B-1, Tab 3.0, Section 3.2.5: Conservation Rate Structures, Enhanced Billing Information, Improved Billing Accuracy, Consolidated Billing for Multiple Customer Locations, Flexible Billing Date and Reduced Need to Access Customer Premises.

Non-financial operational benefits are detailed in Exhibit B-1, Tab 3.0, Section 3.2.5: Enhanced System Modeling, Improved Financial Reporting, Load Forecast and Cost of Service Analyses, Improved Safety, Reduced GHG Emissions, Immediate Notification of Power Outage and Restoration and Improved Power Quality Monitoring.

Information Portal (CIP), the NPV of the net benefit to customers improves by approximately $3.8 million to $21.4 million; and

In-Home Display (IHD), the NPV of the net benefit to customers improves by approximately $9.8 million to $27.4 million.

NON-QUANTIFIED BENEFITS

Functionality	*Means*	*Benefit*	*Notes*	*Reference*	*Duration Note 1*
Transition from analogue to digital meters	Installation of 115,000 new digital meters throughout FortisBC territory	1.Improved accuracy of metered consumption 2. Measurement Canada avoided cost of capital	1.Fairness for all rate payers 2.$9.8 million	1.B-1 Appl p.2 2. B-1 Appl p.94	1.*** 2.*
Energy balancing and loss management; Increased granularity and synchronicity of customer electricity consumption information; multiple attribute sensing	Feeder, transformer and portable meters Customer meters with near real-time information recording Software infrastructure; additional sensors	1.Improved system planning 2.Improved financial reporting/fcsting 3.Enhanced billing options such as flexible dates and consolidated bills 4.Customer portal benefits and IHD information for customers 5.Improved power quality monitoring 6.Improved outage management /restoration 7.Theft and grow op deterrence	1.May have $ value 2.Public interest 3.Customer service 4. Estimated savings of $3.8 mil for Customer Info portal 5.May have $ value 6.Customer service 7.Health and public safety	1.B-1 Appl p.35 2.B-1 Appl p.36 3.B-1 Appl. p32 4.B-11 CEC IR 1 61.1 5.B-1 Appl p.39 6.B-1 Appl.p38 7.B-1 Appl p 83	1.*** 2.*** 3.*** 4.*** 5.*** 6.*** 7.**

Two way communication between the customer and utility	Radio signal	1. Reduction of 170 tonnes of GHG per year 2.Facilitation of Conservation rate structures with IHD 3.Reduced need to access customer premises 4.Improved safety	1.Environment and public health 2. Est.$9.8 mil NPV 3.Customer service 4.Safety and public health derived from vehicle use	1.B-11 CEC IR 1 25.1 2.B-11 CEC IR 61.1 & Appl p.31 3.B-1,Appl pg.34 4.B-1 Appl p.36	1.** 2.*** 3.*** 4.***

Note 1: *One time reduction ** Reduction over project life *** Enduring benefit

2.1. The above table categorizes the FortisBC AMI project Non- Quantified benefits into three classifications (by functionality) as follows: Functionality (Column A); Means by which the functionality is achieved (Column B); the types of benefit (Column C); Notes with characterization as to where the benefit may be attributed and any predicted financial value of each benefit (Column D); source reference (Column E) and the duration for which the benefits can be expected accrue (Column F). Duration is characterized as being a one-time saving; saving over the project life or an enduring benefit which can be expected to last beyond 20 years providing sustaining capital replacements are made as necessary. In the event information is missing or misrepresented, please complete and/or adjust the table to include any and all Non-Quantified benefits that FortisBC expects to achieve with the AMI project.

2.2. Please confirm that those non-quantified benefits for which a dollar value may or may not be assigned may be considered in the customer or public interest and thereby a worthwhile objective for FortisBC to pursue.

2.2.1. Please also confirm that many of the non-quantified benefits for which a dollar value may or may not be assigned are not insignificant and contribute considerable value to the AMI project.

3. Reference: Exhibit B-1, Application, Page 97

Table 6.0 – Future Benefit Implementation

Future Benefit	Trigger Type	Trigger
Distribution Loss Reduction	Event	After AMI Project is implemented and distribution losses are accurately established.
Power Grid Voltage Optimization	Event	Higher power purchase costs or lower implementation costs make the project economic
Outage Management	Date	Possible regulatory application in 2015
Customer Pre-Pay Tariff	Date	Possible regulatory application in 2015
Future Conservation Rate Structures	Date	Possible regulatory application in 2016

FUTURE BENEFITS

Functionality	*Means*	*Benefit*	*Possible Benefit*	*Reference*	*Duration*
Transition from analogue to digital meters	Installation of 115,000 new digital meters			.	
Energy balancing and loss management via Increased granularity and synchronicity of customer electricity consumption information; multiple attribute sensing	Customer, Feeder, and transformer meters;.Meters with near real-time inforecording Tap changers, voltage regulators, Software infrastructure; addit'l sensors	1. Distribution loss reduction 2.Conservation Voltage Regulation 3.Outage management 4.Distribution automation 5.Real time transmission line rating 6.Work mgt system	1.$3.3 mill/year @1% reduction 2.May have $ value 3.May have $ value; customer service 4.May have $ value 5.May have $ value 6.May have $ value	1.B-1 Appl. P.97 2.B-1 Appl p.98 3.B-1 Appl p.101 4.B-6 BCUC 1.12.3 5. B-6 BCUC 1.12.3 6.B-6 BCUC 1.12.3	1.*** 2.*** 3.*** 4.*** 5.*** 6.***
Two way communication between the customer and utility	Radio signal	1.Future conservation rate structures 2.customer pre-pay 3.Improved outage management 4.Distribuion generation	1.May have $ value 2.May have $ value 3.May have $ value; customer service 4. May have $ value; customer service;env't;	1.B-1 Applic p.103 2.B-1 Applic p.103 3.B-1 Applic p.101 4. B-6 BCUC	1.*** 2.*** 3.*** 4.***

		5.Electric vehicle integration 6.HAN (Zigbee) 7.Demand Response	5.env't; cust. Service;may have $ value 6.cust. service Env't 7.$ value; customer service	1.12.3 5. B-6 BCUC 1.12.3 6.B-11 CEC 1.51.1 7.B-11 CEC 1.23.5	5.*** 6.*** 7.***

Note: *One time reduction; ** Reduction over project life *** Enduring benefit

3.1. The above table categorizes the FortisBC AMI project Future benefits into three classifications by functionality as follows: Functionality of the existing AMI as a foundation for benefits which may be pursued in the future(Column A); Means by which the functional foundation is achieved (Column B); description of the possible future benefit (Column C); a characterization of the possible benefits and any predicted financial value of each benefit (Column D); source reference (Column E) and the duration for which the benefits can be expected accrue if undertaken (Column F). Duration is characterized as being a one-time saving; saving over the project life or an enduring benefit which can be expected to last beyond 20 years providing sustaining capital replacements are made as necessary. Please complete and/or adjust the table to include all Future Benefits and any available quantification in the event anything is missing or misrepresented.

3.2. Please confirm that those non-quantified Future benefits for which a dollar value may or may not be assigned may be considered in the customer or public interest and thereby a worthwhile objective for FortisBC to pursue including the AMI project's role as foundation for the Smart Grid and the Smart Home.

3.2.1. Please also confirm that many of the non-quantified benefits for which a dollar value may or may not be assigned are not insignificant and contribute considerable value to the AMI project.

4. Reference: Exhibit B-11, CEC 1.1

> FortisBC confirms that the outcomes noted above will be achieved by the proposed AMI Project. Further, it should be noted that these outcomes are inextricably linked to the significant financial and non-financial benefits (outcomes) that result from the proposed Project. It is these benefits, as identified in the Application, which drive the need for the implementation of AMI at this time.

4.1. Would FortisBC agree that the physical implementation will be conducted in accordance with accepted corporate guidelines and will also result in a visual examination of every meter base during the exchange?

4.2. Would FortisBC agree that by employing wireless technology for communication FortisBC is utilizing a cost-effective and widely accepted technology that has been in use globally for decades?

4.2.1. Would FortisBC agree that similar wireless technology is ubiquitous in North America for a vast array of applications in a vast array of industries including those in which the security of information transmitted is paramount? If not, please explain in what way the wireless technology employed is novel or unique.

4.2.2. Would FortisBC agree that the use of wireless technology is continuing to grow and can be expected to continue to grow world-wide?

5. Reference: Government of Canada website: http://www.climatechange.gc.ca/dialogue/default.asp?lang=En&n=E47AAD1C-1 and Exhibit B-11 BCSEA 1.3.1 Appendix 'The Canadian Smart Grid Standards Roadmap', Foreword, Exhibit B-11, BCPSO 1.4.1 and Exhibit B-11, CEC 1.10.1

"The Clean Energy Dialogue (CED) was established between Canada and the United States in February 2009 to enhance joint collaboration on the development of clean energy science and technologies to reduce greenhouse gases and combat climate change.

This Dialogue is an important initiative in support of our ongoing efforts towards building a low-carbon economy."

This project supports a number of key government objectives, including expanding Canada-United States collaboration under the Clean Energy Dialogue. By identifying a path forward on

- Existing provincial energy policy and legislation articulating the government's desire to have advanced meters and a smart grid in place for customers of other public utilities other than BC Hydro;
- The transition by the electric industry towards the use of advanced meters as the standard form of metering technology;

The CPCN Application assumes a stable regulatory and legislative environment. The Company believes the additional considerations related to the decision to proceed with the Application at this time as articulated in the responses to BCUC IR No. 1 Q2.1 and BCPSO IR No. 1 Q4.1 clearly underscore the fact that the proposed Project ought to be considered as being in the public interest.

5.1. Would FortisBC agree that the Smart Grid is a key element of an international technological trend in advancing clean energy and conserving energy?

5.2. Does FortisBC believe that the Smart Electric Grid may be considered part of the collaborative efforts articulated in the Clean Energy Dialogue? If so, would FortisBC agree that the development of the Smart Electric Grid is in the national as well as the provincial interest?

5.3. Please confirm that in FortisBC's view the AMI project and the Smart Electric Grid is in the public interest regardless of a change in the regulatory and legislative environment because in addition to supporting environmental objectives the AMI project is cost effective for FortisBC customers?

6. Reference: Exhibit B-11, BCSEA 1.3.2 and Exhibit B-11, BCSEA 1.3.1, Appendix - The Canadian Smart Grid Standards Roadmap: A Strategic Planning Document, (The Canadian Smart Grid Standards Roadmap) Foreword

> In general, FortisBC agrees that the referenced document is helpful in establishing a common reference point for utilities and manufacturers.

> The transition to a smarter electric grid holds significant promise for the achievement of a number of important public policy objectives. Smart grid technologies will enhance the reliability, resiliency and efficiency of the electric network, as well as improve environmental performance by enabling consumers to play a more active role in their energy use decisions and helping to integrate renewable resources such as wind

> inform consumers of the amount of energy they consume, and at what cost. It will spur infrastructure development and investment in related technologies such as plug-in electric vehicles. Importantly, an effective standards regime enhances Canada's competitiveness by

> Continental alignment in this regard is critical, given the interconnectedness of our trading relationship and electrical infrastructure.

6.1. Does FortisBC agree with the above three excerpts from the 'The Canadian Smart Grid Standards Roadmap'?

6.2. Does FortisBC believe that the AMI project will provide the foundation and beginning or continuing steps of the Smart Electric Grid in its territory?

6.3. Does FortisBC believe that an Electric Smart Grid has already or will become standard throughout North America within the next 10 years?

6.4. Does FortisBC believe that the AMI project contributes to the 'continental alignment' of standards for the electrical infrastructure? If so, please elaborate and include commentary on whether or not the AMI project using wireless Itron OpenWay smart meters can be expected to capitalize on the technological development trends by serving as a typical platform and interfacing appropriately with Smart Grid developments throughout the continent.

7. Reference: Exhibit B-11, CEC 1.16.1, CEC 1.16.2, CEC 1.16.3 and CEC 1.61.1

> The forecast adoption rate, and therefore the demand calculated from it, was derived primarily from residential studies. However, it is not unreasonable to assume (for IHDs and the customer information portal) that adoption rates for commercial customers would be in similar proportion to the residential rates.

> Commercial users can use the information to help manage their consumption in the same manner that residential customers can: by changing their consumption behaviour (turning lights off when not in use, for example) or by investing in energy efficiency equipment (more efficient lighting).

> Commercial customers that are subject to a demand charge can use hourly (or more frequent from an in-home display) information to find out when their power use is highest to try and reduce their peak use and thereby manage their bill.

Yes, through requests made to the Commercial PowerSense representatives. It is useful information that helps customers mitigate demand spikes (and thereby helps them manage their bills).

- As discussed in the response to BCSEA IR No. 1 Q44.2, if the proposed AMI Project financial analysis took into account the potential savings resulting from customer use of the In-Home Display (IHD), the NPV of the net benefit to customers improves by approximately $9.8 million to $27.4 million.

7.1. Given that some commercial customers have specifically requested more detailed consumption information, would FortisBC agree that commercial customers may be more likely than residential customers to adopt IHDs and employ conservation measures to manage their electricity bills?

7.2. Please calculate the NPV of the potential value of the In-Home Display incorporating commercial customer participation or, if already included, please confirm $9.8 million as the potential savings from all customer groups participating.

8. Reference: Exhibit B-11, CEC 1.23.8, CEC 1.24.1 and CEC 1.24.2

Demand Response control refers to the ability for the utility to dynamically push information on power purchase pricing or system capacity constraints to customers in order to modify their consumption patterns. A simple example would be the ability to send critical-peak pricing information to a customer's thermostat (via the AMI meter and wireless HAN) to automatically increase the temperature setpoint during the summer peak hours when high power purchase costs were being experienced.

Confirmed. Some individual customers may be able to reduce their total annual billings if they are able to alter their consumption patterns to take advantage of the conservation rate structures. Customers in general may benefit if the aggregate customer response results in cost savings to the utility.

Table ES-1: Per Participant Savings for Possible AMI Future Programs

Program Type		Peak	Energy	Source
Conservation Rates	TOU	11%	5.5%	BC Hydro CRP[2]
	CPP/CPR	10%	0	
	Inclining	1.8%	1.8%	BC Hydro CRP[2]
Pre-Pay		5.8%*	11.7%	Woodstock Hydro 2004[3]
Load Control		13.3%	0	FERC 2009
In-Home Displays		2.7%	5.4%	ACEEE 2010

* Assumed that the peak period savings are half of the annual savings

8.1. Would FortisBC agree that Demand Response control would enable customers to reduce their consumption with less effort than would be required to actively manage consumption such as by adjusting thermostats or turning off lights?

8.2. Would FortisBC agree that an individual commercial building owner with multiple tenants could aggregate significant savings with Demand Response control and conservation rates that might otherwise go unaddressed by individual tenants because of the smaller impact on their electricity bill?

8.2.1. Has FortisBC identified any industries where Demand Response Control and conservation rates would be of particular benefit to commercial users? If so, please state the industries and explain why it may be of particular benefit.

8.3. Reference: Exhibit B-11, CEC 1.51.4 and CEC 1.89.1.1 and CEC 1.89.1.1.2

> Confirmed, assuming that "Smart Home" applications require a HAN (Home Area Network) that can provide electricity consumption and pricing information.
>
> 89.1 Does FortisBC agree that customer adoption of conservation practices will likely increase with familiarity of conservation rate programs and the technology that supports them?
>
> <u>Response:</u>
>
> Yes.
>
> If the question is referring to the participation rate in TOU programs, FortisBC believes the most effective means to increase customer participation is education and the implementation of DSM programs designed to help customers take advantage of the pricing periods.

8.3.1. Would FortisBC agree that the future 'Smart Home' technologies can be expected minimize the effort associated with reducing electricity consumption?

8.3.2. Would FortisBC agree that pricing incentives contribute to electricity conservation by financially rewarding a customer for their 'effort' in reducing electricity consumption?

8.3.3. Please identify any ways in which the AMI project will contribute to the advancement of conservation practices or technologies in the absence of pricing signals by building a culture of conservation in society.

9. Reference Exhibit B-11, CSTS 1.37.1

> The proposed AMI meters are manufactured to the ANSI C12.20 standard which specifies increased accuracy over the ANSI 12.1 standard that the existing electro-mechanical meters were required to meet. The new meters are required to be accurate to within 0.5% compared to 2% for the electro-mechanical fleet.

9.1. Do electro-mechanical meters become less accurate over time?

9.1.1. If so, is FortisBC aware of whether or not aging electro-mechanical meters can be expected to record more or less than actual consumption over time and as they age?

9.1.2. If so, could a 1.5% increase in accuracy alone translate into savings for FortisBC or would better accuracy improve fairness in billing to customers? Please explain.

10. Reference: Exhibit B-11, CEC 1.2.1 and Exhibit B-11, CEC 1.3.1

> There would have to be a significant change in the composition of the meter population through obsolescence, technological change or the like that would materially change either the useful life of new meters or the average life of the population.

10.1. Please confirm that FortisBC would consider the risk of the above circumstances occurring to be extremely low.

11. Reference: Exhibit B-11, CEC 1.31.

Would Fortis BC consider not revising the depreciation rate and continuing with 5 percent over the 20-year period?

Yes.

The advantage of a stable depreciation rate is that it supports stable customer rates.

11.1. Please confirm that FortisBC does not see any disadvantages in having a stable depreciation rate.

11.1.1. If not confirmed, what are the disadvantages of not revising the depreciation rate?

11.1.2. Does FortisBC consider stable customer rates as an objective?

12. Reference: Exhibit B-11, CEC 1.61.1.

FortisBC believes the assumptions it has provided in the Application as related to the benefits associated with the implementation of AMI are reasonable. However, changes in the following assumptions could be reasonably foreseen as potentially likely to occur. In each case below, the assumption is made while also assuming that all other variables within the proposed AMI Project remain constant:

- As discussed in the response to BCUC IR No. 1 Q87.2.1, an increase from the 2 percent annual growth rate of marijuana production sites to 5 percent and a decrease in the deterrence rate from 75 percent in 2012 to 60 percent by 2019 for the status quo theft reduction scenario. Such a change increases the NPV of the net benefit related to theft reduction from $38 million to $47 million;
- As discussed in the response to BCUC IR No. 1 Q87.2.7, that grow operations diverting electricity are 50 percent larger on average compared to grow operations not diverting electricity. Such a change increases the NPV of the net benefit related to theft reduction from $38 million to $50 million;
- As discussed in Section 5.3.2 of the CPCN Application (page 85), an increase in the annual growth rate of marijuana production sites from 2 percent to 3 percent in the Status Quo model from 2013 to 2017, plus an increase from 30 to 36 lights per site in both the Status Quo and AMI-potential models, and the theft deterrence factor continues to increase above 95 percent beyond 2021 in the potential AMI forecast. Such a change increases the NPV of the net benefit related to theft reduction from $38 million to $52 million;
- As discussed in the response to BCUC IR No. 1 Q52.2.1, a change in the discount rate from 8% to 6%. Such a change increases the NPV of the net benefit to customers from $17.6 million to $23.6 million;
- As discussed in the response to BCUC IR No. 1 Q58.1.2.2, and CEC IR No. 1 Q66.3.1, currently FortisBC is forecasting customer growth based upon PEOPLE35 from BC Stats (PEOPLE = Population Extrapolation for Organizational Planning with Less Error). If, instead, PEOPLE36 were adopted, the forecast customer growth rate would drop from approximately 1.8% (starting in 2016) to approximately 1.2% (starting in 2016) with the impact being a decrease in the NPV of the net benefit to customers from $17.6 million to $15.9 million;

- As discussed in the response to BCUC IR No. 1 Q96.2, if New Operating Costs were to grow at 3% instead of the 1.8% assumed in the model, the NPV of the net benefit to customers decreases from $17.6 million to $16.5 million. However, also noted in the same response was the unlikelihood that New Operating Costs would appreciate at a rate unlike that used to escalate all other model costs. If it is assumed that 3% replace 1.8% for all model inflationary escalations, the NPV of the net benefit to customers improves from $17.6 million to $20.7 million;
- As discussed in the response to BCUC IR No. 1 Q16.1, if the proposed AMI Project financial analysis took into account the potential savings resulting from customer use of the Customer Information Portal (CIP), the NPV of the net benefit to customers improves by approximately $3.8 million to $21.4 million; and
- As discussed in the response to BCSEA IR No. 1 Q44.2, if the proposed AMI Project financial analysis took into account the potential savings resulting from customer use of the In-Home Display (IHD), the NPV of the net benefit to customers improves by approximately $9.8 million to $27.4 million.

12.1. Please confirm that in FortisBC's view one could calculate a maximum potential Net Present Value of the net benefit to customers of the AMI project by including the following assumptions each of which 'could be reasonably foreseen as potentially likely' to occur:

a) 5% growth of marijuana production sites
b) Theft deterrence rate increasing to 95% and above
c) Grow operations diverting electricity as 50% larger on average than grow operations not diverting electricity
d) A change in the discount rate from 8% to 6%
e) Continued population increase at 1.8%
f) Replacing the inflationary model of 1.8% with 3% in all instances
g) Including potential savings from the Customer Information Portal
h) Including the potential savings resulting from customer use of the IHD
i) Including the Measurement Canada compliance related savings.

12.1.1. If not, what additional assumptions or changes in the above assumptions would FortisBC believe necessary to calculate the maximum reasonable NPV benefit to customers? Please provide an explanation with each change or added assumption.

12.1.2. Please calculate the total maximum NPV for the project and for customer benefits based on all the above assumptions, and please calculate the total maximum NPV for the project and for customer benefits based on any changes to the assumptions FortisBC has identified.

13. Reference: Exhibit B-6, BCUC 1.3.1 and Exhibit B-11, CEC 1.9.1

The contract does not contemplate, 1) FortisBC failure to exit the contract prior to August 1, 2013 without proceeding with the contract after that date or 2) renegotiating any terms of the contract prior to August 1, 2013. The outcome in both of these circumstances is therefore uncertain.

> If the project start date was delayed in a predictable manner, personnel decisions could be made with clarity, allowing FortisBC to allocate internal resources appropriately, and limiting delay costs. If the time delay is unknown or uncertain, FortisBC will have to release personnel to other projects with variable assignment terms, potentially hindering a restart of the project and/or increasing costs.

13.1. Please confirm that in the event of regulatory delay resulting in a lack of decision by July 20th, 2013 as requested, FortisBC would be in the position of having to decide from the following options: a) Exit the contract with Itron, and either abandon the AMI Application or attempt to negotiate a new contract with Itron or others, and submit a revised Application based on a new contract and time frames. b) Attempt to revise the contract with Itron prior to August 1 '2013 allowing for and estimating additional regulatory time, c) Defer the decision, and if a BCUC decision is rendered prior to August 1, 2013, make a decision whether or not to proceed under increased time pressures.

13.2. Does FortisBC agree that all three options place FortisBC in an unfavourable position that could be expected to diminish the value of the AMI project if it were ever to proceed?

13.2.1. Would FortisBC expect to incur additional costs if they were to attempt to renegotiate additional regulatory time for the existing contract with Itron?

13.2.1.1. Please identify and quantify all additional costs FortisBC could reasonably predict would be incurred.

13.2.2. Please confirm that clarity and containment of regulatory time frames are and will remain crucial for any suitable contract with Itron or other AMI suppliers.

13.3. Would FortisBC agree that early identification and limitation of any potential regulatory delays is important to minimizing the costs of the project.

14. Reference: Exhibit B-11, CEC 12.3 and Exhibit B-11, CEC 1.12.4

> Itron produced their last electro-mechanical meter in 2005. It is expected that Elster would have stopped production around the same time to allow them to compete with the other vendors.

> The Company anticipates that under the new Measurement Canada S-S-06 regulations that FortisBC would be fully converted to digital meters in a 21 year period if the AMI project did not proceed.

14.1. Would FortisBC agree that while electro-mechanical meters may remain as an installed base for a period of years in certain jurisdictions, the North American market and production of new meters is going to be exclusively digital?

15. Reference: Exhibit B-11, CEC 1.13.2

> Given the significant deterrent effect of the proposed AMI-enable theft reduction program, the associated benefits may or may not be impacted if deployment is less than 100 percent.

15.1. Would FortisBC agree that 100% deployment would likely result in the highest deterrent effect of the AMI enabled theft reduction program?

15.2. Would FortisBC agree that the deterrent effect of the proposed AMI enabled theft reduction program could be reasonably considered as directly related to potential thieves' perception of its efficacy?

15.3. Would FortisBC agree that incomplete deployment could reasonably detract from thieves' perceptions of the AMI enabled theft reduction program as being efficacious and that perceptions of efficacy would diminish as the deployment declined? If not, why not?

15.4. Would FortisBC agree that the provision of opt-out could negatively impact thieves' perception of the efficacy of the theft reduction program?

16. Reference: Exhibit B-11, CEC 1.32.3

> The Itron OpenWay meters operate in temperatures up to 85°C in the base. The temperature increase in the base versus ambient (outside) temperature is approximately 10°C, leading to a maximum ambient temperature of approximately 75°C for correct operation. As the ambient temperature rises above 75°C, or if the temperature within the base rises above 85°C, the meter will fail.

16.1. Are there minimum temperatures at which the Itron OpenWay meters can function effectively? Please identify the minimum ambient temperature at which the Itron OpenWay meters can operate.

17. Reference: Exhibit B-11, CEC 1.34.2

> A UPC of 12.7 MWh/yr was used in the payback calculation.

17.1. Please confirm that the Average Use per Customer was based on residential use and explain how the average Use Per Customer of 12.7 MWh/yr was derived.

17.2. Please identify and quantify any changes that would result from using commercial customers as the basis.

18. Reference: Exhibit B-11, CEC 1.45.2

> Based upon information currently available to FortisBC, there is not currently a market for the resale and/or refurbishment of digital meters. However, FortisBC would resell the digital meters if it provided more value to customers than scrapping or recycling the digital meters.

18.1. Does FortisBC believe that there is not currently a market for resale/refurbishment of used digital meters because it is being replaced by demand for two-way communicating meters?

18.1.1. If so, does FortisBC believe that there will ever be a market for used digital meters in North America?

18.1.2. Does FortisBC believe that non-two-way communicating digital meters will be obsolete in the North American market within the next twenty-five years?

18.1.3. If not, please identify the main reasons underlying FortisBC's understanding of why there is not currently a market for used digital meters.

19. Reference: Exhibit B-11, CEC 1.71.2 and CEC 1.71.3

Please refer to the below table.

Option	Advantage	Disadvantage
One	• Would not require an accounting variance from the BCUC	• Has the highest rate impact of the three options
Two	• Has a lower rate impact than Option One	• Would require an accounting variance from the BCUC • Would have a higher rate impact than Option Three
Three	• Has the lowest rate impact of the three options	• Would require an accounting variance from the BCUC

Both Option 2 and Option 3 would result in lower customer rates as compared to Option 1.

19.1. Please provide a quantitative comparison of the proposed customer rates under Option 1 to Options 2 and 3.

19.2. Does FortisBC believe that an accounting variance would be difficult to receive from the BCUC?

19.2.1. What costs does FortisBC believe would be incurred in seeking an accounting variance from the BCUC? Please identify and quantify where possible.

20. Reference: Exhibit B-11, BCRUCA 1.1.2

1. Cost savings / improved operating efficiency;
2. Reliability improvements; and
3. Customer uptake of new technologies.

In addition to providing many customer and utility benefits, the AMI component of the FortisBC Smart Grid focuses primarily on the first driver which is reducing costs by improving meter reading efficiency and reducing power theft.

20.1. Please specify all the ways in which the AMI project that can be considered as contributing to 'reliability improvements' and identify which elements of the AMI project infrastructure would be employed to improve reliability.

20.1.1. Please provide the costs associated with each element and if possible attribute percentage costs to the reliability aspects of these elements.

20.2. Does FortisBC believe 'customer uptake of new technologies' is an objective, and if so, why?

20.3. Please identify all the elements of the AMI project that can be expected to contribute to 'customer uptake of new technologies' and identify which elements of the AMI project infrastructure would be employed .

21. Reference: Exhibit B-11, CEC 1.59.2 and Exhibit B-11, CEC 1.59.6

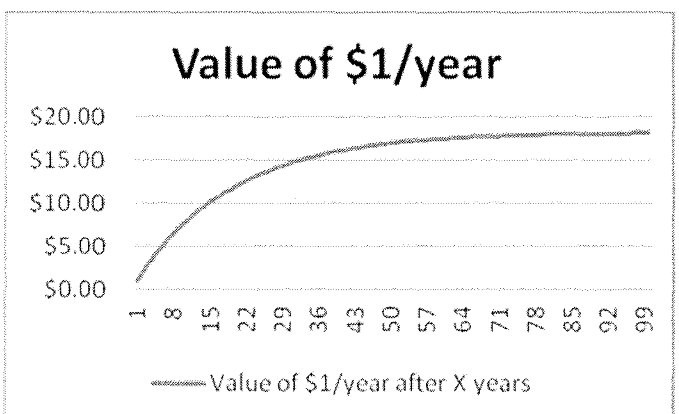
> FortisBC agrees, assuming an analysis of all costs and benefits related to a new and superior technology, including the write-off of any remaining net book value of assets being replaced, indicates a positive and significant benefit in Net Present Value terms.

> Yes, FortisBC believes that advanced (non-manual) metering reading will be industry standard at the end of 20 years and will continue to be into the future.

21.1. Please confirm that, if approved, the twenty year economic life of the AMI project is the only time the financial benefits of transitioning to non-manual meter reading will be captured by FortisBC.

21.2. Please confirm that on-going sustaining capital replacements of meters will preserve the benefits of the AMI project at a minimum and that on-going sustaining capital replacement does not generally require or result in business case justification being required.

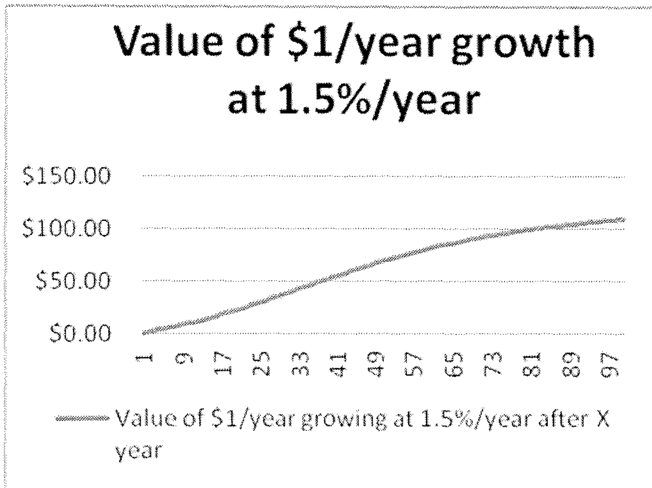
21.3. The following graph presents the terminal value of a $1 annual savings over approximately 100 years and discounted at a real discount rate of 5.5%. Would FortisBC agree that the value of savings such as those derived from non-manual meter reading, which extend beyond the twenty year project life and continue indefinitely into the future, can be quantified over a longer period than the project life to reflect the benefit of the change in technology being implemented?



21.4. Would FortisBC agree that a twenty year time horizon limits the capture of on-going benefits to about 66% of their terminal value assuming zero growth in the underlying cost structure?

21.5. The following Table presents the terminal value of a $1 annual savings growing at 1.5% over approximately 100 years and discounted at a real discount rate of 5.5%. Would

FortisBC agree that a twenty year time horizon limits the capture of on-going benefits to about 20% of their terminal value under these assumptions?



22. Reference: Exhibit B-11, CEC 1.66.2

additional meter readers are required to maintain a consistent average number of reads per meter reader per year.

Time Period	Customer Growth	Additional Reads from Customer Growth	Average Reads per Meter Reader
2014 - 2016	6887	43870	38572
2017 - 2019	6653	42380	38766
2020 - 2022	6494	41367	38902
2023 - 2025	6437	41004	38997
2026 - 2028	6325	40290	39064
2029 - 2031	7986	50871	39244

The additional reads are attributable to forecast customer growth.

22.1. Please confirm that the customer growth rate is forecast at an average of approximately 1.8% for the duration of the project.

22.2. Would FortisBC agree that it would be reasonable to assume continued population growth in the order of 1.8% beyond 2031 and into the future? If not, please explain why not and please provide a rate FortisBC would believe is reasonable to assume and cite the source.

23. Reference: Exhibit B-6, BCUC 1.53.7

- Inflation at 1.8 percent per year, on all aspects of the project not covered by fixed unit or fixed price contract; and

23.1. Please confirm that 1.8% is an appropriate predicted rate of inflation for the AMI project.

23.2. Would FortisBC agree that it would be reasonable to assume continued inflation in the order of 1.8% beyond 2031 and into the future? If not, please explain why not and please provide a rate FortisBC would believe is reasonable to assume and cite the source.

24. Reference: Exhibit B-1, Page 17

> **3.1 Description of Existing System**
>
> FortisBC currently has two types of metering systems:
>
> - For residential, commercial, and some industrial customers:
>   - Electro-mechanical meters, (approximately 80,000);
>   - Solid-state (or digital) meters (non-AMI) for the remaining meter population in the Company's service territory. This includes several hundred interval Time-of-Use meters, as well as wireless Encoder/Receiver/Transmitter (ERT) meters used for hard-to-access meter locations; and
> - MV-90, a cellular modem based system, used to collect reads for approximately 60 industrial customers who require interval metering data (typically collected by hour).

24.1. Please describe the ERT technology from the point of view of the transmitter signals and their similarity and/or differences to the AMI communication technology.

24.2. How long has the ERT technology been in place within the FortisBC Inc. system?

24.3. Please describe the MV-90 collection and communications system relative to the AMI communications technology and their similarity to and/or differences from the AMI technology.

24.4. How long has the MV-90 collection and communication system been in place within the FortisBC Inc. system?

24.5. Please describe any relevant BCUC approval processes which may have been applicable to approving of the ERT and or MV-90 technology applications within the FortisBC Inc. system

25. Reference: Exhibit B-11, BCSEA 1.42.1

> 42.2 Please provide a table similar to Table BCUC IR Q16.1 showing electricity and cost savings attributable to In-Home Displays.
>
> <u>**Response:**</u>
>
> The savings from IHDs results from reaching the 30% adoption rate explained in the response to BCSEA IR No. 1 Q15.3 and the 5.4% savings rate (Exhibit B-1, p44).

Residential IHD Savings (MWh)		
Year	IHD Gross Savings	Value @$85 MWh
2014	150	$ 12,700
2015	500	$ 42,500
2016	1,100	$ 93,400
2017	2,100	$ 178,400
2018	3,700	$ 314,300
2019	6,600	$ 560,600
2020	10,200	$ 866,400
2021	13,800	$ 1,172,200
2022	17,100	$ 1,452,500
2023	16,400	$ 1,390,000
2024	16,400	$ 1,390,000
2025	16,400	$ 1,390,000
2026	16,400	$ 1,390,000
2027	16,400	$ 1,390,000
2028	16,400	$ 1,390,000
2029	16,400	$ 1,390,000
2030	16,400	$ 1,390,000
2031	16,400	$ 1,390,000
2032	16,400	$ 1,390,000
		$ 18,593,000

25.1. While Fortis has limited the growth of the IHD savings as of 2023, would it be logical to expect that the IHD benefit may have a relationship to growth in the Fortis customer base and therefore may increase over time?

25.2. Please confirm that as of 2023 there would be no reason to expect that the IHD benefits would not continue into the future, because it would be highly likely that replacement meters would support such functionality or may improve upon the functionality but would not likely return to having no functionality?

26. Reference: Exhibit B-11, BCSEA 1.59.2

59.2 If a customer was particularly interested in reducing the RF signal within the premises, would placing a dense barrier of some type on the inside wall opposite the meter further reduce the RF signal?

<u>Response:</u>

Considering that an AMI meter mounted on a building or a house already has a metal backplate that reduces the RF signal that enters the house, it is unlikely that the addition of a dense barrier of some type would improve that reduction significantly.

26.1. Please confirm that the metal plate backing on the AMI meters reduces the RF exposure significantly (up to a factor of 10 reduction) because the signal to which people in the home would be exposed to must travel much farther to reach the person than if they were to stand the same distance directly in front of the AMI meter.

27. Reference: Exhibit B-11, BCSEA, 1.61.5

61.5 Please discuss how the RF exposure of RF-Lan in the 902-928 MHz range and ZigBee in the 2400-2482 MHz range compare with exposure at similar distances to the electric and magnetic fieldsof electric current at 60 Hz at the customer meter.

<u>Response:</u>

A customer meter would not be a significant source of 60-Hz electric or magnetic fields.

27.1. Please show the level of exposure from the electric current in wiring in the walls of a home and in appliances operating in a home in comparison to the RF-Lan.

28. Reference: Exhibit B-11, CSTS 1.12.5

12.5 What would be the hard costs for connecting smart meters to fibre optics when a) fibre optic cabling is already in place; and b) when fibre optic cable is not in place? What would be the cost of using of a fibre optic network as an alternative to the RF mesh LAN solution and how would that cost be reflected in rate increases over a long term period? Provide cost analysis of connecting all Fortis BC AMI meters in the province to fibre optic versus the cost of continually replacing wireless components every 7 to 10 years.

<u>Response:</u>

FortisBC does not agree with the assertion that wireless components require replacing every 7-10 years. While it has been acknowledged in section 4.1.3 of the Application (Exhibit B-1) that some technologies, particularly those offered as services by third parties, may have shorter useful lives; the bulk of the wireless equipment to be installed during the proposed AMI project is expected to last 20+ years. All expected upgrades, battery replacements and device replacements have been accounted for in the original financial analysis of the project.

28.1. Please provide the technical physical life expectancy for the AMI meters.

28.2. Please confirm that while FotirsBC has an expected project life of 20 years it is quite possible that some or many of the meters may last more than 20 years and that this is the reason FortisBC has included the expectation of 20+ years.

28.3. Please confirm that even if the meters are replaced early it would most likely be because some technological development would have occurred to provide greater functionality and benefits than the proposed AMI meters, which would be assessed as to its benefit cost at the time and would be based on increased incremental benefits justifying replacement of the meters early.

28.4. Please confirm that FortisBC does not know of any improvement in technology which would lead it to believe that the AMI meters will need imminent replacement to capture a new benefit not supported by the AMI meters proposed.

29. Reference: Exhibit B-11, CSTS 1.17.1

17.0 Reference - Application - Environment - page 134, line 24

17.1 In evaluating the EMF risks posted by the proposed meters, does FortisBC consider it important to consider the following specifics?

A. The frequency and extent of fluctuation of RF levels?

B. The duration of each instance of an RF emission?

C. The frequency with which an RF emission occurs?

Response:

The factors that FortisBC considers important in evaluating EMF exposure are described in the referenced section of the Application, Exhibit B-1, Section 8.4.2, p134-135

All items listed above are considered in determining compliance with Health Canada Safety Code 6.

29.1. Please confirm that in addition to the criteria listed in the question answered that FortisBC would also consider the following criteria relevant.

a) Intensity of the RF signal
b) Average distance away from the RF signal source
c) The existence of a back plate between the individuals who may be exposed and the source of the RF signal
d) The existence of walls and other barriers which may lessen the RF signal intensity.
e) The lack of any substantiated scientific evidence that low levels of RF signals could be harmful to human health
f) The proportional diminutive RF signal from the AMI meters relative to all manner of other RF signals permeating modern society generally and the FortisBC service territory in specific.
g) The substantive and authoritative research and findings of those responsible for reviewing health issues related to RF signals and their conclusion that it is not a public health issue at this time.

30. Reference: Exhibit B-11, CSTS 1.34.1

34.0 Reference - Response to BCUC IR1 117.4

34.1 Will FortisBC suspend service for those customers refusing installation of an AMI meter until such time that an AMI meter is installed?

Response:

As stated in the Application (Exhibit B-1) at page 142:

Regardless of FortisBC's efforts, some customers may continue to refuse the installation of an advanced meter. In these cases, FortisBC intends to follow the following process:

- *Continue productive dialogue with the customer where possible, making an effort to address concerns and ensuring the customer is aware that they have the option of relocating the meter on their property at their expense.*
- *Continue to provide billing using estimated readings for up to six months.*
- *After three months of refusal to provide access to exchange the meter, and in absence of extenuating circumstances, suspension of the customer's service until the advanced meter is installed.*

FortisBC does not take suspension of an individual customer's service lightly, but also cannot support ongoing manual meter reading or estimating once advanced metering has been deployed.

30.1. Would it be technically feasible to install a PLC meter and intercept the signal further out on the electrical system away from the customer's premises and then transmit the signal to the RF-Lan mesh via a transmitter?

30.2. If it were technically feasible could this be done at the customer's cost to obviate the need to deny service but still enable FortisBC to collect all the data required and to communicate with the customer's meter?

31. Reference: Exhibit B-11, CSTS 1.36.1

36.0 Reference - Executive Summary (CPCN Application) Page 2 Lines 3-6

Green house gas (GHG) emissions will be reduced as well. FortisBC meter reading vehicles drive approximately 500,000 kilometres per year and consume approximately 80,000 litres of gasoline. The associated 191 tonnes of resulting GHG emissions will be reduced with the reduction in meter reading vehicles.

36.1 Provide evidence that GHG smog is less hazardous than electromagnetic (RF) smog since both have been classified as 2b carcinogens by the World Health Organization.

Response:

FortisBC could not find "GHG smog", "GHG" or "smog" on the list of 2b carcinogens. FortisBC has not made any assertions regarding the hazards of GHG emissions that would require it to provide evidence in any case.

If "electromagnetic (RF) smog" refers to RF emissions, please see Exhibit B-1, Appendix C-5.

31.1. Please confirm that classification of RF signal as a class 2B does not in any way presume evidence that the RF signals are carcinogenic, particularly the low levels for the FortisBC AMI meter communications, but rather is a classification system used to organize what subjects may be examined as a priority area for some future research.

31.2. Please confirm that while GHG emissions from vehicles are not known or thought to be carcinogenic that other automobile emissions (SO_x, NO_x, VO_x and PM) are known to have serious health effects including known impacts on human mortality.

31.3. Please provide a quantification of the approximate reductions of these other automobile emissions based on the same quantities of reductions of 80,000 litres of gasoline.

31.4. Please confirm that studies such as the one done for the City of Toronto (supplied in Appendix A) to quantify the health impacts of the smog emissions in the city provide a useful proxy for evaluating the additional benefits of reducing automobile trips and truck rolls, which the FortisBC AMI meters will enable FortisBC to do.

31.5. Please provide any better information with regard to other automobile emissions and their potential health impacts to which FortisBC may have access for the purpose of better evaluating this issue.

31.6. Please confirm that the fact that we live with risks such as those related to automobile emissions provides a proxy context for understanding the way society deals with the trade-off between benefit and risk.

31.7. Given that RF signals related to the FortisBC AMI meters are many orders of magnitude less risky than the approved regulatory thresholds for RF signal risks and even many more orders of magnitude less risky than risks society lives with every day, would it be fair to conclude that there is a possible case to be made that the AMI meters FortisBC is proposing to introduce may be on balance a public health benefit.

31.8. Please confirm that the benefits from reduction of these other automobile emissions can be linked to the functionality introduced by the communication capability being introduced with the AMI meters and that this functionality would be intended to be retained by FortisBC continuously into the future with replacements of meters and would not be restricted to just the initial AMI meters being installed.

32. Reference: Exhibit B-11, CSTS 1.36.2

36.2 Explain how the environment is better served by producing layers of RF smog rather than having the meter readers drive electric cars?

Response:

Please refer to the response to CSTS IR No. 1 Q36.1 and the response to Tatangelo IR No. 1 Q42.

32.1. Given that the need for meter reading vehicles with be completely removed and the FortisBC will no longer use or operate a fleet for this purpose, please confirm that this will result in a reduction in environmental emissions related to the supply chain required to build and deliver automobiles to the fleet.

32.2. Please describe the concept to life cycle analysis of product environmental impacts such as emissions of various pollutants.

32.3. Please confirm that the manufacture of electric vehicles, just like the manufacture of internal combustion vehicles has environmental emissions impacts associated with it.

32.4. Please confirm that the Institute of Lifecycle Environmental Assessment data (Appendix B) represents a reasonable proxy for an evaluation of this additional benefit of reduced automobile and truck rolls in the absence of any better information.

32.5. Please provide any information FortisBC has with respect to the life cycle emissions associated with the production and delivery of automobiles to a fleet.

32.6. Please confirm that the fleet required for maintenance of the entire AMI infrastructure would be significantly less than that required for the meter reading and truck rolls, which will be saved with the introduction of the AMI project.

32.7. Please provide an approximate or rough estimate of the vehicle requirements for maintenance of the AMI infrastructure.

32.8. Please confirm that the emissions, direct and full life cycle, related to the one time installation of the AMI meters and infrastructure as well as to ongoing needed replacements will be substantially, over an order of magnitude, less than the emissions savings.

32.9. Exhibit B-11Please confirm that the emissions, direct and life cycle, related to the one time installation of the AMI meters and infrastructure and ongoing replacements will be comparable to the ongoing replacement of the existing meters and related infrastructure over a long term future beyond the initial installation of the AMI project.

33. Reference: Exhibit B-11, CSTS 1.37.1

37.1 What are the new Measurement Canada regulations (S-S-06) and what provisions of those regulations require wireless meters? In what way are the proposed AMI meters more accurate than FortisBC's present mechanical meters?

Response:

Section 5.3.4 of the Application (Exhibit B-1) discusses FortisBC's interpretation of S-S-06 and its implications on Fortis BC operations. FortisBC has not stated that S-S-06 regulations require existing meters to be replaced with wireless meters. A copy of the S-S-06 Regulations is provided as Appendix B-7 to the Application (Exhibit B-1).

The proposed AMI meters are manufactured to the ANSI C12.20 standard which specifies increased accuracy over the ANSI 12.1 standard that the existing electro-mechanical meters were required to meet. The new meters are required to be accurate to within 0.5% compared to 2% for the electro-mechanical fleet.

33.1. Please confirm that the EPRI study (Appendix C) with respect to meter accuracy is in part a reasonable set of evidence upon which to evaluate the issue of the accuracy of meters.

33.2. Please confirm that the consequence of the increased accuracy of the AMI meters FortisBC is expecting to introduce and the consequent compliance with Measurement Canada regulations will provide increased fairness for FortisBC customers in measurement of electrical consumption and the consequent billings for the same.

33.3. Please confirm that the mechanical analog meters being replaced would have a steady decline in accuracy over their lifetimes due to degradation of the mechanical performance.

34. Reference: Exhibit B-11, CSTS 1.57.2

57.2 Considering all signal types, not just data signals, on average how many signals per day will an AMI meter transmit?

Response:

The average number of 900 MHz RF transmissions in a 24 hour period is ~1,268 (less than one time per minute). This includes all types of signals.

34.1. Please provide the duration of each type of RF com and the approximate quantity for each type such that the total quantity adds to the 1268 average.

34.2. Please provide the range of RF duration periods if any applicable to each type of communication.

34.3. Please provide the range of frequency of communication by each type as applicable around the average provided and if possible please provide an appropriate distribution curve for the range (ie normal distribution).

34.4. Please confirm that the total energy involved in the aggregate of all of the types of RF communication over the day is the small fraction of the Safety Code 6 thresholds that FortisBC has claimed and includes all types of RF signals.

35. Reference: Exhibit B-11, JT 1.49

Pages 99 – 101

49. Are not the cost savings you speak of on these pages not already done without AMI meters? You will require many different meters to carry out these scenarios.

Response:

The future potential benefit described in the referenced section of the Application refers to power grid voltage optimization. Table 6.2.a. sets out the estimated costs and potential benefits for the various voltage optimization options available. The potential benefits noted cannot be achieved with existing Company technology, and all would require additional investment, as estimated in the table.

35.1. Please confirm that there would not be requirement for additional or different meters at the customer premises and that the AMI meters installed will be part of the process for achieving voltage optimization but that additional investment in such functionality as voltage regulation equipment may be required.

36. Reference: Exhibit B-11, NCGP 12

12. Do any of the references consulted in question 11 include research by Cindy Sage and David O. Carpenter?

Response:

FortisBC believes that neither Ms. Sage nor Dr. Carpenter have published any original, peer-reviewed, health research studies of radiofrequency fields. Both have offered opinions on published health research studies of radiofrequency fields in documents posted to the internet and some published reviews of research. Exponent scientists have reviewed and considered these opinions.

36.1. Please confirm that the EPRI report (Appendix D) on the Sage claims is the more credible evidence dealing with the issues raised by Ms. Sage.

37. Reference: Exhibit B-1, Appendix C-5, Page 28 of 47

Brain cancer rates over time

If the increased risks suggested by the INTERPHONE Study Group (2010, 2011) in the highest use group and the Hardell study data (Hardell, 2006a, 2006b; Hardell et al., 2011) were correct, we might expect to see some increase in annual rates of brain cancer, particularly 10 years after mobile use became widespread. The period of 10 years or more would allow for the development of tumors, and if causal, would show increases in brain cancer rates as more people had a longer period of exposure through mobile phone use. No increase in brain cancer rates over time was seen in the combined populations of Denmark, Norway, Sweden, and Finland from 1973 to 2003 (Deltour et al., 2009), or in Switzerland from 1969 to 2002 (Röösli et al., 2007). It is important to assess these trends in data extended to longer time periods—the most recent analyses examined trends in England from 1998 to 2007 (de Vocht et al., 2011) and in the United States from 1992 to 2006 (Inskip et al., 2010). These data also did not indicate that the occurrence of brain cancer has increased over the years since the use of mobile phones became increasingly widespread (the late 1980s and 1990s).

37.1. Please confirm that the rates for brain cancer in Canada over time are reported by Statistic Canada and others, which shows on page 44 of the 2012 report (Appendix E) that brain cancer in Canada both in terms of incidence and mortality has been decreasing over the 10 year time frame reported and that this, while not an epidemiological study would support the proposition that there is not an increasing rate of brain cancer in Canada but in fact a decreasing rate of brain cancer in Canada.

37.2. Please confirm that the study done by Little et al (Appendix F) shows no effective support for the proposition that cell phones are causing glioma cancers in the US population studied and that while there are limits to the study the authors have not found support for the two studies which indicated that cell phones might cause these cancers.

38. Reference: Exhibit B-1, Appendix C-5, Page 17 of 47

> Many organizations such as the International Commission on Non-Ionising Radiation Protection (ICNIRP), the Health Council of the Netherlands (HCN), the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), the Swedish Radiation Safety Authority (SSM), and Health Canada have reviewed the research and have independently supported the derivation of exposure limits on the basis of tissue heating, or developed a set of exposure limits for RF energy in various frequency ranges (ICNIRP, 2009; HCN, 2009; SCENIHR, 2009; SSM, 2009; Health Canada, 2009). These organizations have reviewed all of the available research through 2009 and have not concluded that RF exposure below the exposure limits developed by ICNIRP, which are similar to those of Health Canada, causes any type of cancer, other chronic disease, adverse physiologic changes, or symptoms that affect well-being.

38.1. Please confirm that the recent Norwegian study (Appendix G) is another one of the many organizations having reviewed these issue of RF signals and health risks and found no scientific basis for changing the standards governing RF radiation and like Health Canada have not concluded that RF exposures below the threshold standards cause any of the alleged health effects listed above.

39. Reference: Exhibit B-1, Pages 134 and 135

The following specifics of the chosen technology are important to consider when evaluating the EMF risks posed by the proposed meters:

- Power – The proposed meters are low power at a maximum of 1 Watt. The low power minimizes the EMF.
- Distance - The strength of an EMF is inversely proportional to the square of the distance, meaning that the level drops off very quickly as the distance to the meter increases. As meters are intentionally installed outside the home, it is unlikely for customers to be in close proximity to a meter for prolonged periods of time. However, there are a number of meters located inside customer residences, typically a result of home renovations after the meter install, or older installations. Enclosed meters are difficult to access for repair, replacement and reading. FortisBC intends to work with customers before and during the AMI implementation to relocate these meters as necessary. This will benefit both the Company and the customer.
- Frequency – The frequency of operation of the meters is relatively low (902-928 MHz) when compared to other ubiquitous technologies such as cellular phones, microwave ovens and Wi-Fi.
- Duty Cycle – The duty cycle is the percentage of time that the transmitter is on and therefore radiating an EMF. The proposed AMI solution only requires a very limited amount of data from each meter, with an average total transmission time of about one minute per day.

The estimate of emission from the proposed AMI metering system and the relevant Health Canada exposure limit are provided in Table 8.4.2.a below. The table indicates that the average (or "mean") exposure from an AMI meter will be approximately 10,000 times below the Health Canada Safety Code 6 limit of 0.6 mW/cm^2.

Table 8.4.2.a - RF Exposure at 902 MHz to 928 MHz

Condition	Exposure at 0.5 meters (mW/cm^2)
Health Canada Safety Code 6 Limit[19]	0.6
Mean duty cycle 0.06%	0.000056
Maximum typical duty cycle 0.58%	0.00054
Maximum supported duty cycle 5%	0.0047

39.1. Please confirm that in addition to the duty cycle and frequency used in the table above that these exposure levels are for exposure in front of the meter and that because of the backing on the meter and other material between the meter and anyone likely being exposed to the meter the exposure levels are further reduced by an amount in the range of a factor of 10, as shown in the EPRI study of Itron Smart Meters (Appendix H) in their conclusions on page 17-1.

39.2. Please confirm that on average people are much further away from their Smart Meter locations than .5 meters such that the average or "mean" exposure to an AMI meter RF signal would likely be substantially less than 10000 times below the Health Canada Safety Code 6 limit.

39.3. Please confirm that the claim in the text and table above is in fact extraordinarily conservative and that the exposure risk to 99.99% of the population will be at substantially lower levels because of average distance away from the meter and normal orientation behind the meter backing plate.

39.4. Please confirm that it would not be inappropriate to say that the typical exposure risk could be expected to be approximately 1000000 times below the safety code limits but may in some cases be approximately 10000 times below the safety code limits providing sound factual evidence supporting Provincial Health Officer assertions that the Smart Meters are not a public health risk.

40. Reference: Exhibit B-11, CEC 1.51.1

51.1 Please identify the types of home automation devices that are currently available, that can be installed at the customer's discretion, and are facilitated by the Zigbee or other wireless communication protocols?

Response:

The ZigBee™ Alliance website[2] states: ZigBee Home Automation offers a global standard for interoperable products enabling smart homes that can control the following product categories:

- Appliances;
- Audio;
- Cards & Readers;
- Closures, e.g. window shades;
- Energy Efficiency;
- Health & Fitness;
- Information Systems;
- Lighting;
- Networking Devices;
- Payment Equipment; and
- Security

Their website offers a searchable directory of certified products that meet the Alliance standards and protocol.

40.1. Please identify any comparable global standard for interoperable products enabling smart business/commercial sector premises and the kinds of product categories using electricity, which they may assist in controlling for the purposes of reducing wasted consumption.

40.2. Please confirm that the ACEEE report on Long-term Energy Efficiency Potential (Appendix H) which shows, on pages 27 through 34, scenarios for savings which indicate that the potential over the next forty years or so can be quite significant and that savings of this nature and significance would be expected to be similarly possible in BC and in the FortisBC jurisdiction.

40.3. Please provide any estimates of savings potential which FortisBC may have regarding developments which may take advantage of the AMI meters being proposed and if FortisBC does not have any estimates please provide any references to studies which may have a better comprehensive perspective than the ACEEE report, for both residential and commercial applications.

40.4. Please confirm that even though there may not be specific estimates available this does not mean there is not likely beneficial value to come from these developments and does not mean that the value would be non-substantial.

40.5. Please confirm that over the next forty years both the in home and in commercial premises developments may be expected to provide some quite significant savings potential and that the AMI meter and communications base platform is likely to play a significant role in enabling the realization of the benefits.

LIST OF APPENDICES

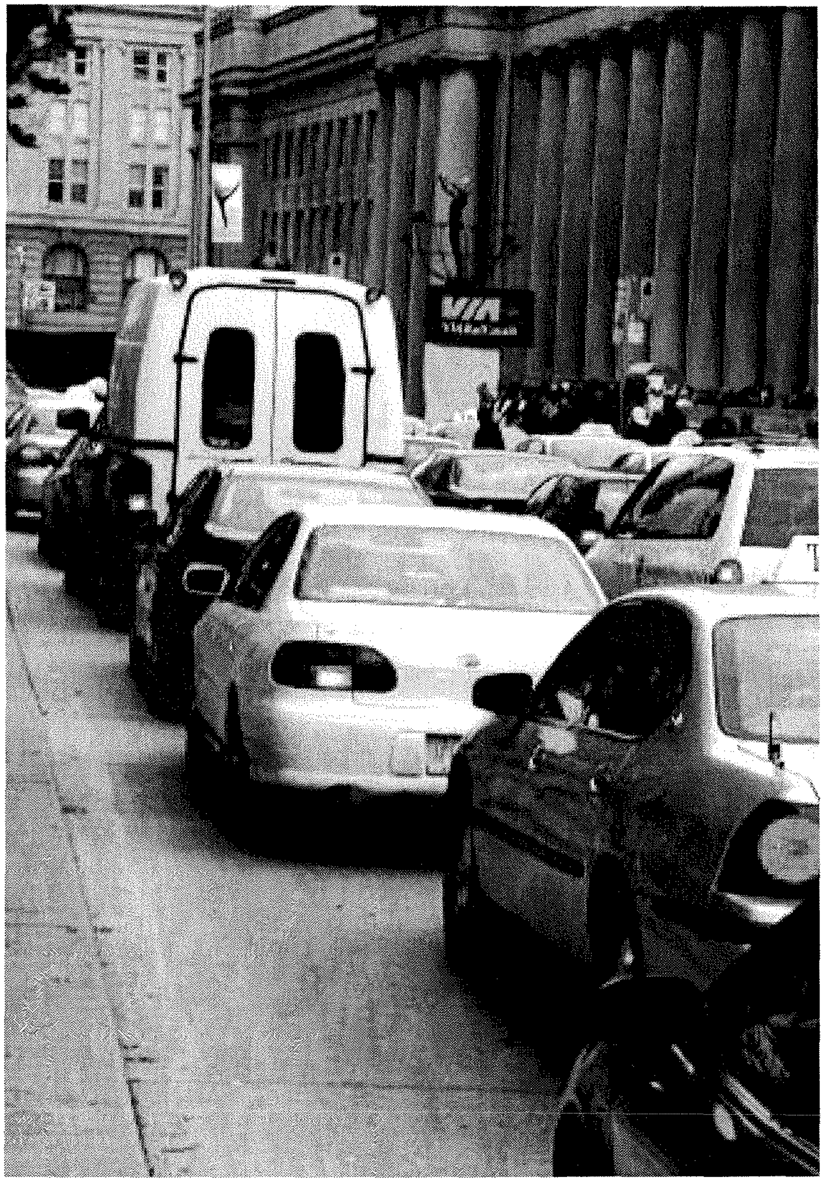
A. Air Pollution Burden of Illness from Traffic in Toronto, November 2007
B. Lifecycle analysis of gas, hybrid and electric cars, Sam Abuelsamid, December 2006
C. Electrical Power Research Institute, Accuracy of Digital Electricity Meters, May 2010
D. Electrical Power Research Institute, Comment: Sage Report on Radio-Frequency (RF) Exposure from Smart Meters, February 2011
E. Canadian Cancer Statistics 2012, Statistics Canada et al., May 2012
F. Mobile phone use and glioma risk: comparison of epidemiological study results with incidence trends in the United States, MP Little et al., March 2012
G. Norwegian Institute of Public Health, Low-level Radio Frequency Electromagnetic Fields: An Assessment of Health Risk and Evaluation of Regulatory Practice, Summary 2012
H. Electrical Power Research Institute, An Investigation of Radio Frequency Fields Associated with the Itron Smart Meter, Technical Report 2010
I. American Council for an Energy-Efficient Economy, Long-term Energy Efficiency Potential: What the Evidence Suggests, John Laitner et al., January 2012

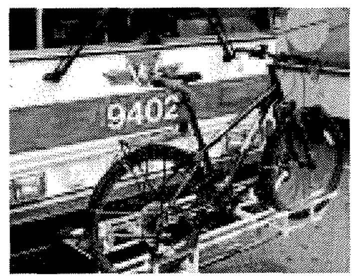
APPENDIX A
Air Pollution Burden of Illness from Traffic in Toronto, November 2007

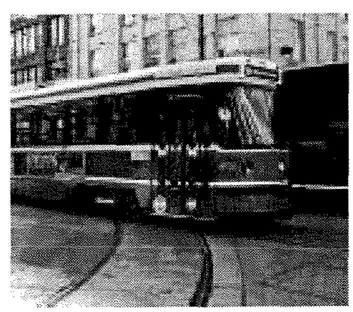
See attached.

Air Pollution Burden of Illness from Traffic in Toronto

Problems and Solutions







November 2007

Dr. David McKeown
Medical Officer of Health

TORONTO
Public Health

Reference: Toronto Public Health. *Air Pollution Burden of Illness from Traffic in Toronto – Problems and Solutions*. November 2007. Toronto, Canada.

Authors: Monica Campbell, Kate Bassil, Christopher Morgan, Melanie Lalani, Ronald Macfarlane and Monica Bienefeld

Acknowledgements:

We thank the following people for their advice and insightful comments regarding this report: Sarah Gingrich (Toronto Fleet Services); Dave Stieb and Stan Judek (Health Canada); Sean Severin and Mark Bekkering (Toronto Environment Office); Rosana Pellizarri, Josephine Archbold, Stephanie Gower, Barbara Macpherson, Marinella Arduini and Jacqueline Russell (Toronto Public Health); and John Mende, Dan Egan and Nazzareno Capano (Transportation Services).

In addition, we acknowledge Miriam Diamond (University of Toronto) and Brian Gibson (Health Professionals Task Force, International Joint Commission) for their contribution to the literature review component of the study. The financial support of the International Joint Commission for preparation of the literature review is gratefully acknowledged.

Report at: http://www.toronto.ca/health/hphe

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Executive Summary

This report summarizes new work completed by Toronto Public Health, with assistance from the Toronto Environment Office, to assess the health impacts of air pollution from traffic in Toronto. The study has two major components: a comprehensive review of published scientific studies on the health effects of vehicle pollution; and, a quantitative assessment of the burden of illness and economic costs from traffic pollution in Toronto. This report also examines air pollution and traffic trends in Toronto, and provides an overview of initiatives underway or planned by the City to further combat vehicle-related air pollution.

Burden of illness studies provide a reliable and cost-effective mechanism by which local health authorities can estimate the magnitude of adverse health impacts from air pollution. In 2004, Toronto Public Health (TPH) estimated that air pollution (from all sources) is responsible for about 1,700 premature deaths and 6,000 hospitalizations each year in Toronto. The study indicated that these deaths would not have occurred when they did without chronic exposure to air pollution at the levels experienced in Toronto.

Since that time, Health Canada has developed a new computer-based tool, called the *Air Quality Benefits Tool* (AQBAT) which can be used to calculate burden of illness estimates. TPH staff used this tool in the current study to determine the burden of illness and economic impact from traffic-related air pollution.

Toronto Public Health collaborated with air modelling specialists at the Toronto Environment Office to determine the specific contribution of traffic-related pollutants to overall pollution levels. Data on traffic counts and flow, vehicle classification and vehicle emission factors were analysed by Toronto Environment Office and Transportation Services for input into a sophisticated air quality model. The air model takes into account the dispersion, transport and transformation of compounds emitted from motor vehicles. Other major sources of air pollution in Toronto are space heating, commercial and industrial sources, power generation and transboundary pollution.

The current study determined that traffic gives rise to about 440 premature deaths and 1,700 hospitalizations per year in Toronto. While the majority of hospitalizations involve the elderly, traffic-related pollution also has significant adverse effects on children. Children experience more than 1,200 acute bronchitis episodes per year as a result of air pollution from traffic. Children are also likely to experience the majority of asthma symptom days (about 68,000), given that asthma prevalence and asthma hospitalization rates are about twice as high in children as adults.

This study shows that traffic-related pollution affects a very large number of people. Impacts such as the 200,000 restricted activity days per year due to days spent in bed or days when people cut back on usual activities are disruptive, affect quality of life and pose preventable health risk.

This study estimates that mortality-related costs associated with traffic pollution in Toronto are about $2.2 billion. A 30% reduction in vehicle emissions in Toronto is projected to save 189 lives and result in 900 million dollars in health benefits. This means that the predicted improvements in health status would warrant major investments in emission reduction programs. The emission reduction scenarios modelled in this study are realistic and achievable, based on a review by the Victoria Transport Policy Institute of policy options and programs in place in other jurisdictions. Taken together, implementation of comprehensive, integrated policies and programs are expected to reduce total vehicle travel by 30 to 50% in a given community, compared with current planning and pricing practices.

Given there is a finite amount of public space in the city for all modes of transportation, there is a need to reassess how road space can be used more effectively to enable the shift to more sustainable transportation modes. More road space needs to be allocated towards development of expanded infrastructure for walking, cycling and on-road public transit (such as dedicated bus and streetcar lanes) so as to accelerate the modal shift from motor vehicles to sustainable transportation modes that give more priority to pedestrians, cyclists and transit users.

Expanding and improving the infrastructure for sustainable transportation modes will enable more people to make the switch from vehicle dependency to other travel modes. This will also benefit motorists as it would reduce traffic congestion, commuting times and stress for those for whom driving is a necessity. Creating expanded infrastructure for sustainable transportation modes through reductions in road capacity for single occupancy vehicle use will require a new way of thinking about travelling within Toronto and beyond. To be successful, it will require increased public awareness and acceptance of sharing the road in more egalitarian ways, as well implementation of progressive policies and programs by City Council.

This study provides a compelling rationale for investing in City Council's plan to combat smog and climate change, and for vigorously pursuing implementation of sustainable transportation policies and programs in Toronto. Fostering and enabling the expansion and use of public transit and active modes of transportation, such as walking and cycling, are of particular benefit to the public's health and safety.

Table of Contents

Tables and Figures

Abbreviations

AQBAT	Air Quality Benefits Assessment Tool
AQHI	Air Quality Health Index
CO	Carbon Monoxide
COPD	Chronic Obstructive Pulmonary Disease
CRF	Concentration Response Function
GHG	Greenhouse Gases
NO_2	Nitrogen Dioxide
NOx	Nitrogen Oxides
O_3	Ozone
PAHs	Polycyclic Aromatic Hydrocarbons
PM	Particulate Matter
$PM_{2.5}$	Particulate Matter < 2.5 μm in diameter
PM_{10}	Particulate Matter < 10 μm in diameter
ppb	parts (of contaminant) per billion (parts of air) by volume
ppm	parts (of contaminant) per million (parts of air) by volume
SES	Socioeconomic Status
SO_2	Sulphur Dioxide
TSP	Total Suspended Particulate
$\mu g/m^3$	micrograms (of contaminant) per cubic metre (of air) by weight
VOC	Volatile Organic Compound

Introduction

This report summarizes new work undertaken by Toronto Public Health, with assistance from the Toronto Environment Office, to assess the health impacts of air pollution from traffic in Toronto. The study is comprised of two major components: a comprehensive review of published scientific studies throughout the world on the health effects of vehicle pollution; and, a quantitative assessment of the burden of illness and economic costs from traffic pollution in Toronto. This report also examines air pollution and traffic trends in Toronto, and provides an overview of initiatives underway or planned by the City to further combat vehicle-related air pollution.

Burden of illness studies provide a cost-effective and reliable approach to estimating the magnitude of the health impact associated with air pollution conditions in a given community, based on the most current health outcome and pollution data available. In 2004, Toronto Public Health released a study that calculated the burden of illness associated with ambient (outdoor) levels of air pollution in Toronto. The study estimated that smog-related pollutants from *all* sources contributed to about 1,700 premature deaths and 6,000 hospitalizations each year in Toronto. The study indicated that these deaths would not have occurred when they did without chronic exposure to air pollution at the levels experienced in Toronto.

An estimated 1,700 Toronto residents die prematurely each year from exposure to outdoor air pollution in the city

Since that time, Health Canada scientists have developed and made available a computer-based tool to enable local health units to estimate air-related burden of illness in their respective communities. This tool, known as the *Air Quality Benefits Assessment Tool* (AQBAT), was used in the current study to quantify the health and economic impacts of traffic pollution in Toronto.

While it is recognized that bicycles are a type of vehicle, the word 'vehicle' is used in this report to refer to only motorized vehicles such as cars, vans, sport utility vehicles, trucks and so on.

In the preparation of this report, Toronto Public Health collaborated with many people and organisations. The literature review was prepared in with guidance from researchers at the University of Toronto and the Health Professionals Task Force of the International Joint Commission. The Toronto Environment Office provided the estimates of the contribution of traffic-related emissions to concentrations of pollutants, which were then entered into AQBAT. Health Canada experts provided guidance on the use of their model and then reviewed the results of the AQBAT calculations.

Health Effects of Air Pollution from Traffic:
A Review of the Scientific Literature

There is clear evidence that air pollution gives rise to adverse effects on human health. As a major source of both primary emissions and precursors of secondary pollutants, vehicle traffic greatly contributes to the overall impact of outdoor air pollution. Despite the diversity of regulations that have been imposed to reduce vehicle emissions, several indicators suggest that they have only been partially effective. Traffic emissions are associated with morbidity (illness) and premature mortality (early death), and hence continue to be a very significant urban health concern.

Traffic emissions continue to be a very significant urban health concern

This review of the scientific literature presents the broad diversity of inhalation-related health effects caused by traffic. It synthesizes multiple lines of evidence of effects that range from immediate to transgenerational ones, and from those seen in infants to the elderly. Various exposure scenarios are described that illustrate the influence of geographic, individual, and environmental factors on the effects of traffic-related pollution. Finally, intervention studies that demonstrate the immediate health benefits of reducing vehicle emissions are described to illustrate the positive public health impact from reductions in vehicle emissions.

Nature of Traffic-Related Pollution

Traffic-related emissions are a complex mix of pollutants comprised of nitrogen oxides (including nitrogen dioxide), particulate matter, carbon monoxide, sulphur dioxide, volatile organic compounds, ozone, and many other chemicals such as trace toxics and greenhouse gases. This concentration of pollutants varies both spatially (by location) and temporally (by time).

Exposure to pollutants is elevated in urban areas with high traffic volumes and heavily travelled highway corridors (Peace et al. 2004; Zeka et al. 2005). High levels of vehicle-related emissions have been linked to high density traffic sites (Campbell et al. 1995). Street canyons (streets lined with tall buildings that impede the dispersion of air pollutants) and areas very close to busy roads typically have a high concentration of emissions (Hoek et al. 2002; Kaur et al. 2006; Longley et al. 2004). These areas may also contain a high concentration of people, including pedestrians and cyclists, or people within buildings alongside the road. Individual drivers or passengers of cars are also exposed to vehicle-related emissions. Individuals at all stages of their life are at risk from traffic pollution, however, the severity of the hazard varies with age and underlying medical conditions.

Factors That Affect Exposure to Traffic Pollutants

The extent to which people are exposed to air pollutants depends on a variety of factors, such as being inside a vehicle, working or living close to traffic, physical activity level, duration of exposure, stage of life and health status.

Individuals at all stages of life are at risk from traffic pollution; however the severity of the hazard varies with age and underlying medical conditions

Driving a Vehicle

Several studies have investigated the air pollution health effects associated with driving a vehicle. The majority of these consider professional drivers like taxi and truck drivers. Others look at non-professional drivers, like commuters on public transport or individuals driving their own vehicles. Lung cancer is one of the most commonly studied effects. A study in Denmark of 28,744 men with lung cancer found an increased risk among taxi drivers and truck drivers when compared with other employees, after adjustment for socioeconomic factors (Hansen et al. 1998). Other studies have found similar effects for lung cancer in taxi, truck, and bus drivers (Borgia et al. 1994; Guberan et al. 1992; Jakobsson et al. 1997; Steenland et al. 1990). It has been suggested that diesel exhaust may be the primary cause for this association as well as the effects of carcinogens like benzene.

Increased levels of respiratory conditions have also been associated with professional driving. A study in Shanghai compared respiratory symptoms and chronic respiratory diseases in 745 professional drivers, including bus and taxi, with unexposed controls (Zhou et al. 2001). Higher rates of throat pain, phlegm, chronic rhinitis, and chronic pharyngitis were seen in the exposed group. A recent study in Hong Kong evaluated the lung function and respiratory symptoms in drivers of air-conditioned and non-air-conditioned bus and tram drivers (Jones et al. 2006). Lung function was reduced in drivers of non-air-conditioned buses compared with air-conditioned buses. This difference was attributed to the increased exposure to vehicle-emissions of drivers of non-air-conditioned buses where direct air flow through open windows results in heightened exposure.

Commuters are also a population of interest for these effects and include populations of in-vehicle commuters on passenger cars, public buses, and school buses, as well as bicycle commuters. A study in Manchester, UK monitored exposure of bus commuters to $PM_{4.0}$ using personal sampling pumps (Gee and Raper. 1999). Levels inside the buses were much higher than background levels measured at national monitoring stations (Gee and Raper, 1999). A study that measured the level of CO in commuters in Los Angeles found nearly three times higher exposures in-vehicle than compared with exposure at home or work (Ziskind et al. 1997). Levels of $PM_{2.5}$ were reported to be twice as high in on-road vehicles during commutes in London, UK, when compared with background urban monitor levels (Adams et al. 2001).

Pollution levels inside vehicles during commutes tend to be higher than background levels at urban monitors

While the evidence supports an association between driving or being a passenger in a vehicle and adverse health outcomes, there are several factors that influence the degree and magnitude of this association. For example, different ages of vehicles contribute differently to individual levels of exposure. Older and more poorly maintained vehicles are typically associated with higher levels of emissions (White et al. 2006). Time of day of travel also has an influencing effect on exposure to vehicle emissions. There is evidence to suggest that exposure levels to CO and ultrafine particle counts are highest during the morning and at lower levels later in the day, increasing again in the early evening (Kaur et al. 2005b). However, it has been suggested that this is due to the greater traffic density at this time of day, during typical commute rush-hours resulting in a greater number of vehicles, possibly travelling at a lower speed and emitting a higher concentration of pollutants. Longer trip times have been associated with higher levels of exposure (Peace et al. 2004).

Work-related Exposure to Vehicle Emissions

Aside from exposures while travelling inside a vehicle, a significant proportion of the population are exposed through occupations that lead to extended periods of time on or near roads and highways or close to traffic like asphalt workers (Randem et al. 2004), traffic officers (de Paula et al. 2005; Dragonieri et al. 2006; Tamura et al. 2003; Tomao et al. 2002; Tomei et al. 2001), street cleaners (Raachou-Nielsen et al. 1995), street vendors, and tollbooth workers. Health impacts are greater for these groups who work close to traffic than for those that are not occupationally exposed.

The same studies show increased cardiovascular and respiratory in these groups. A study in Copenhagen found that street cleaners had a greater risk for chronic bronchitis and asthma when compared with cemetery workers (Raaschou-Nielsen et al. 1995). It has been reported that traffic policemen present with airway inflammation and chronic respiratory symptoms at higher rates than in non-exposed groups (Dragonieri et al. 2006; Tamura et al. 2003). Asphalt workers have also been reported to have an increased risk of respiratory symptoms including lung function decline, and chronic obstructive pulmonary disease (COPD) as compared with other construction workers (Randem et al. 2004). The risk of cardiovascular diseases has been investigated in traffic controllers in Sao Paulo, Brazil. Exposure to both CO and SO_2 resulted to increased blood pressure and SO_2 also resulted in decreased heart rate variability, associated with an imbalance of the autonomic system (de Paula et al. 2005).

People who work close to traffic emissions experience higher rates of cancer and respiratory and cardiac illnesses compared to less exposed workers

Increased concentrations of vehicle exhaust carcinogens that have been associated with cancer risk like PAHs and VOCs (e.g. benzene and 1, 3-butadiene) have been reported in street vendors (Ruchirawat et al. 2005) and tollbooth workers (Sapkota et al. 2005) as measured by personal samplers. Interestingly, tollbooths have been found to offer a significant protective effect to tollbooth workers, where concentrations of 1, 3-butadiene and benzene inside the booth were found at less than half the concentration directly outside of the booth (Sapkota et al. 2005).

A higher rate of cancer incidence has been reported in a group of 19,000 Nordic service station workers who were followed for 20 years (Lynge et al. 1997) for kidney, pharyngeal, laryngeal, lung, and nasal cancer.

The risk of exposure to PAH and other carcinogens has been assessed using biomarker measurements in a Danish study of bus drivers and mail carriers. Bus drivers were more exposed than mail carriers working in indoor offices, and higher pollutant levels were reported in bus drivers than in outdoor mail carriers (Hansen et al. 2004). Higher levels of benzene exposure have also been found in traffic wardens in Rome (Tomei et al. 2001).

Pedestrians are also exposed to vehicle-emissions, although they are a less studied group. Pedestrians who walk on the side of the pavement further away from the road have been found to experience up to 10% lower exposure to traffic-related emissions than those who walk on the side of the pavement closest to the road (Kaur et al. 2005a). This has implications for urban planning and design.

Proximity to Roadways

Individuals living close to major roads are at increased risk of exposure to traffic-related pollution and related health effects. In fact, residential proximity to a major road has been associated with a mortality rate advancement period of 2.5 years (Finkelstein et al. 2004). Of particular concern are communities close to border crossings, where traffic levels are high and include a large proportion of transport trucks. For example, individuals living close to the Peace Bridge, one of the busiest US-Canada crossing points, show a clustering of increased respiratory symptoms, particularly asthma (Lwebuga-Mukasa et al. 2005; Oyana et al. 2004; Oyana et al. 2005). Similar associations have been reported for respiratory hospital admissions in Windsor, Ontario, another geographic area with high air pollution levels associated with border crossings (Luginaah et al. 2005).

People living close to busy roads experience increased respiratory symptoms

There are fewer studies of non-residential exposures, however, this is important to consider given the significant amount of time spent at work or in school for much of the population. Higher concentrations of traffic-related pollutants have been reported in schools in close proximity to busy roads, high traffic density, and the percentage of time a school is located downwind (Janssen et al. 2001). Furthermore, it has been suggested that public schools and day care facilities that are closest to busy roads also typically have a disproportionate number of economically disadvantaged children than those that are located at a further distance away (Green et al. 2004; Houston et al. 2006). This supports other findings that people living in more deprived neighbourhoods have greater exposure to air and traffic pollution than those in other neighbourhoods (Finkelstein et al. 2005). This raises an important issue of the complex factors that collectively contribute to individual exposure to vehicle-related emissions.

Level of Physical Activity

Exercising individuals may be at a higher risk of the adverse health effects because even at low intensities, a significant increase in pulmonary ventilation occurs. This results in an increase in inhaled particles that are deposited into the lungs during any outdoor exercise (Sharman et al. 2004), and has been demonstrated frequently in studies of cyclists (O'Donoghue et al. 2007; van Wijnen et al. 1995). There is temporal variability in the concentration of pollutants during the day, with particularly high levels during morning rush-hour in urban environments. Given this and the heightened exposure during exercise, it has been suggested that vigorous outdoor physical activity should be taken when air pollution levels tend to be lowest, particularly very early in the morning, before rush hour, and in low-traffic areas (Campbell et al. 2005).

As physical activity level increases, more air pollutants are deposited in the lungs

Duration of Exposure

Exposure to traffic-related pollutants is both constant and chronic, particularly for individuals who reside near busy roads for many years, and acute and short-term as a result of daily changes in pollutant levels over short periods of time. Chronic obstructive pulmonary disease (COPD) provides an example of a health effect that can result from both of these kinds of exposure. Short-term exposure to low levels of air pollution, particularly particulate matter, have repeatedly been associated with exacerbations of COPD (MacNee et al. 2000; Pope and Dockery. 2006; Yang et al. 2005). More recently, the risk of developing COPD has also been linked with long-term exposure to air pollution in a study of individuals living close to busy roads for at least five years (Schikowski et al. 2005).

Vulnerable Populations

There are some populations which are particularly susceptible to the effects of traffic-related pollution. These include fetuses and children, the elderly, and those with pre-existing breathing and heart problems. However, healthy individuals are also at risk of these effects from both short-term exposures as well as chronic exposure over several years or a lifetime.

The human fetus is particularly susceptible to the effects of traffic-related pollution given physiological immaturity. A study of the genotoxic effects of exposure to PAHs in pregnant mothers in Manhattan, Poland, and China used personal air monitors to assess exposure to air pollution. This study reported that in utero exposure increases DNA damage and carcinogenic risk to the fetus (Perera et al. 2005). Prenatal exposure to high levels of PAHs has been associated with decreased subsequent cognitive development at 3 years of age (Perera et al. 2006). Fetal growth impairment has also been linked to in utero exposure to airborne PAHs, even at relatively low levels of exposure (Choi et al. 2006).

Children are particularly vulnerable to the health impacts of traffic, as are seniors and people of all ages with underlying medical problems

Children are particularly vulnerable to the health impacts of traffic given their immature physiology and immune system which are still under development. Furthermore, children breathe more per unit body weight than adults. In addition, children tend to spend more time outdoors, engaged in strenuous play or physical activity, resulting in greater exposure to air pollution than adults.

Several studies suggest that the effect size from exposure to traffic-related pollution is greater among the elderly than other age groups (Goldberg et al. 2001; Pope 2000; Zeka et al. 2005). These individuals are also likely to have pre-existing illness and have been subject to a lifetime of exposure.

Individuals with pre-existing illness are particularly vulnerable to the effects of traffic-related pollution, especially those with illnesses with systemic effects like diabetes and cancer. It has been reported that increased levels of CO exacerbate heart problems in individuals with both cardiac and other diseases (Burnett et al. 1998b). Several studies support the suggestion that individuals with diabetes are particularly at risk of suffering from heart disease during periods when air pollution is high

(Goldberg et al. 2006; O'Neill et al. 2005; O'Neill et al. 2007). This has been attributed to the effects of fine particles and elemental carbon as well as other components of the air pollution mixture.

A slightly higher risk of mortality associated with vehicle-related pollutants has been associated with low socioeconomic status (SES), a variable that is known to be correlated with health status. This effect may result from the fact that individuals of low SES may live in lower value dwellings that are in close proximity to major roads and therefore at a higher risk of exposure (Smargiassi et al. 2006). Furthermore, vehicles may be newer and create less pollution in high SES neighbourhoods, with homes with better ventilation and insulation to offer protection against these effects (Ponce et al. 2005).

Poverty is linked with increased health risk from traffic

Environmental Influences

Ambient temperature and local meteorology influences the concentration and location of vehicle-emitted pollutants. For example, elevated sulphur dioxide levels are typically reported in the winter, and elevated ground-ozone levels in the summer (Goldberg et al. 2001; Rainham et al. 2005). Cold weather can result in higher levels of pollutants in ambient air due to reduced atmospheric dispersion and degradation reactions.

The genotoxic effects of $PM_{2.5}$ and PM_{10} have also been found to be greater in the winter months (Abou Chakra et al. 2007). Dispersion of pollutants is also affected by other meteorological factors like humidity, wind speed and direction and general atmospheric turbulence.

Adverse Health Effects of Traffic Pollution

Exposure to vehicle-related pollutants is associated with excess overall mortality as well as with diverse health effects. These detrimental outcomes occur over multiple pathways with varying end points.

Overall Mortality

Traffic pollution is strongly linked with premature mortality

There is little doubt that exposure to traffic-related emissions results in increased risks of mortality, particularly from respiratory and cardiopulmonary causes. A meta-analysis of 109 studies found that PM_{10}, CO, NO_2, O_3, and SO_2 were all positively and significantly associated with all-cause mortality (Stieb et al. 2002). A large study of mortality in Los Angeles for the period 1982-2000 found a strong increase in all-cause mortality with increased exposure to $PM_{2.5}$ (Jerrett et al. 2005). Two large Canadian studies investigated the association between several pollutants associated with traffic and mortality (Burnett et al. 1998a; Burnett et al. 2000). Daily variations in NO_2, SO_2, O_3, and CO were associated with daily variations in mortality in 11 Canadian cities from 1980 to 1991 (Burnett et al. 1998a). Of these, NO_2 was the strongest predictor of the 4 gaseous pollutants investigated. When fine particulate matter was included in the next study (Burnett et al. 2000), NO_2 was again a strong predictor of mortality. This effect was evident again during a later time series analysis of 12 Canadian cities between 1981-1999 where a positive and statistically significant association was again observed between daily variations in NO_2 concentration and fluctuation in daily mortality rates (Burnett et al. 2004). This is interesting given the ongoing debate in the current literature about whether the effect of NO_2 on health is independent, or if it is actually an indicator of other pollutants in vehicle emissions that are not necessarily directly observable.

Respiratory Effects

Perhaps the most commonly studied and most frequently reported health effect associated with traffic-related pollution are those associated with respiratory morbidity. Numerous studies have found an association with vehicle emissions and a diversity of respiratory symptoms and diseases. These adverse outcomes range from acute symptoms like coughing and wheezing to more chronic conditions such as asthma and chronic obstructive pulmonary disease (COPD), which includes chronic bronchitis and emphysema. Exposure to fine PM and ozone have been associated with these conditions. Studies have produced varying results on the relationship between NO_2 exposure and respiratory health. NO_2 is most clearly associated with cough (Sunyer et al. 2006), however, it is uncertain as to whether it acts as an indicator of traffic related pollution, rather than having a direct adverse health effect (Pattenden et al. 2006).

Many studies on the effect of vehicle emissions and respiratory health consider short-term changes in exposure and daily symptoms in the study population, particularly in exacerbating symptoms in asthmatics as well as inducing asthma in otherwise healthy individuals (Sarnat and Holguin. 2007). The Children's Health Study in southern California found that asthma and wheeze were strongly associated with residential proximity to a major road (McConnell et al. 2006), a finding that is consistent with many other studies of children (Oyana and Rivers. 2005). Interestingly, similar effects have been found in populations of infants and very young children (Ryan et al. 2005), as well as adolescents (Gauderman et al. 2007).

A recent study used modelled exposures to traffic related air pollutants and found significant associations with sneezing/runny/stuffed noses and absorbance of $PM_{2.5}$, as well as an association between cough and NO_2 exposure in the first year of life (Morgenstern et al. 2007). A similar relationship has been demonstrated in adult populations in the SAPALDIA (Swiss Cohort Study on Air Pollution and Lung Disease in Adults) studies. These have demonstrated that living near busy streets not only induces or exacerbates asthma and wheeze but also is associated with bronchitis symptoms including regular cough and phlegm production (Bayer-Oglesby et al. 2006). A recent study in Paris investigated the relationship between daily levels of $PM_{2.5}$, PM_{10}, and NO_2 and the number of doctors' house calls for asthma, upper and lower respiratory diseases in adults (Chardon et al. 2007). A significant association was found for $PM_{2.5}$ and PM_{10} for upper and lower respiratory disease, but no association with NO_2. Other studies of respiratory hospital admissions (Chen et al. 2007; Luginaah et al. 2005; Oyana et al. 2004; Smargiassi et al. 2006) and modelled pollutant exposure (Buckeridge et al. 2002) support these findings.

Another respiratory effect that has been associated with exposure to vehicle emissions is reduced lung function. While the magnitude of the effect reported is often small, there is consistency in these findings. Most studies investigate the effects in children, however, of particular interest is a study of exposure to NO_2 in healthy university students in Korea (Hong et al. 2005). Exposure levels were found to be significantly associated with proximity of residence to main roads, and this exposure was associated with a reduction in lung function.

Living near traffic is associated with increased asthma symptoms, wheeze and chronic bronchitis, and with reduced lung function

Finally, there is an increasing body of literature that examines the chronic respiratory effects resulting from exposure to vehicle emissions. A study in Germany of 4757 women concluded that chronic exposure to PM_{10}, NO_2 and living near a major road for at least 5 years was associated with decreased pulmonary function and COPD (Schikowski et al. 2005). Chronic bronchitis has also been associated with close proximity to busy roads (and NO_2), particularly in women (Sunyer et al. 2006).

Cardiovascular Effects

There is substantial evidence that supports an association between vehicle emissions and cardiovascular disease, particularly mortality from cardiovascular causes (Gehring et al. 2006; Pope et al. 2004a; Miller et al. 2007). Cardiovascular and stroke mortality rates have been associated with both ambient pollution at place of residence as well as residential proximity to traffic (Finkelstein et al. 2005). Several recent studies also consider nonfatal cardiovascular outcomes like acute myocardial infarction (AMI) and have found an association with exposure to vehicle emissions, particularly as a result of long-term exposure to $PM_{2.5}$ and/or close residential proximity to busy roads (Hoffmann et al. 2006; Jerrett et al. 2005; Rosenlund et al. 2006; Tonne et al. 2007; Peters et al. 2004).

Short-term exposures have also been shown to be associated with ischemic effects (Lanki et al. 2006a). A case-crossover study of 772 individuals in Boston found that elevated concentrations of $PM_{2.5}$ were associated with an increased risk of AMI within a few hours and one day following exposure (Peters et al. 2001). Another study of 12,865 individuals in Utah found a similar effect for both AMI and unstable angina, and that this effect was worse for patients with underlying coronary artery diseases (Pope et al. 2006). The specific toxicants most commonly associated with these effects are PMs, although there is also evidence of an adverse influence of CO (Lanki et al. 2006b) and SO_2 (Fung et al. 2005).

Increased levels of CO and NO_2 have also been implicated in increased incidence of emergency department visits for stroke (Villeneuve et al. 2006). It has been suggested that it is the strong association between air pollution and ischemic heart disease that drives the cardiopulmonary association with air pollution (Jerrett et al. 2005). Many plausible pathophysiological pathways linking PM exposure and cardiovascular disease have been suggested and include systemic inflammation, accelerated atherosclerosis, and altered cardiac autonomic function reflected by changes in heart rate variability and increases in blood pressure (Brook et al. 2002; Brook et al. 2003; Luttmann-Gibson et al. 2006; Pope et al. 2004a; Pope et al. 2004b; Schwartz et al. 2005; Urch et al. 2005).

Living near heavy traffic is associated with increased cardiac problems, including heart attacks

Cancer

There is an increasing body of literature that suggests that vehicle emissions are also associated with the development of cancer, particularly lung cancer, although other types have been implicated. A large recently published study in Europe of 4000 individuals studied the relationship between lung cancer and vehicle-related pollution (Vineis et al. 2006). Exposure to air pollution was measured as proximity of residence to heavy traffic roads. Additionally, exposure to NO_2, PM_{10}, and SO_2 was assessed from monitoring stations. The findings from this study indicate that residence in close proximity to heavy-traffic roads, or exposure to NO_2 increases the risk of lung cancer. This is consistent with studies conducted in Oslo (Nafstad et al. 2003) and Stockholm (Nyberg et al.2000) that found a similar relationship between increased risk of lung cancer and levels of traffic-related NO_2. This effect has also been demonstrated in studies of fine PM and SO_2 (Pope et al. 2002) and exposure to diesel exhaust (Parent et al. 2007).

The effect of vehicle emissions on childhood cancers, particularly leukemia, is also of concern. While the research is this area is somewhat limited, there is some indication that vehicle emissions are associated with an increased risk of childhood cancer as indicated by residential proximity to busy streets (Pearson et al. 2000; Savitz and Feingold. 1989). An Italian study which modeled benzene concentrations (based on traffic density) found a nearly four-fold increase in the risk of childhood leukemia in the highest exposure group (Crosignani et al. 2004). An ecological study in Sweden (Nordlinger and Jarvholm. 1997) and a UK study of children residing close to main roads and petrol stations (Harrison et al. 1999) provide further support for this association.

Chronic elevated exposure to vehicle emissions is linked with increased rates of lung cancer in adults and leukemia in children

Information on the relationship between vehicle-emissions and other types of cancers are sparse. However, one recent study suggests that early life exposure to traffic emissions (which include PAHs) may be associated with breast cancer in women (Nie et al. 2007). Specifically, higher exposure to traffic-related emissions at menarche was associated with pre-menopausal breast cancer, while emissions exposure at the time of a woman's first childbirth was associated with postmenopausal breast cancer (Nie et al. 2007). Lastly, a study in Finland of individuals exposed to diesel and gasoline exhaust occupationally found an association between ovarian cancer and diesel exhaust (Guo et al. 2004).

Hormonal and Reproductive Effects

There is evidence that suggests that exposure to traffic pollutants affects fertility in men. An Italian study evaluated sperm quality in men employed at highway tollgates (De Rosa et al. 2003). Total motility, forward progression, functional tests, and sperm kinetics were significantly lower in tollgate employees versus controls. In particular, nitrogen oxide and lead were implicated as toxins with adverse effects (De Rosa et al. 2003).

There is emerging evidence that vehicle-related emissions are associated with an increased risk of adverse pregnancy outcomes. Several studies have reported an association with low birth weight in infants and maternal exposure to emissions during pregnancy (Bell et al. 2007; Liu et al. 2003; Salam et al. 2005; Sram et al. 2005; Wilhelm and Ritz. 2005). It has also been suggested that there is an association with preterm births and intrauterine growth retardation, but these studies are less consistent (Ponce et al. 2005; Sram et al. 2005). Finally, there have been a few suggestions of an increased risk in these infants of sudden infant death syndrome and birth defects like congenital heart defects but further research is needed to confirm these findings (Dales et al. 2004; Ritz et al. 2002; Sram et al. 2005).

Chronic exposure to heavy traffic pollution is associated with reduced fertility in men and low birth weight

As has been discussed, prenatal and early exposure to traffic-related pollution has a significant impact on the health of the fetus and infant, but it can also predispose them to a range of other illnesses. Adverse birth outcomes like low birth weight have been linked to the development of chronic illnesses later in life like cardiovascular disease, type 2 diabetes, hypertension, lower cognitive function, and increased cancer risk (Perera et al. 2005; Perera et al. 2006).

Intervention Studies Related to Reducing Traffic

Despite the diversity and seriousness of health effects linked with vehicle emissions, there are many actions that can be undertaken to improve the current situation. Intervention studies, while not common, provide a unique opportunity to demonstrate the health benefits of taking specific policy or regulatory actions to improve air quality. A few vehicle-related intervention studies are highlighted here.

During the 1996 Summer Olympic Games in Atlanta, Georgia, a strategy for minimizing road traffic congestion was implemented. An ecological study comparing the 17 days of the Olympic Games to a baseline period of the 4 weeks prior to and following the Olympic Games was conducted (Friedman et al. 2001). Morbidity outcomes were measured and compared between these time periods and included the number of hospitalizations, emergency department visits, and urgent care centre visits for asthma. In addition, data were collected for meteorological and air quality conditions and traffic and public transportation information. The results demonstrate a significant decrease in the number of asthma acute care events (by 42%) in children between the ages of 1 and 16 during this time. Air quality improved with a decrease in peak daily ozone and carbon monoxide by 28% and 19% respectively. There was a significant correlation between the decrease in weekday traffic counts and peak daily ozone. These results suggest that decreased traffic density have a direct effect of the risk of asthma exacerbations in children.

In 1990, a fuel composition restriction was implemented in Hong Kong where all road vehicles were required to use fuel with a sulphur-related content of not more than 0.5% by weight. This resulted in an average reduction in SO_2 concentrations by 45% over five years (Hedley et al. 2002), which was sustained between 35% and 53% over the next five years. One study of the health effects of this intervention reported a reduction in bronchial hyper-responsiveness in young children 2 years after the intervention (Wong et al. 1998). A more recent study of this same intervention assessed its relationship with mortality over the 5 years and found a decline in average annual trend in deaths from all causes (2.1%), respiratory (3.9%) and cardiovascular (2.0%) (Hedley et al. 2002).

Studying the effects of relocating individuals from more to less polluted areas also presents a unique opportunity to demonstrate the associated health benefits. Over the duration of a 10-year prospective study of respiratory health and air pollution in children in Southern California, 110 participants moved to a new place of residence. This provided an opportunity to study the effect of relocation to communities with higher or lower levels of air pollution on their lung function performance (Avol et al. 2001). Subjects who had moved to communities of lower PM_{10} showed increased lung function while those who moved to areas of higher PM_{10} showed decreased lung function (Avol et al. 2001).

Intervention studies also provide evidence of decreased emissions resulting from strategies to reduce traffic. During the 2004 Democratic National Convention in Boston, Massachusetts, numerous road closures were implemented as a security measure. To investigate the effects these closures had on air quality NO_2 monitoring badges were placed at various sites around metropolitan Boston and levels were compared before, during, and after the convention. The study demonstrated lowered NO_2 concentrations in the air with traffic reductions (Levy et al. 2006).

In 2003 the London Congestion Charging Scheme (CCS) was implemented in an effort to reduce traffic density in London, UK. A recent review of the impact of this scheme analysed traffic data and emissions modelling (Beevers and Carslaw. 2005). There was a 12% reduction in both NO_2 and PM_{10} emissions at the time of the study, and even greater reductions are likely with expansion of the program. Emission reductions were attributable to the reduction in number of vehicles, and to the higher speed vehicles could travel as a result of less congestion, and therefore fewer emissions per distance travelled.

These intervention studies provide evidence that reduction in vehicle-related emissions can have a significant impact on reducing associated morbidity and mortality. This has tremendous implications for individuals, but also for public health on a population level. A public health impact assessment in Europe reported that air pollution is responsible for 6% of total mortality, at least half of which can be attributed to be vehicle-related (Kunzli et al. 2000). An analysis of the impact of air pollution on quality-adjusted life expectancy in Canada reports that a reduction of 1 $\mu g/m^3$ in sulphate air pollution would yield a mean annual increase in quality-adjusted life years of 20,960, a very substantial positive impact (Coyle et al. 2003). It is clear that reducing vehicle emissions will have a significant impact on improved health outcomes. There is an urgent need to implement plans and policies that will work towards mitigating these adverse effects.

Intervention studies provide compelling evidence that reducing vehicle emissions improves health outcomes

Air Pollution and Traffic Trends in Toronto

Air pollutants generated by motor vehicle traffic are comprised of criteria pollutants, air toxics (toxic chemicals in the air) and greenhouse gases (GHG).

Criteria Pollutants

The combustion of fossil fuels (such as gasoline, diesel, propane, natural gas, oil, coal, and wood) generates common smog pollutants

In Toronto, as in most major urban centres in North America, vehicles are a significant source of 'criteria' (common) air pollutants of health concern. Criteria pollutants are commonly emitted from the combustion of fossil fuels, whether gasoline, diesel, propane, natural gas, oil, coal or wood. Toronto sources of these pollutants include vehicle, space heating of buildings, commercial and industrial operations. These common pollutants include nitrogen dioxide (NO_2), sulphur dioxide (SO_2), carbon monoxide (CO) and particles of various sizes. Particles are measured as total suspended particles (TSP), inhalable particles of 10 micron diameter or less (PM_{10}), and respirable particles of 2.5 micron diameter or less ($PM_{2.5}$). Vehicles also emit pollutants such as nitrogen oxides (NOx) and volatile organic compounds (VOCs) that enable ozone to form in the presence of sunlight.

Table 1 summarizes the sources of common air pollutants emitted as a result of activities by Toronto, based on 2004 data. Emission sources are categorized as follows:

- Mobile – cars, trucks, buses (but not trains);
- Area – residential and small scale commercial/industrial emissions;
- Point – industrial emissions (from 'smokestacks' reportable to NPRI);
- Natural gas combustion – all buildings (such as for space heating).

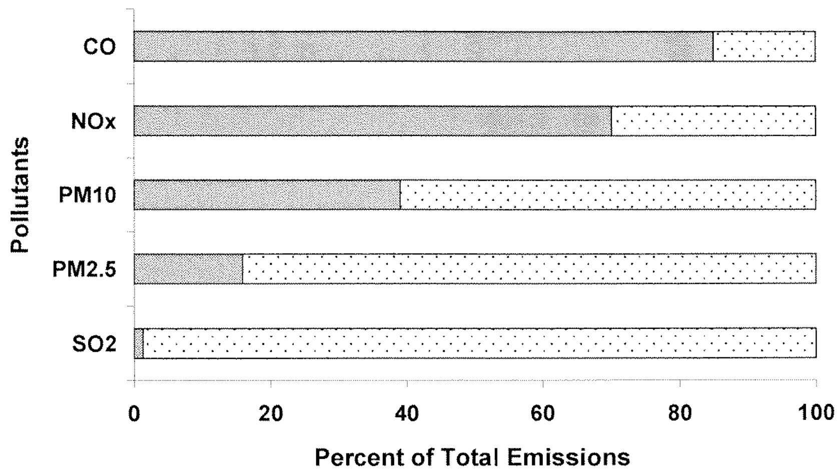
Table 1. Annual Emissions of Criteria Pollutants by Toronto (2004)

Pollutant	Emissions by Source (Tonnes/Year)				
	Mobile (Vehicles)	Area	Point	Natural Gas Combustion	Total
CO	306,174	47,573	435	4,154	358,336
NOx	27,434	3,740	1,749	6,684	39,607
PM_{10}	7,432	10,848	470	525	19,275
$PM_{2.5}$	1,576	7,305	408	525	9,814
SO_2	117	8,531	304	41	8,993

Source: *Greenhouse Gases and Air Pollutants in the City of Toronto: Towards a Harmonized Strategy for Reducing Emissions*. Prepared by ICF International in collaboration with Toronto Atmospheric Fund and Toronto Environment Office. Toronto June 2007

Figure 1 illustrates the proportion of the total emissions from Toronto activities that come from vehicles. These same emissions can be compared by source in Table 1. Vehicles are the largest source of CO (85%) and NOx (69%) emissions within Toronto. They also are a significant source of PM_{10} (39%) and $PM_{2.5}$ (16%). While vehicles (or other combustion sources) do not emit ozone directly from the tailpipe, vehicles emit precursor chemicals (such as NOx) which give rise to large amounts of ozone that form in the air (usually downwind) and are of substantial health concern.

Figure 1. Vehicle Emissions as Proportion of Total Emissions from Toronto



Source: *Greenhouse Gases and Air Pollutants in the City of Toronto: Towards a Harmonized Strategy for Reducing Emissions.* Prepared by ICF International in collaboration with Toronto Atmospheric Fund and Toronto Environment Office. Toronto June 2007

The amount of pollutants in Toronto's air results from sources within the city, as well as emission sources upwind of Toronto, such as coal-fired power plants in Ontario and the U.S. Weather plays a large part in the fluctuation of ambient pollutant levels in the city. Wind, temperature and precipitation factors all strongly affect daily and seasonal air quality.

Figure 2 shows the trend in annual average concentrations of common air pollutants in Toronto over a 26 year span (1980 to 2006), based on data from the Ontario Ministry of the Environment. Some pollutants, such as CO and SO_2 are showing a decline in recent years, while other pollutants, such as TSP are not. Although NO_2 levels show a decline in the last decade, current levels are similar to levels in the 1980s, prior to the upward trend during the 1990s. Of greatest concern is ozone, which is showing a steady increase in the last decade.

Figure 2. Trends in Average Annual Pollutant Concentrations in Toronto

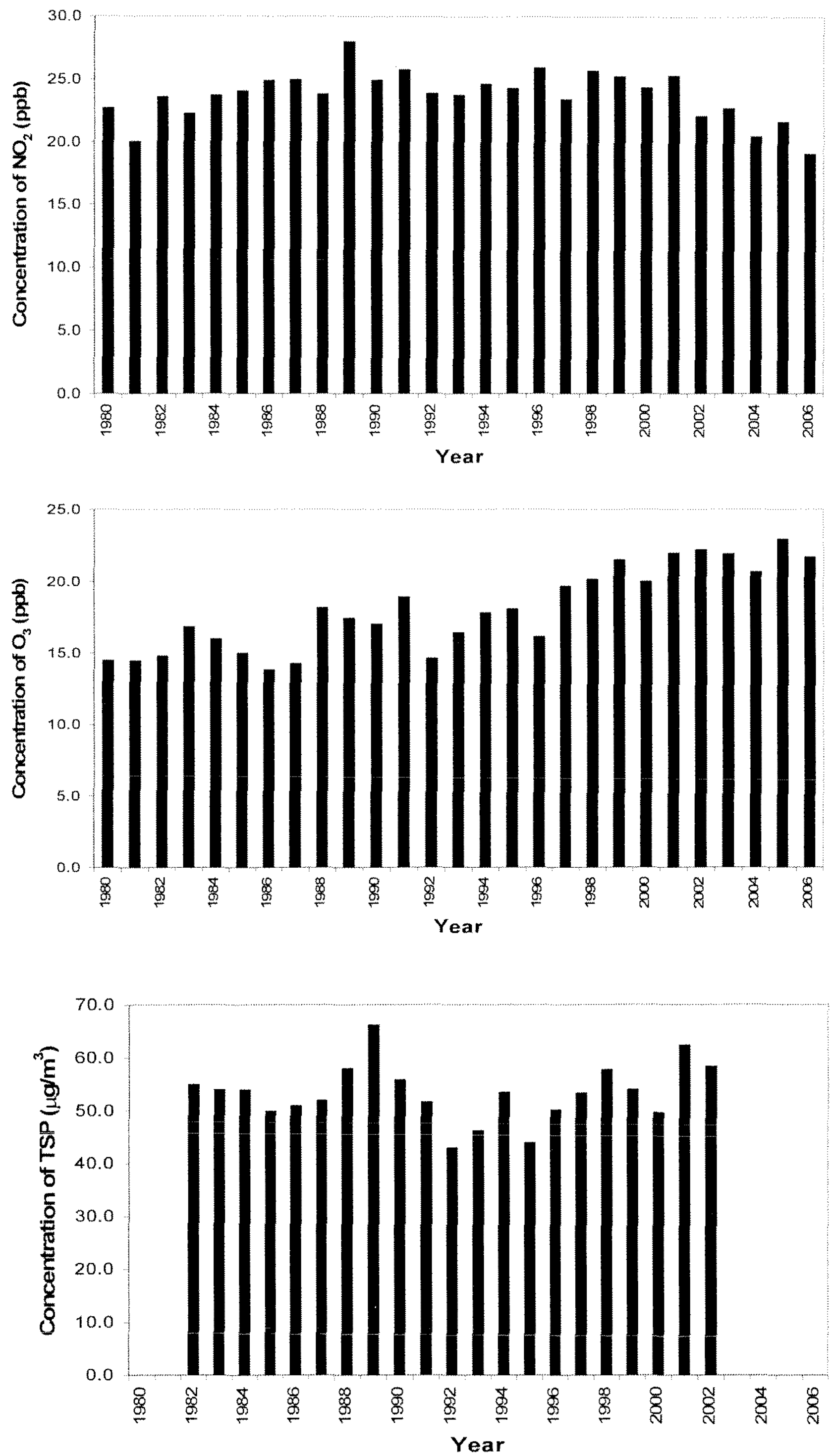
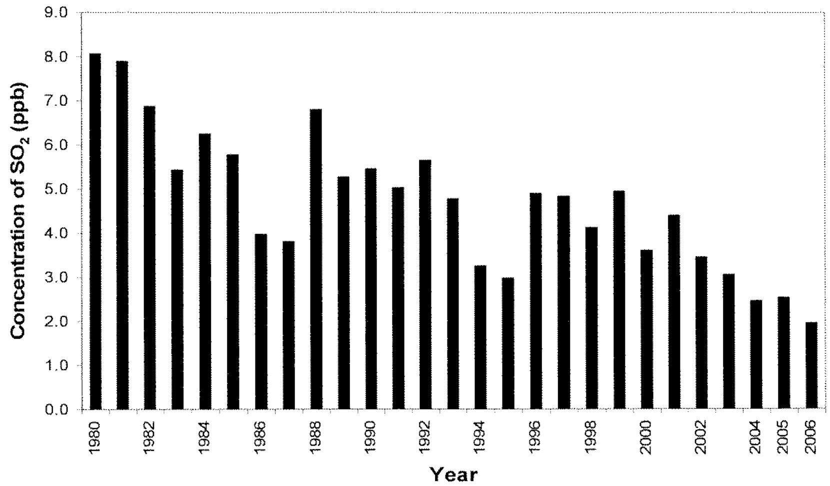
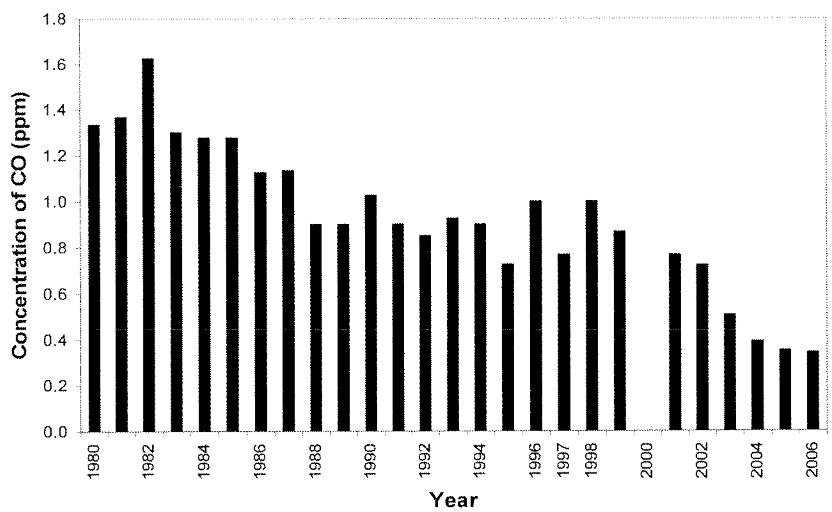


Figure 2 (continued). Trends in Average Annual Pollutant Concentrations in Toronto





It is of concern that pollution trends in Toronto for some key pollutants of health concern reveal little improvement in air quality over the last two decades. The trend data suggest that despite many important initiatives by all levels of government to improve air quality, progress is slow. It may be that gains in the transportation sector, such as the introduction of less polluting vehicles and improvements in fuel quality, are being off-set by the increased volume and frequency of vehicle use.

Trend data suggest that progress is slow in improving air quality in Toronto. Gains in cleaner vehicles are being offset by increases in traffic volumes

Air Toxics

Vehicles are a significant source of 'air toxics' (toxic chemicals in the air). Air toxics are substances that occur in the air in much smaller amounts than 'criteria' pollutants, but which are much more potent in terms of adverse impacts. In general, air toxics are of particular concern with chronic (long term) exposure, and are associated with serious health outcomes such as cancer and reproductive effects.

At present, no air toxics emissions inventory exists in Toronto, unlike for criteria pollutants or greenhouse gases. Such an inventory may be a possibility in the future if a community right to know bylaw is put in place. Such an inventory would enable the relative amounts of air toxics by source to be calculated. We can then determine air toxics of priority health concern in Toronto by comparing Environment Canada surveillance data with health benchmarks.

Table 2 indicates relative health risk of priority air toxics, based on exposure ratios relative to health benchmarks, and using average and maximum pollutant levels measured in Toronto's air during 2003, 2004 and 2005. The greater the exposure ratio number, the greater the health risk. Exposure ratios greater than 1 indicate health concern because they exceed health benchmarks for cancer or non-cancer effects. For non-carcinogens, the health benchmark is the level without observable adverse impacts. For carcinogens, the health benchmark corresponds to a 1-in-million excess cancer risk.

Vehicle-related pollutants such as benzene, PAHs, and 1,3-butadiene are of concern because they routinely occur in Toronto air at levels above health benchmarks

Table 2 provides a list of air toxics associated with vehicle emissions, and that occur in Toronto's air at levels of health concern. For many of these pollutants, industrial and commercial facilities also contribute to ambient levels observed in Toronto Of particular concern are vehicle-related exposures to chromium, benzene, polycyclic aromatic hydrocarbons (PAHs), 1,3-butadiene, formaldehyde, acrolein and acetaldehyde because these pollutants routinely occur at levels above health benchmarks.

Table 2. Priority Air Toxics in Toronto Associated with Vehicle Emissions

Air Toxic	Relative Health Risk (Exposure Ratio)	
	Based on Maximum Pollutant Concentration	Based on Average Pollutant Concentration
Chromium	1150	225
Benzene	176	30
PAHs	302	20
1,3-butadiene	102	26
Formaldehyde	67	27
Acrolein	20	2
Acetaldehyde	15	6
Nickel	4	0.8
Manganese	2	0.08

Source: Toronto Public Health. 2007. *Process to Identify Priority Substances of Health Concern for Enhanced Environmental Reporting*. Environmental Protection Office, Toronto Public Health, Toronto.

Greenhouse Gases

Vehicles are a very large source of greenhouse gases (GHGs) in Toronto. Table 3 summarizes total GHG emissions generated by Toronto activities in 2004, as expressed by carbon dioxide equivalents (eCO_2). By expressing GHGs in terms of eCO_2, it is possible to use a common measure to sum the global warming potential (GWP) of a variety of GHGs. The three primary GHGs are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).

Table 3. Annual Emissions of Greenhouse Gases for Toronto (2004)

Source of Emissions	GHG Emissions (eCO_2 tonnes/year)
Residential	5,997,042
Commercial & small industry	6,884,767
Large commercial & industry	2,002,172
Transportation	8,558,966
Waste transport to Michigan	35,507
Streetlights & traffic signals	29,203
Waste (methane from landfills)	942,550
Total	24,450,207

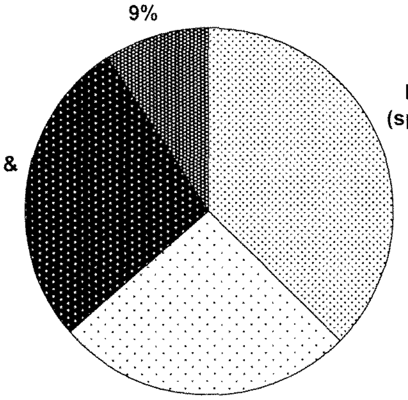
Source: *Greenhouse Gases and Air Pollutants in the City of Toronto: Towards a Harmonized Strategy for Reducing Emissions.* Prepared by ICF International in collaboration with Toronto Atmospheric Fund and Toronto Environment Office. Toronto June 2007

The transportation sector contributes about 35% of the total GHGs emitted as a result of activities in Toronto. Figure 3 shows the distribution in energy-related (fuel and electricity) GHG emissions by Toronto. Of the GHG emissions produced by vehicles, about 25% are attributable to transport trucks and 75% are generated by personal vehicles (cars and light trucks).

The transportation sector contributes about 35% of total greenhouse gases emitted as a result of activities in Toronto

Greenhouse gas emissions have continued to rise in the City during the period between 1990 and 2004. Over this period, greenhouse gas emissions have risen from 22.0 million tonnes to 24.4 million tonnes annually, with transportation emissions from the use of gas and diesel-powered vehicles continuing to be a major contributor.

Figure 3. Distribution in Energy-Related Greenhouse Gases Emissions (2004)



Source: *Greenhouse Gases and Air Pollutants in the City of Toronto: Towards a Harmonized Strategy for Reducing Emissions.* Prepared by ICF International in collaboration with Toronto Atmospheric Fund and Toronto Environment Office. Toronto June 2007

Unlike criteria pollutants and air toxics which have direct adverse impacts on health, GHGs are of health concern because of secondary effects such as global warming and climate disruption. Based on recent research, Toronto Public Health has determined that on average (over the 46 year study period), about 120 people die prematurely from heat-related causes in Toronto. Furthermore, it is projected that global warming could result in a doubling of heat-related deaths by 2050, and a tripling by 2080 (Toronto Public Health, 2005).

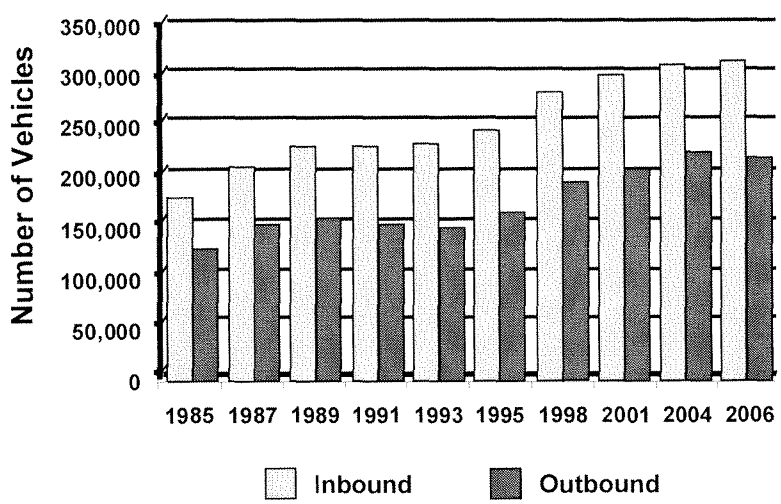
Traffic Trends

Data showing traffic trends in Toronto demonstrate that the number of vehicles travelling into Toronto each morning has increased each year from 1985 to 2006. Figure 4 illustrates that between 1985 and 2006, the number of inbound vehicles increased from 179,300 vehicles to 313,900 vehicles, an increase of 75% (City of Toronto, 2007).

The number of vehicles travelling out of the city each morning has fluctuated since 1985 and reached its peak level in 2004 (224,200 vehicles). Between 1985 and 2006, vehicles leaving the city each morning increased from 122,400 to 219,100 vehicles, showing an increase of 79%, as shown in Figure 4 (City of Toronto, 2007). This increase is attributed in part to employment growth in the region around Toronto and beyond.

In the last two decades, the number of vehicles entering the city each weekday morning has increased by 75%

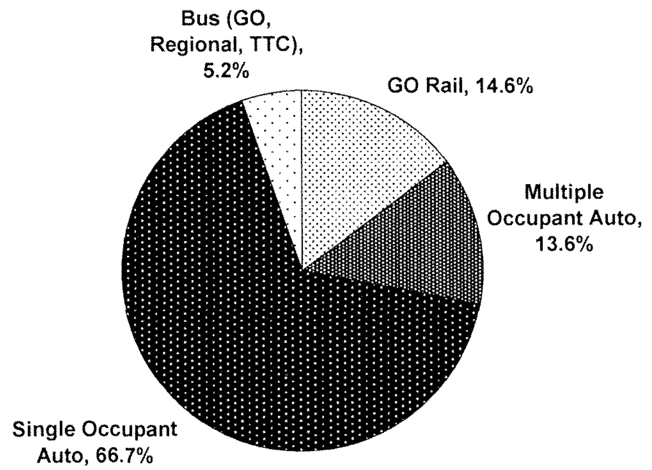
Figure 4. Trend in Mean Daily Number of Vehicles Entering and Exiting Toronto (6:30 a.m. – 9:30 a.m.)



Source: *2006 City of Toronto Cordon Count Program Information Bulletin*. Prepared by City Planning Division - Transportation Planning. Toronto June 2007

Figure 5 shows that 67% of trips entering Toronto in 2006 were made in single occupant vehicles. Only one in every five trips into Toronto during the morning peak travel period is made using GO train, GO bus, TTC and buses from other municipalities (City of Toronto, 2007).

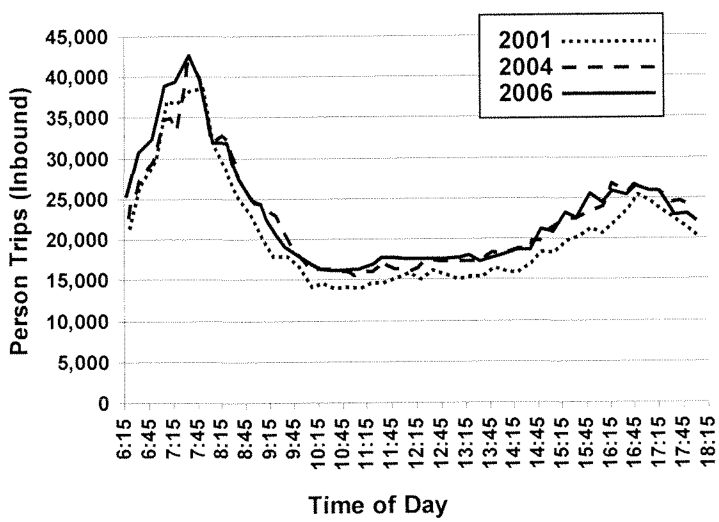
Figure 5: Mode of Travel – Inbound Person Trips (6:30 a.m. – 9:30 a.m.) 2006



Two thirds of the vehicle trips into the city in 2006 were made by single occupancy vehicles

Source: *2006 City of Toronto Cordon Count Program Information Bulletin.* Prepared by City Planning Division - Transportation Planning. Toronto June 2007

Figure 6. All-Day Inbound Travel (Person Trips – 6:30 a.m. – 6:30 p.m.)



Source: *2006 City of Toronto Cordon Count Program Information Bulletin.* Prepared by City Planning Division - Transportation Planning. Toronto June 2007

Figure 6 shows the steady growth in the volume of vehicles travelling into Toronto from 2001 to 2006. Of note is the pronounced peak in vehicle traffic during morning rush hour (6:30 to 9:30 a.m.). Continued population growth in the City combined with strong increases in both population and employment in the region surrounding Toronto has also led to increased off-peak travel, which is reflected in the growth of all-day traffic volumes crossing the City boundaries (City of Toronto, 2007).

Assessment of Air-Related Burden of Illness from Traffic

Methodology

Pollutant Concentration Data

In order to calculate an estimate of the health and economic impacts of traffic-related pollution, the traffic component of ambient pollutant levels must be isolated. Toronto Public Health collaborated with air modelling specialists at the Toronto Environment Office (TEO) to determine the specific contribution of traffic-related pollutants to overall pollution levels. Using 2004 data, TEO modelled emissions from vehicles in Toronto and provided Toronto Public Health the average concentrations for four key pollutants of significant health concern: carbon monoxide (CO), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), and fine particles (particles of 2.5 micron diameter or less) ($PM_{2.5}$) that could be attributed to traffic. The air quality model used was not able to provide modelled ozone (O_3) concentrations, so the ozone contribution from traffic was estimated based on monitoring data from the Ministry of Environment.

To estimate the health impact of traffic pollution, the traffic component of ambient air pollution must be isolated

The City of Toronto's Air Quality Model

Air quality models can be used to predict the concentration of pollutants that people are exposed to that arise from various sources including those specifically from traffic. Unlike measurements taken directly from monitoring stations, these models are mathematical descriptions of air pollution. They take into account the relationship between emissions and air quality, including the dispersion, transport, and transformation of compounds emitted into the air.

The TEO uses an air quality dispersion model called CALPUFF (Atmospheric Sciences Group, TRC Solutions). CALPUFF is a sophisticated computer modelling system that models the dispersion and diffusion of emissions. The model has been adopted by the U.S. Environmental Protection Agency (U.S. EPA) in its *Guideline on Air Quality Models* as the preferred model for assessing long range transport of pollutants and on a case-by-case basis for certain applications involving complex terrain and meteorological conditions as occurs in Toronto given Toronto's proximity to Lake Ontario. The modelling system consists of three main components: CALMET (a diagnostic 3-dimensional meteorological model), CALPUFF (an air quality dispersion model), and CALPOST (a post-processing package). In addition to these components, there are numerous other processors that are used to prepare geophysical and meteorological data.

Traffic emissions were modelled from traffic flow count data provided by Transportation Services (TS). Effectively, the model utilizes hourly traffic count and flow data for every highway, major arterial, minor arterial and collector road in Toronto. Transportation Services also estimates and provides traffic volumes to typify the smaller local roads and lanes. The traffic flow and count data was then multiplied by Provincial vehicle classification volumes for Toronto and multiplied by Environment Canada emission factors to provide tailpipe emission inputs into the

TEO CALPUFF model. Using these data, the model provided an estimate of the concentrations of air pollutants in the air that could be attributed to traffic.

Actual traffic flow and count data were linked to vehicle classifications and emission factors, and input into a model to determine pollutant concentrations

Since the model was not able to provide accurate data for the contribution of vehicles to ozone found in the air, this contribution was estimated using air quality monitoring data for 2004 in Toronto, and assuming that the proportion of ozone from traffic would be the same as the proportion of nitrogen dioxide.

Air Quality Benefits Assessment Tool (AQBAT)

The modelled pollutant concentrations provided by TEO were then applied to the Air Quality Benefits Assessment Tool (AQBAT) to calculate estimates of health and economic impacts. AQBAT is a computer-based tool developed by Health Canada to enable local health units to estimate air-related burden of illness. AQBAT contains population data, pollutant concentrations, and health endpoint values so that the user can define specific scenario reduction models to determine associated benefits and see the effects of changing the levels of pollutants. The current study used this tool to determine the number of deaths and adverse health outcomes that could be prevented if air pollution from traffic in Toronto was reduced.

Pollutant concentrations attributable to traffic were used in AQBAT to model burden of illness and economic impacts

Health Outcomes

AQBAT calculates the health and economic impacts for 13 health endpoints. These health outcomes are described in Table 4.

Table 4. Description of Health Outcomes Assessed by AQBAT

Health Outcome[a]	Description
Acute exposure mortality	Premature deaths from short-term exposures; generally restricted to deaths from non-traumatic causes (i.e. excludes suicide and deaths from injuries)
Chronic exposure mortality	Number of people who die prematurely from chronic exposures; generally restricted to deaths from non-traumatic causes (i.e. excludes suicide and deaths from injuries)
Elderly cardiac hospital admissions	Number of cases involving seniors admitted to hospital for heart failure (over the age of 65 years)
Cardiac hospital admissions	Number of admissions to hospital for heart problems (e.g. angina/myocardial infarction, heart failure, dysrhythmia/conduction disturbance)
Respiratory hospital admissions	Number of admissions to hospital for breathing problems (e.g. asthma, COPD (emphysema and chronic bronchitis), and respiratory infection (croup, acute bronchitis and bronchiolitis, pneumonia)
Cardiac emergency room visits	Number of visits to emergency department for heart problems that do not result in hospital admissions
Respiratory emergency room visits	Number of visits to emergency department for breathing problems that do not result in hospital admissions
Adult chronic bronchitis cases	Number of incident (new) cases of adult chronic bronchitis attributable to traffic pollution in adults (age 25 and over)
Child acute bronchitis episodes	Number of episodes of acute bronchitis involving children
Asthma symptom days	Total number of days that people with asthma experience symptoms or an asthma attack.
Acute respiratory symptom days	Total number of days when any of the following respiratory symptoms or related conditions are reported: chest discomfort, coughing with or without phlegm, wheezing, sore throat, head cold, chest cold, sinus trouble, croup, hay fever, headache, eye irritation, fever, doctor-diagnosed ear infection, flu, pneumonia, bronchitis, bronchiolitis
Minor restricted activity days	Restricted Activity Days less days spent in bed
Restricted activity days	Total number of days spent in bed or days when people cut down on usual activities.

(a) Pollutants linked to each outcome in the analysis are shown in Appendix 1.

Source: Judek et al. *Air Quality Benefits Assessment Tool (AQBAT)* Release 1.0. Ottawa: Health Canada, 2006.

Economic Valuations

To calculate the economic impact of air pollution, AQBAT uses health endpoint valuations which assign a monetary value to a health outcome. Mortality valuation ("value of a statistical life") is based on an individual's willingness to pay to reduce mortality risks or willingness to accept compensation to experience increased mortality risks (i.e. wage premiums for riskier jobs). The morbidity outcomes are valued using a variety of approaches which evaluate costs of treatment (e.g. medical costs), lost productivity, pain and suffering and averting expenditures.

Concentration Response Functions

In AQBAT, concentration response functions (CRFs) are used to determine the percent excess occurrence of a health outcome associated with an increase in pollutant concentration. These are based on risk coefficients from epidemiology studies in the scientific literature.

This analysis likely underestimates the true burden of illness given the limited number of morbidity (illness) outcomes currently captured in AQBAT

Appendix 1 provides an overview of the CRFs available in AQBAT. It is clear that a limited number of mortality and illness outcomes are captured relative to all those potentially attributable to the mix of air pollution. This likely results in an underestimate of the true burden of illness resulting from exposure to the combined mix of pollutants.

Air-Related Morbidity and Mortality from Traffic

Table 5 summarizes of the morbidity and mortality estimates that result from application of AQBAT to the traffic-related pollution data modelled by the Toronto Environment Office. The results show the number of Toronto residents who experience premature death, hospitalizations, chronic bronchitis, asthma symptoms and more minor health impacts that are attributable to year-long exposure to air pollutants from traffic (vehicles). Mean values are presented given that they are the most reasonable estimate of health impact and most likely to reflect the true burden of illness without over- or underestimation. Confidence intervals are also presented to illustrate the upper and lower bounds of each estimate. These confidence intervals reflect the amount of uncertainty on the concentration response functions as reported in the literature, with wide confidence intervals representing greater uncertainty than narrow ones.

Table 5. Traffic-Related Morbidity and Mortality Estimates (Toronto 2004)

Health Outcome	Mean (number of occurrences per year)	95% Confidence Interval (CI)
Acute exposure mortality	257	161 - 352
Chronic exposure mortality	183	104 - 262
Elderly cardiac hospital admissions	1,595	149 - 3,032
Cardiac hospital admissions	14	7 - 20
Respiratory hospital admissions	60	20 – 100
Cardiac emergency room visits	5	0 - 15
Respiratory emergency room visits	244	60 - 449
Adult chronic bronchitis cases	190	0 - 377
Child acute bronchitis episodes	1,234	0 - 2,651
Asthma symptom days	67,912	24,918 – 110,374
Acute respiratory symptom days	66,830	60,782 – 1,355,571
Minor restricted activity days	99,182	0 - 423,332
Restricted activity days	211,674	124,654 – 298,447

Researchers have long recognized that air pollution results in a ‘pyramid’ of health effects, with the least common but most serious health outcomes (such as premature death) appearing at the peak of the pyramid, and the less serious but more numerous health outcomes (such as chronic bronchitis and asthma symptom days) appearing in progressive levels below that peak).

Figure 7 illustrates the pyramid of health effects from traffic-related air pollution, as determined through this study. This pyramid is used to illustrate some of the data shown in Table 5, according to severity of illness. It shows that traffic pollution gives rise to about 440 premature deaths per year. These deaths would not have occurred when they did without exposure to traffic-related air pollution.

Also of concern is that traffic pollution gives rise to about 1,700 respiratory and cardiovascular hospitalizations. The current study suggests that the majority of these hospitalizations (96%) occur in the elderly.

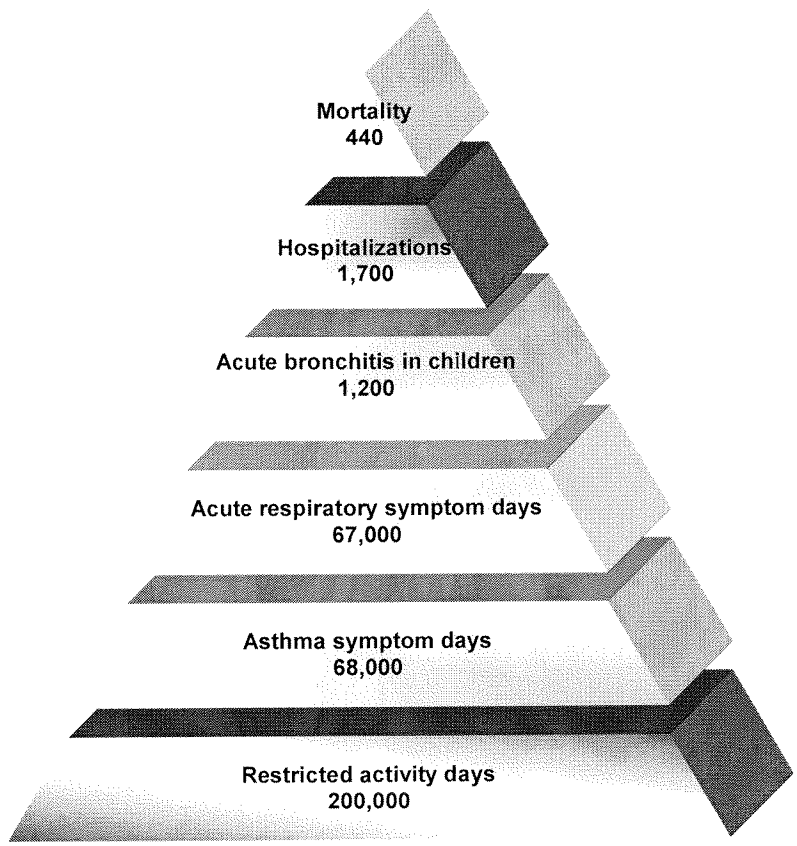
Children are also adversely impacted by traffic-related air pollution, including nearly 1300 episodes of acute bronchitis. Children are also likely to experience the majority of asthma symptom days (about 68,000), given that asthma prevalence and asthma hospitalization rates are about twice as high in children as adults (Toronto Public Health, 2004).

In addition to asthma symptom days, traffic pollution gives rise to about 67,000 acute respiratory symptom days. As shown in Table 4, these are the total number of days when respiratory symptoms or related conditions are reported. Symptoms include chest discomfort, coughing, wheezing, sore throat, headache and eye irritation.

Traffic pollution affects a very large number of people in Toronto. Children and seniors are particularly at risk

The current study shows that traffic-related pollution affects a very large number of people. Impacts such as the 200,000 restricted activity days per year due to days spent in bed or days when people cut back on usual activities are disruptive, affect quality of life and pose preventable health risk.

Figure 7. Pyramid of Health Effects from Traffic-Related Air Pollution[a]: Annual Illness outcomes for Toronto in 2004



(a) Numbers are rounded

Economic Costs Associated with Traffic Pollution

Assessments of the health benefits of interventions to improve air quality are intended to provide information to policy makers which permits them to directly weigh the cost of implementing a program with the benefits to society resulting from the program. While this is not the only consideration in policy decision making, it ensures that decisions are not determined strictly by costs without due consideration to benefits. While benefits described here are estimated for a single year, it must also be borne in mind that current capital investments in some programs will result in a stream of benefits continuing into future years.

There is considerable variation among researchers regarding the methods used to estimate the economic costs associated with air pollution. While economic impact assessments differ among air-related studies, the studies are consistent in showing that financial costs associated with air pollution are substantial. For example, the health-related economic impacts of transport emissions (not including paved road dust) in Canada for the year 2000 were recently estimated at $3.7 billion (in 2000 dollars), of which of $1.6 billion was estimated to occur in Ontario (Transport Canada, 2007).

Based on the application of the AQBAT model, this study estimates that the mortality-related economic impact of traffic pollution in Toronto is about $2 billion (in 2004 dollars) annually (Table 6).

The mortality-related economic impact of traffic pollution in Toronto is about 2 billion dollars

Table 6. Annual Economic Costs Associated with Traffic-Related Air Pollution (a)

Health Outcome	Economic Cost (billion dollars)	95% Confidence Interval (CI) (billion dollars)
Mortality	2.2	1.1 – 4.1

(a) Based on dollar value in 2004

Modelled Health and Economic Benefits from Emission Reductions

While most studies to date have focussed on the adverse impacts of air pollution, a growing number of studies are evaluating the health benefits of policy and regulatory measures that have reduced exposure to pollution (see previous section 'Health Benefits of Reducing Traffic Emissions' for a summary of research findings).

In this study, we have used AQBAT to project the number of premature deaths that could be avoided in Toronto as a result of reductions in traffic-related air pollution. Table 7 shows the results of this analysis, based on emission reduction scenarios of 10, 20 and 30%. Also shown are the cost savings related to deaths avoided. A 30% reduction in vehicle emissions is projected to save 189 lives and result in 900 million dollars of health benefits annually.

A 30% reduction in vehicle emissions is projected to save about 190 lives and result in 900 million dollars in health benefits each year in Toronto

Table 7. Annual Premature Deaths and Costs Avoided With Traffic Emission Reductions

Emission Scenario (% reduction in pollutant emissions)	Deaths Avoided (number)	Value of Health Benefits (Million $)
10	63	300
20	126	600
30	189	900

The emission reduction scenarios modelled in this study appear to be realistic and achievable. Table 8 summarizes policy options identified by the Victoria Transport Policy Institute. The table shows the capacity of each option to reduce vehicle use, based on observations from other cities. Some options (such as planning reforms and fuel tax shifting) affect everyone who travels by car, whereas other options (such as school trip management and car-sharing) affect only a portion of people who drive. The Institute estimates that if these various policies and programs are implemented in a comprehensive and integrated approach, when taken together they are expected to reduce total vehicle travel by 30 to 50%, when compared with current planning and pricing practices in place in most communities.

Table 8. Capacity of Policy Options to Reduce Vehicle Use

Policy Option	Description	Reduction in Vehicle Use (%)	
		Targeted [a]	Total [b]
Transportation Planning	Adoption of options that consider all direct and indirect costs and benefits	10 – 20	10 - 20
Mobility Management Programs	Local Transportation Demand Management (TDM) programs that support and encourage use of alternative modes	10 – 20	4 – 8
Commute Trip Reduction	Programs by employers to promote alternative commuting options	5 – 15	1 – 3
Commuter Financial Incentives	Offers commuters financial incentives for using alternative modes.	10 – 30	1 – 6
Fuel Taxes – Tax Shifting	Increases fuel taxes and other vehicle taxes	5 – 15	5 - 15
Pay-as-You Drive Pricing	Converts fixed vehicle charges into distance-based fees.	10 – 15	7 -13
Road Pricing	Charges users directly for road use, with rates that reflect true costs.	10 – 20	1 – 3
Parking Management	More efficient use of parking facilities.	5 – 10	2 – 8
Parking Pricing	Direct charges for using for parking facilities, with rates that may vary by location	10 – 20	3 - 10
Transit and Rideshare Improvements	Enhances public transit and car-sharing services.	10 – 20	2 - 12
HOV Priority	Improves transit and rideshare speed and convenience based on high-occupancy vehicle lanes.	10 – 20	1 – 2
Walking and Cycling Improvements	Improves walking and cycling conditions.	10 - 20	1 – 4
Smart Growth Policies	More accessible, multi-modal land use development patterns.	10 – 30	3 - 15
Location Efficient Housing & Mortgages	Encourages businesses and households to choose more accessible locations.	10 - 30	1 – 6
Mobility Management Marketing	Improved information and encouragement for transport options.	5 - 10	2 – 5
Freight Transport Management	Encourages businesses to use more efficient transportation options.	5 - 15	0.3 – 2
School & Campus Trip Management	Encourage parents and students to use alternative modes for school commutes.	5 - 15	0.3 – 1.5
Regulatory Reforms	Reduces barriers to transportation and land use innovations.	5 – 10	0.1 - 1
Car sharing	Vehicle rental services that substitute for private car ownership.	20 - 30	0.2 – 0.6
Traffic Calming & Traffic Management	Roadway designs that reduce vehicle traffic volumes and speeds.	3 - 6	0.1 – 0.4

(a) 'Targeted Reduction' refers to typical reductions in area affected by the specific policy.
(b) 'Total Reduction' refers to reduction as a % of total vehicle travel in the community.

Source: Todd Litman. *Win-Win Transportation Solutions.* Victoria Transport Policy Institute. September 2007.

Sustainable Transportation Approach

A sustainable transportation system incorporates environmental, social and economic best practices. Sustainable transportation:

- allows the movement needs of individuals and societies to be met safely and in a manner consistent with human and ecosystem health, and with equity within and between generations;
- is affordable, operates efficiently, offers choice of transport mode, and supports a vibrant economy; and
- limits emissions and waste, minimizes consumption of non-renewable resources, re-uses and recycles its components, and minimizes the use of land and the production of noise (Centre for Sustainable Transportation, 2005).

Efforts to implement a sustainable transportation system typically focus on improvements to transit services, urban form, and efforts to modify human behaviour towards becoming more physically active and driving less.

Implementation of a sustainable transportation system typically focuses on enhancements to transit services, urban form, and behaviour shifts towards becoming more physically active and driving less

Sustainable Transportation Hierarchy

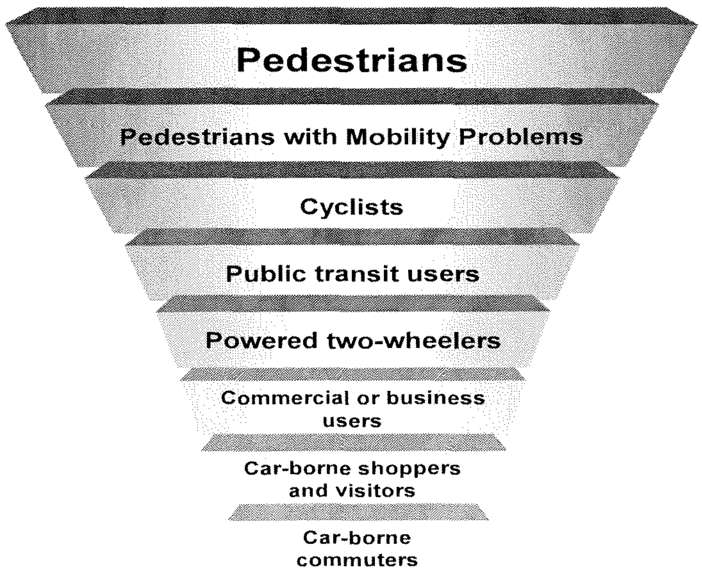
Modes of transportation that are alternatives to motor vehicles provide benefits to both individuals and the community. 'Active transportation' refers to modes of travel that rely on using one's own energy to get from one place to another. Examples include walking, cycling, roller-blading and self-propelled scooters. Active transportation is a core component of a sustainable transportation system. Among its many benefits are:

- Reduced greenhouse gas emissions, smog pollutants, and air toxics;
- Reduced congestion on roads, and
- Increased physical activity, good health and well-being.

The City of York in England has developed an integrated transportation network that focuses on active transportation alternatives to vehicles in order to meet local air quality objectives. Walking, addressing needs of individuals with mobility problems, cycling, and public transit are emphasized. York was one of the first local authorities to adopt a hierarchy of transportation users when making decisions related to land use and transportation (World Health Organization, 2006).

Figure 8 illustrates the hierarchy of transportation users implemented by the City of York. In this hierarchy, cities are designed around people, not cars. A sustainable transportation network focuses on active transportation modes first, followed by modes that are vehicle dependent. It is also important to note the emphasis placed on the needs of individuals with mobility problems. These individuals require special attention to enable them to enjoy active modes of transport. Toronto is considering adopting this transportation hierarchy as part of its Walking Strategy, which is currently being developed. In order to be most effective, this priority setting approach needs to be applied to all land use and transport decisions.

Figure 8. Hierarchy of Transportation Users (In Descending Order of Priority)



Source: World Health Organization. 2006. *Promoting Physical Activity and Active Living in Urban Environments.*

Addressing transportation needs by fostering excellent public transit, walking and cycling infrastructure helps to stimulate an effective mobility network. Enabling individuals to connect seamlessly within these nodes increases the convenience of transportation options, encourages daily physical activity, and reduces adverse impacts on air quality and associated health impacts.

Furthermore, active transportation contributes to sustainability from an economic perspective. Active transportation is relatively inexpensive to the user and to the community in terms of dollars required to sustain infrastructure. The International Association of Public Transport (IAPT) has demonstrated that higher density cities spend the least on providing mobility infrastructure for their residents when trips are being made using predominantly public transport, walking and cycling. The proportion of community income used on transportation rises from less than 6% in densely populated cities where most trips are made by walking, cycling and public transit, to 12% in cities where the car is relied upon almost exclusively for transportation (IAPT, 2005).

Health Benefits of Active Transportation

Active transportation is relatively inexpensive to the user and the community in terms of infrastructure costs

The World Health Organization is among many international and national agencies that highlighted the importance of moderate activity for health, encouraging at least 30 minutes of physical activity daily. The 30 minutes can be built up over a day, with even two to three episodes of 10 to 15 minutes each to provide important health benefits (WHO, 2002a). A study from the Centers for Disease Control and Prevention in Atlanta indicates that each additional kilometre walked per day is associated with a 4.8% reduction in obesity (Frank et al. 2000). These examples illustrate the health benefits that may be realized just by incorporating walking or cycling into daily routines, such as getting to public transit, walking from the transit stop to work, or walking or cycling to the store. These short, but important additions of physical activity are lacking when individuals rely exclusively upon a vehicle for mobility.

Toronto's rate of physical activity is well below what is needed for good health.

Toronto's rate of physical activity is well below what is needed for good health (Toronto Public Health, 2003). Recent studies have indicated that the Canadian population and children in particular are not as physically active as recommended by health professionals (Ontario Ministry of Health and Long-term Care, 2004). Over 2.6% of all health care costs in Canada are spent dealing with the ill health effects of physical inactivity (Katzmarzyk & Janssen, 2004).

Studies provide evidence of the importance of regular physical activity for children (WHO, 2006). Regular physical activity is necessary for the healthy growth and development of children and youth. Physical activity also provides social, behavioural and mental benefits to young people (TPH, 2003). Including the perspectives of young people and their care givers in mobility- related decision-making is important to the overall success of any sustainable transportation endeavour (WHO, 2006).

Evidence also shows that even modest increases in physical activity among older people can make a major difference in their well-being and in their ability to remain independent and actively contribute to civic life. Enabling and encouraging increased physical activity among this population may be one of the most effective means of preventing and lowering the high costs associated with health and social services (WHO, 2006).

Individuals with disabilities are generally less physically active than those without a disability. Yet, physical activity is critical for people with disabilities to prevent disease as well as to reduce the number of secondary conditions that can result from an initial disability (WHO, 2006). Sidewalks and curb ramps at intersections and rough surfaces on trails and paths make maintaining balance and mobility extremely difficult for those with disabilities and the elderly. Knowing that these issues are addressed may encourage vulnerable individuals to become more physically active.

A report by the Ontario College of Family Physicians (OCFP) notes that car-dependent neighbourhoods contribute significantly to air pollution and traffic fatalities (Bray et al. 2005). Further, the OCFP concluded that people who live in spread-out, car-dependant neighbourhoods walk less, weigh more and suffer from obesity and high blood pressure and consequent diabetes, cardiovascular and other diseases, as compared to people who live in higher density, "walkable" communities. The low-walkability of sprawling neighbourhoods and the resulting increase in car use contributes to the growing obesity epidemic, especially in children (Bray et al. 2005).

People who live in spread-out, car-dependent neighbourhoods walk less, weigh more, and suffer from more high blood pressure, diabetes and heart problems than people who live in high density, walkable communities

Increased cycling and walking are good forms of moderate-intensity physical activity to improve public health. Incorporating just thirty minutes per day of moderate activity such as swift walking or cycling helps to maintain or improve muscular strength, flexibility and healthy bones, and contributes towards healthy weights. Other benefits of being physically active include improving concentration and boosting self-confidence (Toronto Public Health, 2003). When active transport is easily integrated into regular routines such as getting to and from work and school, social activities, running errands, it becomes part of a healthy lifestyle. (Agence de la sante et des services sociaux de Montreal, 2006).

Increased levels of participation in physical activity can contribute to social cohesion, neighbourhood vitalization and a greater sense of community identity (Social Exclusion Unit, 2006). Green spaces, skateboarding parks, trails, and sports facilities provide a social focus and enhance people's perception of their neighbourhood (WHO, 2006). Providing equitable and safe opportunities for active living may also encourage the expansion of social networks, which is especially important for members of minority ethnic, racial and religious groups and for older residents (WHO, 2006).

Investments that support active transportation result in important social benefits, including better social cohesion, neighbourhood vitalization, and sense of community

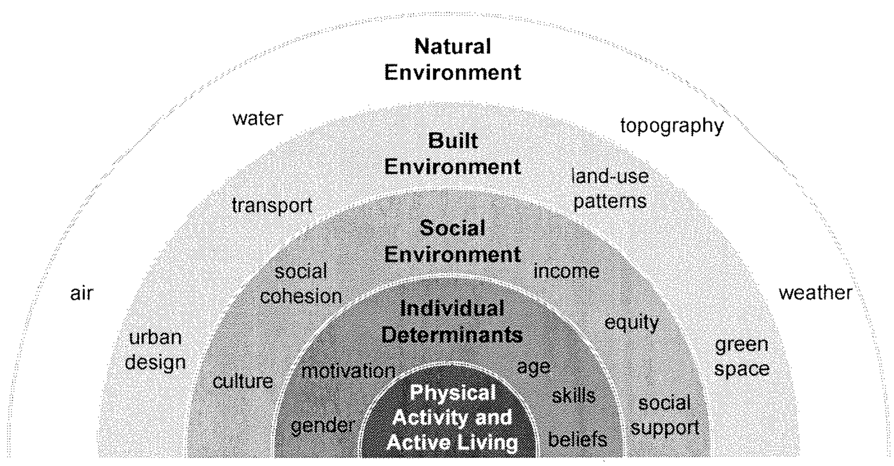
Some research findings suggest that where safe opportunities exist to walk and cycle, low-income Canadians are more likely to make use of cycling and walking infrastructure (Agence de la sante et des services sociaux de Montreal, 2006). Therefore, investments that support active transportation result in important social benefits.

Factors that Enable Active Transportation

Researchers are beginning to quantify neighbourhood elements that encourage or discourage active transportation (Butler et al., 2007). Figure 9 illustrates the many factors that influence an individual's activity level. Design elements in the built environment, such as street layout, land use, public transit, and the location of recreational facilities, green space and public buildings, are all components of a community that can either encourage or discourage active living. It is important to understand how urban planning decisions impact on citizens' decisions to walk or cycle as a form of transportation and to make planning decisions accordingly (Agence de la sante et des services sociaux de Montreal, 2006).

Density, variety, and type of destinations available in a neighbourhood affect a resident's choice in leisure walking and travelling to work and to do errands. For example, the availability of preferred destinations for walking and cycling, such as errands and leisure activities, friends and family, schools, and workplaces, is critical to one's decision to engage in active transportation (Agence de la sante et des services sociaux de Montreal, 2006). Overall, an integrated approach to transportation planning is essential in order to reduce the burden of illness associated with vehicle traffic. Increasing and promoting public and active transportation that enables people to get to important destinations such as work and school is an important way of achieving this.

Figure 9. Factors Influencing Physical Activity in Communities



Source: World Health Organization. 2006. *Promoting physical activity and active living in urban environments.*

As urban density increases, walking, cycling, and use of transit increases while car travel declines

Residents of more densely populated zones tend to engage more extensively in walking than residents of less densely populated areas because density affects the distances between destinations and the proportion of destinations that are within convenient walking or cycling distance (Agence de la sante et des services sociaux de Montreal, 2006).

Access to public transit also promotes physical activity, since many trips involve walking or cycling links. As density increases, the number of hours and kilometres of car travel tend to decline while walking, cycling and use of public transit increase. The degree to which the street network provides direct and safe routes for pedestrians and cyclists also influences citizens' decisions to engage in active transportation (WHO, 2006).

Several individual determinants influence participation in physical activity including gender, age, skill level, ability and disability, beliefs, attitudes and motivation (WHO, 2006). A key barrier to engaging in physical activity involves concerns about safety and security. For example, residents will not use a cycle lane or path if they believe it is dangerous (WHO, 2006).

Shared road use by motor vehicles, pedestrians and cyclists increases the risk of a traffic injury among walkers and cyclists (WHO, 2006). This is especially true for older adults. Research suggests that people often identify safety concerns as a barrier to engaging in walking or cycling. A survey shows that 82% of Canadians have expressed an interest in walking more regularly, and 66% of Canadians have indicated a desire to cycle more, however, safety concerns prevent them from becoming more active (Agence de la sante et des services sociaux de Montreal, 2006).

Safety concerns are a significant barrier to engaging in walking or cycling

Traffic injuries and fatalities from vehicles travelling at high speeds, heavy traffic flow and a lack of separate lanes and paths are key reasons why citizens do not walk or cycle in cities. Seniors and children are particularly affected by these safety factors. Short traffic signals and wide streets with inadequate lane marking on roadways have also been shown to compromise the safety of older pedestrians. High vehicle speed, the number of kilometres of major arterial streets in a neighbourhood, poorly located bus stops and crosswalks, inadequately maintained sidewalks and poor lighting are also associated with greater risks to the safety of pedestrians of all ages (WHO, 2002a). Sidewalks and protected areas for walking and cycling can help reduce collisions between vehicles and pedestrians and cyclists (WHO, 2002a). Also at issue is enabling safer year-round cycling through snow removal on bike routes and lanes.

Efforts that increase physical safety are important to increase people's uptake of active transportation. For cyclists in Toronto, this means completing the 1,000 km bikeway network of bicycle lanes, routes and trails recommended by the Toronto Bike Plan, as quickly as possible. Other important cycling improvements include more and higher security bicycle parking at work places and other destinations and better integration with public transit for longer trips. For pedestrians, this means implementing measures that encourage Toronto residents to make more walking trips, including wider and more continuous sidewalks and walkways, enhancements to pedestrian crossings and traffic signal timing, narrowing pavements where feasible, and promoting a culture of walking.

A key barrier to engaging in physical activity involves concerns about safety and security. People will not cycle if they believe it is dangerous. Shared road use by vehicles, pedestrians and cyclists increases the risk of a traffic injury among walkers and cyclists. This is especially true for children and seniors. Also of concern is the speed of vehicle traffic along bicycle routes. A survey shows that 66% of Canadians have a desire to cycle (or cycle more) but that safety concerns prevent them from being more active.

Given the finite amount of space for all traffic modes, more roadway space needs to be allocated towards expanded infrastructure for walking, cycling, and public transit, and less to vehicle use.

Many current cyclists, and people who would like to cycle, are also concerned about breathing vehicle emissions on roads with heavy traffic. The closer one is to the tailpipe of vehicles, the greater the exposure to pollutants, and the greater the health risk.

Given there is a finite amount of public space in the city for all modes of transportation, there is a need to reassess how road space can be used more effectively to enable the shift to more sustainable transportation modes. More road space needs to be allocated towards development of expanded infrastructure for walking, cycling and on-road public transit (such as dedicated bus and streetcar lanes) so as to accelerate the modal shift from motor vehicles to sustainable transportation modes that give more priority to pedestrians, cyclists and transit users.

Expanding and improving the infrastructure for sustainable transportation modes will enable more people to make the switch from vehicle dependency to other travel modes. This will also benefit motorists as it would reduce traffic congestion, commuting times and stress for those for whom driving is a necessity. Creating expanded infrastructure for sustainable transportation modes through reductions in road capacity for single occupancy vehicle use will require a new way of thinking about travelling within Toronto and beyond. To be successful, it will require increased public awareness and acceptance of sharing the road in more healthy and sustainable ways, as well implementation of progressive policies and programs by City Council.

Health Promotion Initiatives Underway

Municipalities make decisions concerning planning, transportation, health, housing, recreation and economic development that affect opportunities for active living. Neighbourhood design, the location of schools and businesses and the priority assigned to cars, cyclists and pedestrians all affect citizen's ability to engage in physical activity and active living. Local strategies and plans should aim towards promoting physical activity among people of all ages, in all social circumstances and living in all parts of cities, with special attention afforded to equity and vulnerable populations (WHO, 2006).

In 2002, Toronto City Council approved the Toronto Pedestrian Charter, a set of six principles that recognizes the importance of pedestrian movement in the city. The Charter reflects the principle that a city's walkability is one of the most important measures of the quality of its public realm, and of its health and vitality. This is the first pedestrian charter in North America, and the first approved by a municipality anywhere.

In approving the development of the Charter in 2000, The City intended:

- to outline what pedestrians have a right to expect from the City in terms of meeting their travel needs;
- to establish principles to guide the development of all policies and practices that affect pedestrians; and
- to identify the features of an urban environment and infrastructure that will encourage and support walking.

Transportation Services is preparing the Toronto Walking Strategy, in partnership with several City divisions and agencies. The Walking Strategy will build on the existing policies of the Official Plan to set out the policies, programs and projects required to promote a culture of walking in Toronto. The main theme of the strategy is "putting pedestrians first" in future city building. The Walking Strategy will call for a change in mindset from a transportation system designed principally for automobiles to one that places pedestrians at the top of the transportation hierarchy.

Putting pedestrians first is a critical component of efforts to create a sustainable transportation infrastructure in Toronto. As discussed in *Sustainable Transportation*

Initiatives: Short Term Proposals, a report prepared by Transportation Services and City Planning (September 2007), the City is considering numerous options for encouraging safe walking in the City. For example, placing a greater focus on planning pedestrian zones and streets, enhancements at intersections to make it easier for pedestrians to cross, and trail corridors that are separated from traffic are important considerations for fostering sustainable transportation.

The City of Toronto has also identified priority initiatives to encourage more individuals to cycle. These include enhancing bike storage and parking, assessing the development of bike share programs, establishing dedicated bicycle paths and trail corridors throughout the City, with particular attention to the downtown core.

The City of Toronto is engaged in other projects as well that promote active transportation, such as:

a) ***Get Your Move On***: a program that works with individuals, community groups, agencies, institutions, businesses and all levels of government to achieve increased physical activity among all residents. Partners in the program promote healthy active living for all Toronto residents and develop and promote a civic culture where active living is part of everyday life;

b*)* ***Toronto Bike Plan***: the vision for cycling in Toronto. To shift towards a more bicycle friendly city, the Plan sets out integrated principles, objectives and recommendations regarding safety, education and promotional programs as well as cycling related infrastructure, including a comprehensive bikeway network.

c) ***Walking School Bus***: The City of Toronto is a participant through the Active and Safe Routes to School program. A Walking (or Cycling) School Bus is two or more families, traveling to school together for safety.

d) ***20/20 The Way to Clean Air***: This program provides individuals with a Planner to help reach a 20 per cent energy reduction goal. This practical guide identifies some easy-to-do activities as well as longer-term, greater cost savings actions. It also connects individuals with programs and services in the Greater Toronto Area that will help reduce energy use at home and on the road. Reducing vehicle use is one of the primary goals of 20/20 and active transportation is emphasized as an alternative to driving.

e) ***Air Quality Health Index*** (AQHI): a new national health-based index to help individuals protect their health. The AQHI helps individuals find out the health risk from air pollution on an hourly basis. The AQHI forecast allows people to plan and enjoy outdoor activities for times when health risks are low, and to reduce their exposure to pollutants when the health risks are moderate or high. An important way to minimize exposure is to reduce the intensity of strenuous physical activity outdoors during peak pollution periods.

Toronto's Commitment to Improving Air Quality

In July 2007, Toronto City Council adopted the *Climate Change, Clean Air and Sustainable Energy Action Plan.* This comprehensive and ambitious plan targets the following air quality improvements:

- Reduction in greenhouse (GHG) emissions from 1990 levels of 6% by 2012, 30% by 2020 and 80% by 2080; and

- Reduction in locally-generated smog-causing pollutants from 2004 levels of 20% by 2012.

The plan consists of a broad range of actions involving community, business and government participants. Components include: engaging neighbourhoods; greening the economy (institutions, commercial and industrial sectors); fostering creation and use of renewable energy; making more sustainable transportation choices; greening City operations; increasing the tree canopy; preparing for climate change; enhancing public awareness; and monitoring and evaluating progress.

A key component of the plan is to develop and implement a more sustainable transportation system. Advancing sustainable transportation in Toronto consists of many planned initiatives, some of which are highlighted here:

- Implement environmental, engineering and financial planning studies to support the Transit City Plan;
- Expand the network of bike lanes and trails from 300 to 1,000 km by end of 2012;
- Prepare a Sustainable Transportation Implementation Strategy, drawing from and integrating existing policies and plans (e.g. Official Plan, Bike Plan, Transit City Plan, TTC Ridership Growth Strategy, Walking Strategy);
- Create an initiative to 'green' commercial fleets in the city;
- Develop a program to shift taxis and limousines to low emission or hybrid technologies by 2015 or earlier;
- Encourage provincial and federal governments to provide policy, program and funding support to Toronto to achieve a sustainable transportation system. Aspects of key concern include:
  - (i) improved vehicle engine and fuel standards
  - (ii) financial incentives for using public transit;
  - (iii) stable funding for transit operation and expansion;
  - (iv) management of urban growth to reduce car dependency;
- Work with province, GTA Transportation Authority and GTA municipalities to investigate a road pricing regime that reduces vehicle use and helps finance transit improvements.

In October 2007, City Council endorsed the staff report *Sustainable Transportation Initiatives: Short Term Proposals.* The report identified a number of helpful initiatives, including those affecting pedestrians and cyclists, that could be implemented fairly quickly and in most cases at relatively little expense.

Toronto Public Health's current study demonstrates the significant burden of illness and health-related costs associated with current levels of smog-generating pollutants, greenhouse gases and air toxics that are emitted by vehicles in Toronto. The study also highlights the health and economic benefits of preventing traffic-related air pollution. As such, this study provides an important rationale for investing in Council's plan to combat smog and climate change, and for renewing the vigour with which sustainable transportation is pursued.

Conclusion

Burden of illness studies provide a reliable and cost-effective mechanism by which local health authorities can estimate the magnitude of adverse health impacts from air pollution. In 2004, Toronto Public Health (TPH) estimated that air pollution (from all sources) is responsible for about 1,700 premature deaths and 6,000 hospitalizations each year in Toronto.

Since that time, Health Canada has developed a new computer-based tool, called the *Air Quality Benefits Tool (AQBAT)* which can be used to calculate estimates of burden of illness and economic impacts. TPH used this tool in the current study to determine the burden of illness from traffic-related air pollution. TPH collaborated with air modelling specialists at the Toronto Environment Office to determine the specific contribution of traffic-related pollutants to overall pollution levels. Data on traffic counts and flow, vehicle classification and vehicle emission factors were analysed by Toronto Environment Office and Transportation Services for input into a sophisticated air quality model. The air model takes into account the dispersion, transport and transformation of compounds emitted from motor vehicles. Other major sources of air pollution in Toronto are space heating, commercial and industrial sources, power generation and transboundary pollution.

The current study determined that traffic gives rise to about 440 premature deaths and 1,700 hospitalizations per year in Toronto. While the majority of hospitalizations involve the elderly, traffic-related pollution also has significant adverse effects on children. Whereas adults experience 190 cases of chronic bronchitis, children experience more than 1,200 acute bronchitis episodes per year. Children are also likely to experience the majority of asthma symptom days (about 68,000), given that asthma prevalence and asthma hospitalization rates are about twice as high in children as adults.

This study shows that traffic-related pollution affects a very large number of people. Even minor impacts, such as the more than 200,000 restricted activity days, are disruptive, affect quality of life and present preventable health risk to Toronto residents.

This study estimates that mortality-related costs associated with traffic pollution in Toronto are greater than $2 billion per year. A 30% reduction in vehicle emissions is projected to save 189 lives and results in 900 million dollars in health benefits annually.

Given there is a finite amount of public space in the city for all modes of transportation, there is a need to reassess how road space can be used more effectively to enable the shift to more sustainable transportation modes. There is a need to allocate more road space towards development of expanded infrastructure for walking, cycling and on-road public transit (such as dedicated bus and streetcar lanes) so as to accelerate the modal shift from motor vehicles to sustainable transportation modes that give more priority to pedestrians, cyclists and transit users.

Expanding and improving the infrastructure for sustainable transportation modes will enable more people to make the switch from vehicle dependency to other travel modes. This will also benefit motorists as it would reduce traffic congestion, commuting times and stress for those for whom driving is a necessity. Creating expanded infrastructure for sustainable transportation modes through reductions in road capacity for single occupancy vehicle use will require a new way of thinking about travelling within Toronto and beyond. To be successful, it will require increased public awareness and acceptance of sharing the road in more egalitarian ways, as well implementation of progressive policies and programs by City Council.

Enabling greater development and use of public transit and active modes of transportation such as walking and cycling is of significant benefit to the public's health and safety. This study provides a compelling rationale for investing in City Council's plan to combat smog and climate change, and for vigorously pursuing implementation of a comprehensive sustainable transportation strategy in Toronto.

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Appendix 1. Concentration Response Functions Currently Available in AQBAT

Health Endpoint	Pollutant					
	CO	NO_2	O_3	O_3 (May-Sept)	$PM_{2.5}$ (dichot)	SO_2
Acute exposure mortality	✓ (24 hr.)	✓ (24 hr.)	✓ (1 hr. max.)			✓ (24 hr.)
Acute respiratory symptom days				✓ (1 hr. max.)	✓ (24 hr.)	
Asthma symptom days				✓ (1 hr. max.)	✓ (24 hr.)	
Cardiac emergency room visits					✓ (24 hr.)	
Cardiac hospital admissions					✓ (24 hr.)	
Child acute bronchitis episodes					✓ (24 hr.)	
Chronic exposure mortality					✓ (24 hr.)	
Elderly cardiac hospital admissions	✓ (1 hr. max.)					
Minor restricted activity days				✓ (1 hr. max.)		
Respiratory emergency room visits				✓ (1 hr. max.)	✓ (24 hr.)	
Respiratory hospital admissions				✓ (1 hr. max.)	✓ (24 hr.)	
Restricted activity days					✓ (24 hr.)	

Source: Judek S, Stieb D, Jovic B. Air Quality Benefits Assessment Tool (AQBAT) release 1.0. Ottawa: Health Canada, 2006.

APPENDIX B

Lifecycle analysis of gas, hybrid and electric cars, Sam Abuelsamid, December 2006

See attached.

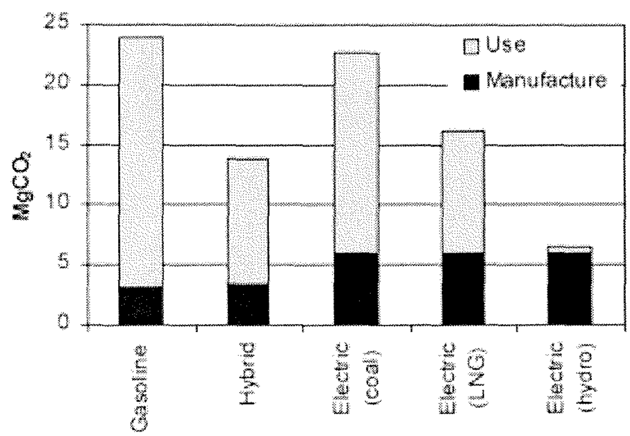
Lifecycle analysis of gas, hybrid and electric cars

By Sam Abuelsamid RSS feed

Posted Dec 24th 2006 6:48PM

0 1
Comments6

Treehugger has a post about a life cycle analysis of carbon emissions for various drive-train types that includes manufacturing and use of the vehicles. The study was originally done by researchers from Seikei University in Tokyo, Japan in 2001. They did a detailed analysis of the energy consumption to manufacture the different types of vehicles, based on the CO2 emissions for each.



Institute for Lifecycle Environmental Assessment

The battery-powered cars are much more energy intensive to build than gas or hybrid cars, based mostly on the cost of producing the batteries themselves. For the use phase of the analysis, they also did three different examples for the electric car, based on the energy source for the electricity. When using electricity from coal, the total CO2 emissions for the electric car was almost as much as the gasoline car and almost twice as much as the hybrid. Electricity from natural gas was much better but still not as as good as the hybrid and the cleanest by far was the EV with hydro-electric power.

However, one thing that seems to be missing from this analysis is the post life phase. How much energy is used (and subsequent CO2 emissions) will also vary for these different types of vehicles. The iron and aluminum that comprise most of the content of an internal combustion engine are fairly easy to recycle by simply melting down and re-casting. Disposing of batteries is substantially more complicated.

[Source: Institute for Lifecycle Environmental Assessment via TreeHugger]

APPENDIX C

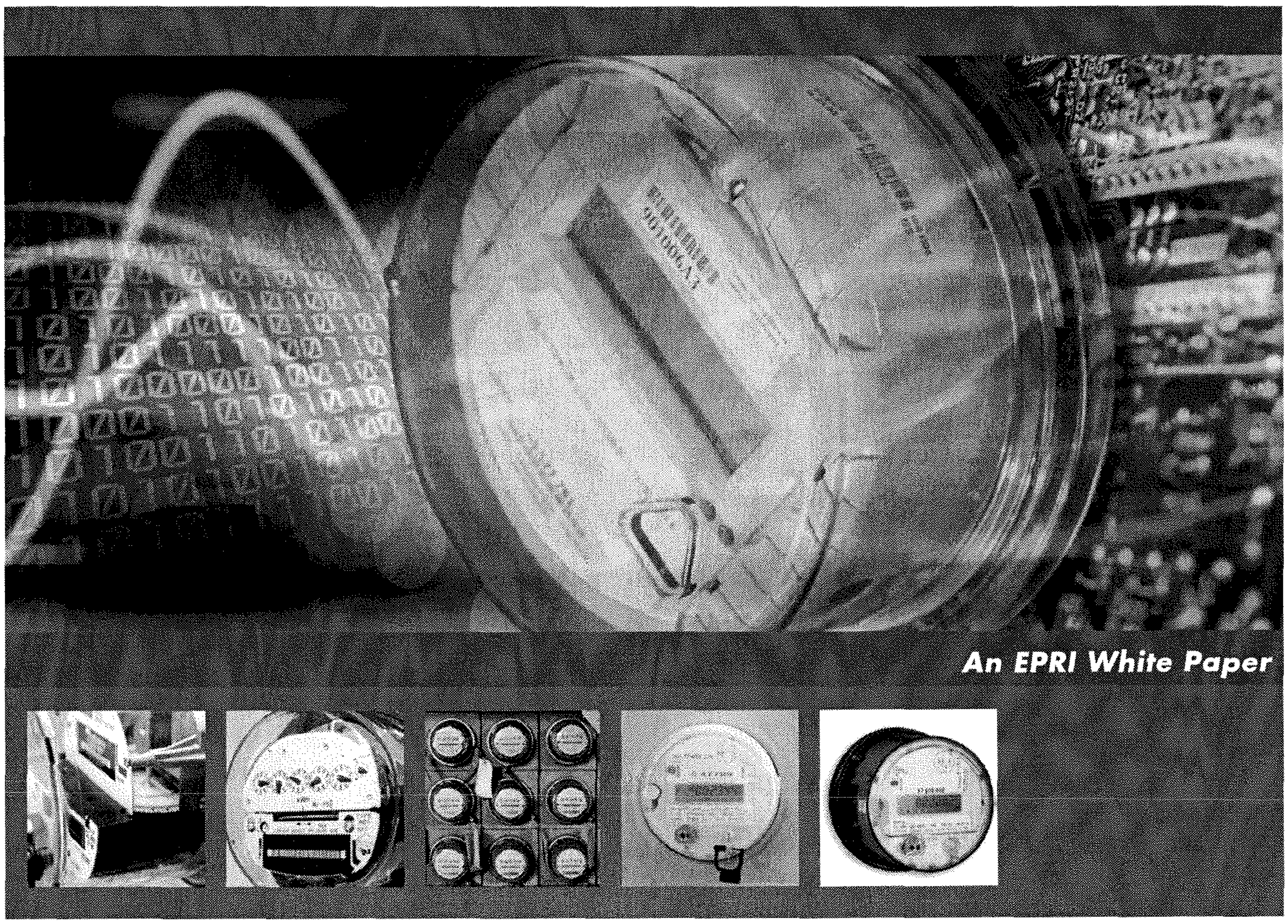
Electrical Power Research Institute, Accuracy of Digital Electricity Meters, May 2010

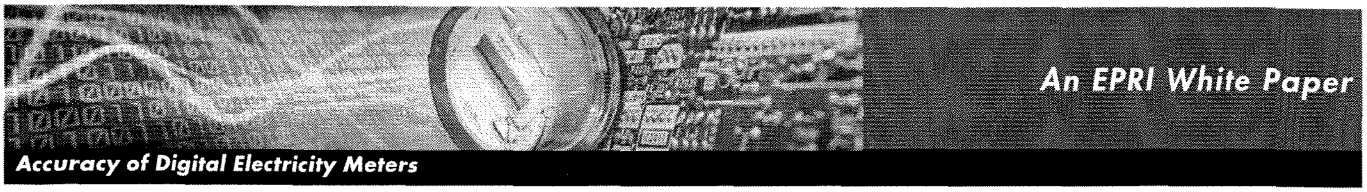
See attached.

ELECTRIC POWER
RESEARCH INSTITUTE

Accuracy of Digital Electricity Meters

May 2010





Background

The meter is a critical part of the electric utility infrastructure. It doesn't provide a control function for the power system, but it is one of the most important elements from a monitoring and accounting point of view. Meters keep track of the amount of electricity transferred at a specific location in the power system, most often at the point of service to a customer. Like the cash-register in a store, these customer meters are the place where the transaction occurs, where the consumer takes possession of the commodity, and where the basis for the bill is determined. Unlike a cash-register, however, the meter sits unguarded at the consumer's home and must be trusted, by both the utility and the home owner, to accurately and reliably measure and record the energy transaction.

Electricity is not like other commodities because it is consumed in real-time. There is nothing to compare or measure later, nothing to return, nothing tangible to show what was purchased. This makes the meter all the more critical for both the utility and the homeowner. For this reason, meters and the sockets into which they are installed are designed to standards and codes that discourage tampering and provide means of detecting when it is attempted. Intentional abuses aside, the electricity meter itself must be both accurate and dependable, maintaining its performance in spite of environmental and electrical stresses.

In general, electricity meters have been able to achieve these goals and in so doing to earn the trust of utilities and homeowners alike. The average person may have experienced a broken-down car, a worn-out appliance, or a piece of electrical equipment that died in a lightening storm, but most don't likely recall their electricity meter ever failing. Such is the reliable legacy of the electromechanical meter.

Historical Perspective – The Electromechanical Meter

By anyone's assessment, traditional electromechanical meters are an amazing piece of engineering work. Refined over a hundred years, the design of a standard residential electricity meter became an impressive combination of economy, accuracy, durability, and simplicity. For this reason, electricity meters have been late in converting to solid state electronics, compared to other common devices.

Three phase commercial and industrial meters, being inherently more complex, were first to make the transition to solid state, beginning in the 1980s, and becoming the norm in the 1990s. As recently as the year 2000, however, some still questioned if and when the simpler residential meter would be replaced by a solid state version, and whether they could attain the same balance of economy and durability.

Now just a decade later, it is clear that this conversion has taken place. Over the last decade, major electricity meter manufacturers have introduced solid state models and discontinued electromechanical production as indicated in Figure 1. This transition diminished the value of both the facilities and the art of traditional meter making and opened the doors of the meter business to new companies.

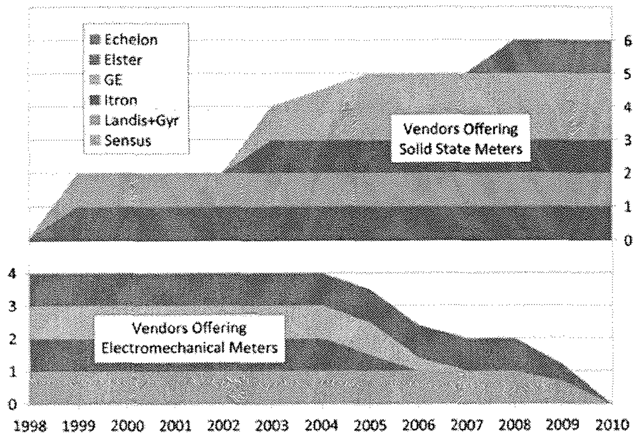


Figure 1 – Replacement of Electromechanical Meter Production with Solid State Versions

Table of Contents

This white paper was prepared by Brian Seal and Mark McGranaghan of Electric Power Research Institute.

Functionality, the Driving Factor for Change

The impetus that finally drove the transition to solid state metering was not cost reduction, nor improvements in service life or reliability, but the need for more advanced functionality. Electromechanical meters, with that familiar spinning disk, did a fine job of measuring total energy consumption, but became extremely complex if required to do anything more. Versions that captured peak demand and versions that measured consumption in multiple time-of-use (TOU) registers have existed, but were not economical for residential purposes.

Today, residential meters are expected to provide a range of measurements, with some including demand, TOU, or even continuous interval data. Some may also be required to keep a record of additional quantities like system voltage – helping utilities maintain quality of service in a world that includes fast-charging electric vehicles and solar generation. In many cases, these solid state meters also include communication electronics that allow the data they measure to be provided to the utility and to the home owner without requiring a meter reader to visit the site.

The Solid State Electricity Meter

Manufacturers who designed the first solid state residential meters understood the challenge they faced. The electromechanical devices they intended to replace held the trust of both utilities and the general public. Because dependable power delivery is critical for the economy, public safety and national security, utilities and regulators have been appropriately cautious in undertaking change. Manufacturers had to not only design a suitable replacement, but also to prove that the new meters could perform and be trusted.

From a utility perspective, several meter performance factors are of concern, including robustness, longevity, cost, and accuracy. But from the homeowner's perspective, the dominant concern is accuracy. If a meter breaks, the utility will fix it. If it becomes obsolete, it is the utility's problem to deal with. If however, a meter is inaccurate in the measurement of energy use, there is a potential that customers could be charged for more energy than they actually used. If the effect were only slight, then it could go undetected. For this reason, accuracy and dependability remain a common concern and a continued focus of dialogue regarding solid state meters.

Keeping in-step with the technology improvements associated with solid state metering, the American National Standards Institute (ANSI) developed new standards with more stringent accuracy requirements during the late 1990s. ANSI C12.20[1] established Accuracy Classes 0.2 and 0.5, with the Class numbers representing the maximum percent metering error at normal loads. Typical residential solid state electricity meters are of Class 0.5, whereas electromechanical meters were typically built to the less stringent ANSI C12.1 standards, as illustrated in Figure 2.[2] In addition, C12.20 compliant meters are required to continue to meter down to 0.1A (24 Watts), whereas C12.1 allowed metering to stop below 0.3A (72 Watts). While metering of such low loads is not likely significant on a residential bill, it is an accuracy improvement nonetheless.

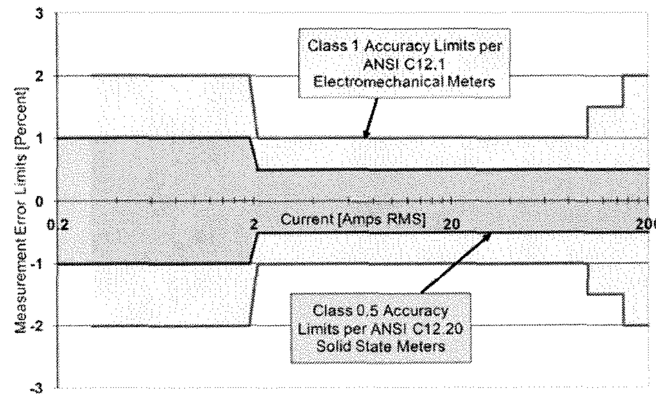


Figure 2 – Accuracy Class Comparison

Manufacturers and utilities use a range of tests and equipment to verify that meters adhere to the ANSI requirements. During the manufacturing process, it is common that each individual meter is calibrated and verified. Once a utility receives new meters, there is often another accuracy test, either on each meter or on a sample basis. States generally establish requirements for how utilities are to check accuracy when new meters are received and at intervals thereafter.

Regardless of their specified performance, solid state meters have been met with mistrust in some early deployments. The most significant of the complaints has been that the meters are simply inaccurate, resulting in higher bills. Given that these new meters are designed to the more stringent ANSI requirements, the factors that may lead to these observations and perceptions are important to understand.

1 American National Standards Institute, 1998, 2002, available from NEMA at http://www.nema.org/stds/c12-20.cfm

2 Data from Metering Standards ANSI C12.1-1988 and ANSI C12.20-2002

Factors in How Digital Meters May Be Perceived

Changes in Billing Periods

The duration of billing periods can vary from month to month, making it difficult to compare one month's bill to the next. If deployment of solid-state meters happens to correspond to a month with a billing period that is particularly long, then customers could incorrectly interpret the associated higher bill with the meter itself. An example of such a long billing period during new meter deployment occurred in January for many customers of Texas utility Oncor. Due to holidays, this billing period was as long as 35 days for some customers.

Complexity of Commissioning New Meters of Any Type

When meters are replaced, and automated reading is instituted, care must be taken to associate the new meter with the correct billing address. Automated tools and processes may be used to aid in this process and are important to guarantee that the right consumption is associated with each residence.

When a meter is replaced, the metering and billing process for that month is more complicated than usual. A closing read from the old meter has to be captured and the associated consumption added to that from the new meter to cover the full billing period. Although the meter replacement process is generally automated to minimize opportunity for human mistakes, the data-splicing process adds complexity and opportunity for error.

If such an error were unreasonably large, it would be recognized as such by both the homeowner and the utility. If, however, a small error occurred, it could be difficult to distinguish from real consumption. It is therefore hypothetically possible that a bill could be in error for the month when the meter replacement occurred, even if both the old and the new meter were accurate.

Connectivity and Estimation

Utility billing systems often have an estimating capability that can apply an algorithm to estimate a customer's bill until an actual read is collected. Historically, such estimation has been used when a manual meter read is missing and any errors in the estimation are corrected in the next bill.

When solid state meters are installed as part of an advanced metering infrastructure program, manual meter reading will halt as the automated process begins. New communication systems may not have good connectivity to every premise at first, so the number and frequency of estimated intervals may be elevated during the first few months after deployment. It is possible that such estimation could result in consumption from one month being billed in another, and hence more variation in bills.

Early Life Failures

Products of many kinds exhibit changes in failure rate over time. As illustrated in Figure 3, these changes often follow a familiar trend. More products tend to fail either very early or very late in the service life of individual devices, with the rate of failure stabilizing at a low level during most of the useful life of the product.

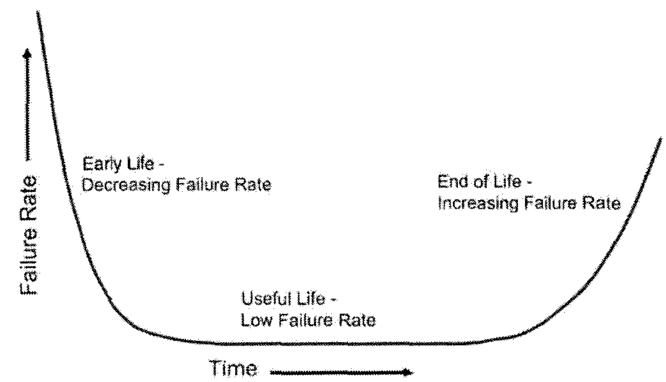


Figure 3 – The Failure Rate Bathtub Curve

Electricity meters are no exception. Both electromechanical and solid state meters have components and assemblies that can result in higher failure rates early in life, and wear-out after their useful life expires. A typical meter population is mature, is centered in the "useful-life" portion of the bathtub curve, and includes only a few new meters installed each year.

Today, the majority of solid state meters put into service are elements of advanced metering systems that are being mass deployed. These deployments can result in an entire meter population that is just a year or two old and therefore may experience sharply increased, but not unexpected, early-life-failure rates. If high registration were among the failure modes of a meter, then an exaggerated percentage of the population could experience higher bills during a new deployment.

Extraordinary Weather

Extraordinary weather can occur at any time. Both record cold winters and hot summers have occurred in North America in recent years and can result in electric bills that are higher than normal. If such events coincide with a deployment of solid-state meters, some may conclude that the new meter is the cause.

One example of how extraordinary weather can result in higher consumption of electricity relates to the use of electric heat pumps used to heat homes in moderate climate zones. These heat pumps, while normally much more efficient than resistive heating, are typically designed with a second stage of electric resistance heat which is triggered when the heat pump itself can no longer satisfy the indoor set point temperature. As outdoor temperature declines, this second stage is called for more frequently. As was the case in many parts of the U.S. this past winter, extreme cold causes abnormally high dependence on second-stage electric heat and in-turn, unusually high electric bills.

Growing Consumption

Average residential electricity consumption has risen for decades, with the addition of increasing numbers and types of electronic devices. Larger televisions, outdoor lighting, and new pools and spas are common additions that can result in notable increases in residential consumption. In other cases, faulty equipment can cause increases. Loss of refrigerant in an HVAC system or a duct that has fallen loose in an attic can cause devices to run excessively, unnoticed until exposed by an electric bill.

If these new purchases or equipment failures happen to coincide with a new electricity meter, one might assume that the resulting bill is the fault of the metering device.

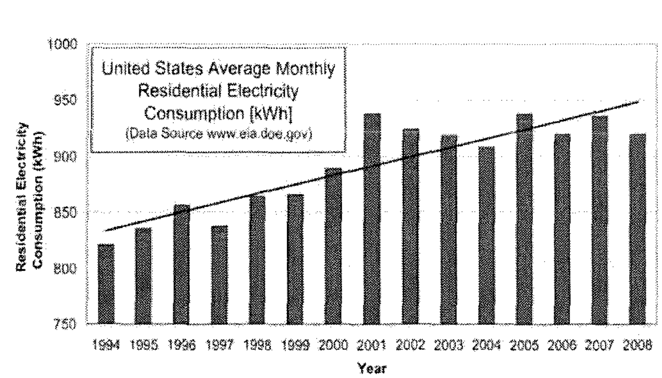


Figure 4 – Residential Electricity Consumption vs. Time

New Rate Structures

New meters may enable new rate structures such as time-of-use or critical peak pricing. These programs offer to make the grid more efficient by motivating consumers to use less energy during times of peak consumption and more when energy is readily available. The improvement in load factor allows for better utilization of assets and, in some cases, deferral of infrastructure upgrades.

While new rate structures may benefit customers on average, individual results depend on the degree to which the consumer heeds the high and low price periods. Customers who select time-based rate plans and do not modify their behavior accordingly could experience higher bills, even though lower bills were possible. Because the new rate plans may go into effect about the same time as a meter-replacement, homeowners could mistakenly associate increased bills with metering errors.

Replacing Defective Meters

Although electromechanical meters are extremely reliable, they do fail. The most common "failure" mode is reduced registration. Anything that increases the drag on the rotating disk can cause a meter to run slow, resulting in reduced bills. Worn gears, corrosion, moisture, dust, and insects can all cause drag and result in an electromechanical meter that does not capture the full consumption of the premise. Failure modes also exist that could cause an electromechanical meter to run fast, but are less common. Figure 5[3] illustrates this effect, based on the average registration versus years-of-service for a sample of 400,000 electromechanical meters.

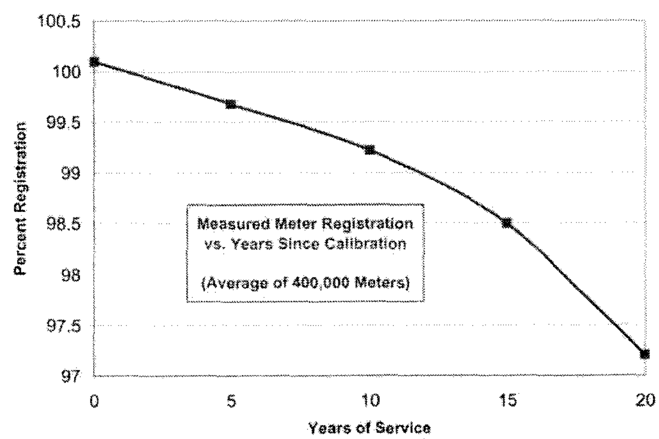
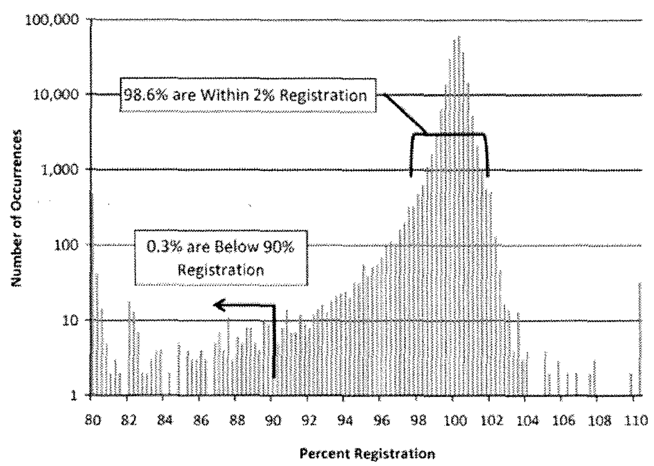


Figure 5 – Electromechanical Meter Registration Loss vs. Time

3 Data by permission from Chapman Metering, www.chapmanmetering.com

When all the meters in a service area are replaced, it is reasonable to expect that some of those taken out of service were inaccurate and running slow. Some may have gradually slowed over many years so that the homeowner never noticed and became accustomed to lower electricity bills. The sudden correction to full accounting and billing could naturally surprise these homeowners and result in questioning of a new meter. While the average meter might be only slightly slow, a few could be significantly so. As indicated in the distribution shown in Figure 6,[4] 0.3% of electromechanical meters tested registered less than 90% of actual consumption. Although 0.3% is small as a percentage, in a service area of a million meters, it represents 3,000 residences that might be under-billed by 10 to 20% prior to a new meter deployment.



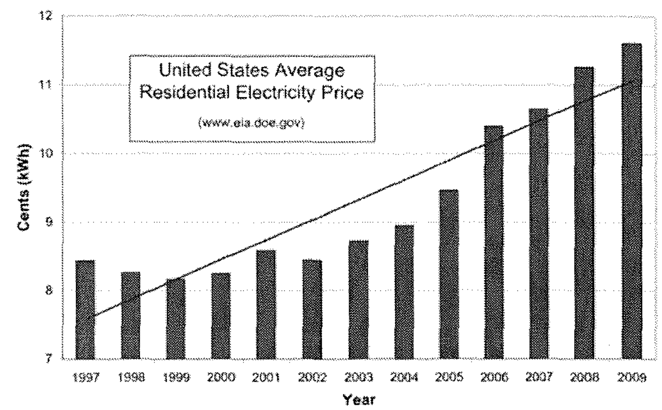
Note the Logarithmic Vertical Scale for Better Resolution

Figure 6 – Electromechanical Meter Registration Distribution

Rising Electricity Costs

Although not the case everywhere, basic energy rates have risen in most areas as a result of increased costs of generating electricity and increased costs of the infrastructure required to deliver electricity to the consumer. As indicated in Figure 7, the average residential electricity price in the United States has increased at an average rate of 0.3 cents per kilowatt-hour per year over the last 12 years. In the event that a rate increase coincides with a rollout of new meters, homeowners experiencing higher bills might conclude that their new meter is in error.

4 Data by permission from Chapman Metering, www.chapmanmetering.com



Note the Exaggerated Vertical Scale

Figure 7 – Average Residential Electricity Price vs. Time

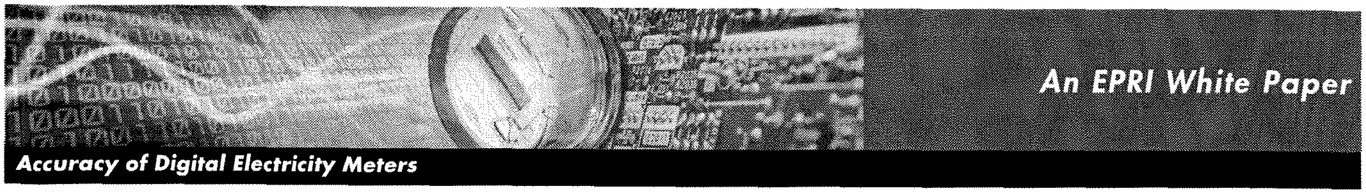
Use of Embedded Software

Electromechanical meters utilized a set of gears and dials to keep a running count of how many times the disk rotated. This assembly, referred to as a "register," maintained a measure of the total power consumption that passed through the meter over time. Like a car's mileage odometer, each gear fed the next so that ten turns of the less significant dial were required to make one turn of the next. These registers had only one input, driven by the spindle of the meter's disk, and could not be moved from one reading to another by any other mechanism. Although simple and mechanical, the result was like a vault, locking-in and protecting the reading of cumulative consumption and immune to sudden shift or loss of data.

Solid state electronic meters are designed to provide this same register function, but using embedded software and non-volatile memory chips as the storage mechanism. Even before the recent deployment of "smart meters," millions of solid state meters have been deployed by utilities since the 1990s and the accuracy of their registration has not been an issue.

Still, as electronic devices, there is the possibility of imperfections in the embedded software or sensitivities in the electronic circuitry. Hypothetically, such imperfections or sensitivities could result in glitches that could affect the meter reading. An error of this nature that occurred only rarely would be difficult to detect prior to field deployment.

With electromechanical meters, modes of failure tend to be permanent. Once a meter or its register fails, due to wear, dust, etc, it is



generally still found to be in a failed state when tested later. Software flaws, on the other hand, could create a transient glitch, leaving a meter that checks-out perfectly afterwards. This possibility complicates the diagnostic process for solid state meters and may make it difficult to discern the root cause of problems.

If it were to occur, the effect of a glitch in a solid state meter or in an AMI system may be mitigated using interval data. Typically, the homeowner's consumption is measured in individual time intervals, such as 15 minutes or 1 hour. This interval data is typically collected by the utility every few hours or daily. Verification of data is thereby made simple because the sum of the entries in each time interval must add up to the total. If a meter's aggregate reading were to suddenly shift, or if a single interval suggested an unrealistic level of consumption, then validation, estimation, and editing software in the utility office could automatically identify the problem and either correct it or flag the issue for customer service.

Voltage Transient Susceptibility

The electronic circuits of solid state meters connect to the AC line to draw operating power and to perform voltage measurement. Although the line voltage is nominally regulated to a stable level, such as 240VAC, transients and surges can occur during events such as electrical storms. A range of electronic clamping and filtering components are used to protect the electronics from these voltage surges, but these components have limitations. The ANSI C12.1 metering standard specifies the magnitude and number of surges that meters must tolerate. In addition, some utilities have instituted surge withstand requirements for their meters that exceed the specification. In any case, surges that exceed the tested limits, either in quantity or magnitude, could cause meter damage or failure.[5]

Electromechanical meters had no digital circuitry. They utilized spark-gaps to control the location of arc-over and to dissipate the energy of typical voltage events. As a result, they were generally immune to standard surge events. This nature is evidenced in the section of ANSI C12.1 that specifies voltage surge testing, but allows that "This test may be omitted for electromechanical meters and registers."[6]

5 *Testing and Performance Assessment for Field Applications of Advanced Meters*, EPRI, Palo Alto, CA. 2009. 1017833

6 ANSI C12.1-2001, Section 4.7.3.3 Test No. 17: *Effect of High Voltage Line Surges*

Summary

Electromechanical meters are dependable products that have served society well. Over a hundred years, their design was optimized so that they provided an excellent combination of simplicity and reliability while providing a single measurement - cumulative energy consumption. Unfortunately, these products did not support the additional functionality needed to integrate customers with a smart grid, such as time of use and real time prices, a range of measured quantities, communication capability, and others.

For these utilities, the transition to solid-state electric meters is therefore not one of choice, but of necessity. Due in part to the large number of announced AMI programs, many homeowners in the United States will likely see their electromechanical meter replaced by a solid-state electronic device in the next five to ten years. During such a transition, there will likely be both real and perceived issues with solid-state designs that need addressing. Care must be taken to consider each case thoroughly and to use sound diagnostic practices to trace each issue to its root cause. Temptations to either blame or exonerate the solid state meter must be resisted. Ideally, each investigation should not only resolve any homeowner concerns, but also discover any product imperfections so that solid-state meter designs may be continually improved. When advanced metering functions are needed, reverting to electromechanical meters is not a viable option.

The Electric Power Research Institute, Inc. (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies. EPRI's members represent more than 90 percent of the electricity generated and delivered in the United States, and international participation extends to 40 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; and Lenox, Mass.

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Smart Distribution Applications and Technologies (Program 124)

1020908 May 2010

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APPENDIX D

Electrical Power Research Institute, Comment: Sage Report on Radio-Frequency (RF) Exposure from Smart Meters, February 2011

See attached.

EPRI Comment: Sage Report on Radio-Frequency (RF) Exposures from Smart Meters

Electric Power Research Institute (EPRI)

Summary

A report by Sage Associates dated January 1, 2011 and entitled, "Assessment of Radiofrequency Microwave Radiation Emissions from Smart Meters" was posted on the internet. The "Sage Report" uses various approaches to characterize radio-frequency (RF) field levels and to compare them to the exposure limits published by the Federal Communications Commission (FCC) in FCC OET Bulletin 65, Edition 97-01, dated August 1997. The report concludes that, "FCC compliance violations are likely to occur under normal conditions of installation and operation of smart meters and collector meters in California." The report also compares field levels from smart meters to those from studies reporting biological and health effects. However, the research findings referred to in the Sage Report have not been replicated or are inconsistent with the results of other studies. Furthermore, virtually every recent mainstream expert scientific review of the RF health literature conducted in North America and Europe has not recognized the effects cited by the Sage Report as confirmed or definitive. This commentary deals with the engineering and source characterization aspects of the Sage Report.

The Sage Report misapplies the specifications in the FCC rule as follows:

Time averaging exposure: Exposures from smart meters may be time-averaged according to the FCC statement in OET Bulletin 65 that, "'source-based' time-averaging based on an inherent property or duty-cycle of a device is allowed." Clearly, smart meters fall into the "source-based" category of emitters. An extensive analysis of smart meter transmissions for almost 47,000 units in southern California was conducted for EPRI ("An Investigation of Radiofrequency Fields Associated with the Itron Smart Meter" EPRI Report 1021126 December 2010; available to the public at www.epri.com). The report estimated that 99.5% of the sample was operating at a duty cycle of about 0.22% or less, a value that translates to 3 minutes and 10 seconds of transmitting over a day; the maximum duty cycle in any residence did not exceed 5%. The duty cycle for cell relays (referred to as "collectors" in the Sage Report) within the same sample did not exceed 1%. The Sage Report defaults to compute exposures based on a 100% duty cycle, thus over-estimating exposure in the sample cited above by no less than 20-fold and more typically more than 400-fold.

Spatial averaging of exposure: The FCC states that to characterize a person's exposure properly, the RF power density should be averaged across the entire volume of an exposed body. An example in the EPRI Report indicates that power density averaged over the body of a 6-foot person situated one foot in front of a meter is less than approximately one-quarter of the emission at the point of the wavefront's peak at that distance. The Sage Report assumes a uniform field across the body that is equal to the peak power density within a body's cross-section, thus overestimating an individual's exposure.

Reflections: Radio frequencies "bounce" or reflect off of surfaces exactly the way light is reflected off the surface of a mirror. The level of a reflected wave that is present at any point is expressed as a percent of the electric field of the incident wave, which is the free-space wave in the absence of any reflection. The power density at that point is the incident power density multiplied by $[1+(\text{percent of reflection}/100)]^2$. The FCC's worst-case scenario is a 100% reflection (4-fold increase in power density), with a less conservative though more realistic value of 60% (2.56-fold increase in power density) used in many cases as an upper bound (e.g., see EPRI White Paper 1020798, "A Perspective on Radio-Frequency Exposure Associated With Residential Automatic Meter Reading Technology"). A key element to factoring reflections into an exposure calculation is that, for RF emitters like smart meters in real-world residential environments, the percent reflection diminishes as one approaches the meter. Thus, at the distance at which incident power density is maximal, the contributions of reflections to total power density are minimal. The Sage Report assumes that incident power density is enhanced by reflections uniformly throughout the space surrounding the meter. Furthermore, in adopting reflection values from one particular study (Hondou et al., 2006), it uses reflection factors that, in terms of power density, are between 30 and 110 times greater than the worst-case power density enhancement due to reflections identified by the FCC.

In addition, this commentary points out several other pertinent issues:

- The Sage report, in discussing exposure with relation to specific anatomic sites that include eyes and testes, referred to stipulations in an outdated 1999 IEEE standard. The current IEEE standard, published in 2005, with extensive documentation on the topic, removed any exceptions for such anatomic sites.
- In comparing field calculations to the FCC limits, the Sage Report did not frequency weight the contributions from the end-point meter (~900 MHz), the Home Area Network (HAN) antenna (~2,400 MHz) and the cell relay (~850 MHz). Because the FCC exposure limits are frequency dependent, a simple arithmetic addition of contributions from various sources is an inappropriate approach to compliance assessment.

Therefore, the Sage Report, for the reasons enumerated in this commentary, has over-estimated exposures from smart meters using assumptions and calculations that are inconsistent with the FCC's rule and that do not recognize the basic physical characteristics of RF emissions.

Section I: Background

A report by Sage Associates dated January 1, 2011 and entitled, "Assessment of Radiofrequency Microwave Radiation Emissions from Smart Meters" was posted on the internet; it will be referred to here as the Sage Report for short. The report's authorship was not specifically identified. The proprietor of Sage Associates, Ms. Cindy Sage, also coordinated the BioInitiative Working Group (BWG) report that was published in 2007. That report included chapters by about a dozen scientists known in the EMF research field. Ms. Sage and Dr. David Carpenter the report's other signatory concluded that health effects of various kinds result from low-level radio-frequency exposure, and:

> There may be no lower limit at which exposures do not affect us. Until we know if there is a lower limit below which bioeffects and adverse health impacts do not occur, it is unwise from a public health perspective to continue "business-as-usual" deploying new technologies that increase ELF [extremely-low-frequency] and RF exposures, particularly involuntary exposures.

The BWG report, which covered RF as emitted from various sources (cell phones, base stations) suggested that safety standards for RF exposures, as specified by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the U.S. Federal Communication Commission (**FCC**[1]), are not sufficiently conservative. EPRI's commentary (EPRI publication #1016233) on the BWG Report can be found at www.epri.com.

The recently issued Sage Report takes a two-fold approach. First, it uses a number of engineering assumptions to calculate presumed exposure levels from one or more smart meters with or with out a **cell relay** (referred to as "collectors" in the Sage Report) also present, and to then identify "violations" of FCC exposure limits for the general public. The Sage Report concludes that:

> FCC compliance violations are likely to occur under normal conditions of installation and operation of smart meters and collector meters in California. Violations of FCC safety limits for uncontrolled public access are identified at distances within 6" of the meter. Exposure to the face is possible at this distance, in violation of the time-weighted average safety limits. FCC violations are predicted to occur at 60% reflection (OET Equation 10 and 100% reflection (OET Equation 6) factors, both used in FCC OET 65 formulas for such calculations for time-weighted average limits. Peak power limits are not violated at the 6" distance (looking at the meter) but can be at 3" from the meter, if it is touched.

Secondly, it compares these exposure levels with those in selected studies that have reported biological or health effects resulting from RF exposures that are considered adverse. However, the research findings referred to in the Sage Report have not been replicated or are inconsistent with the results of other studies. Furthermore, virtually every recent mainstream expert scientific review of the RF health literature conducted in North America and Europe has not recognized the effects cited by the Sage Report as confirmed or definitive.

This commentary will not deal any further with the health aspect of the report, and will focus primarily on its technical assumptions, treatment of engineering factors, and source characterization. This commentary will also draw from

[1] Bolded terms are defined in the Glossary

measurement and modeling data published in an Electric Power Research Institute (**EPRI**) study of smart meters ("An Investigation of Radiofrequency Fields Associated with the Itron Smart Meter" EPRI Report 1021126, December 2010; available to the public at www.epri.com). In the commentary that follows, Section II deals with the Sage Report's understanding of the FCC rule governing RF exposures. Section III comments on how the FCC formula for computing RF field levels was used in the Sage Report, and Section IV provides conclusions.

Section II: Sage Report's Interpretation of the FCC Rule Specifying Exposure Limits for Radio-Frequency Electromagnetic Fields

The Federal Communications Commission established limits for exposure to radio-frequency electromagnetic fields, which are published in FCC OET Bulletin 65 (August 1997), and codified in the Code of Federal Regulations (47 CFR § 1.1310). The FCC rule was adopted from two previous guidelines, one published by the National Council on Radiation Protection and Measurements (NCRP Report No. 86) in 1986, and the other by the Institute for Electrical and Electronic Engineers (IEEE C95.1 1991) in 1991. Both had extensively reviewed the biological and health literature, concluding that the only established effects were associated with tissue heating and no confirmed effects below heating thresholds were identified. The effects associated with heating, so-called "thermal effects", concerned diminished response rates in food-motivated behavioral experiments in laboratory animal subjects (rhesus monkeys and rats) and were accompanied by a rise in body core temperature of about 1° C. Such behavioral changes are considered amongst the most sensitive indicators of potentially adverse effects. In the absence of heating, there have been no consistently demonstrated "non-thermal" mechanisms that could lead to adverse biological or health effects either acutely or chronically. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the IEEE have since developed guidelines very similar to the FCC's based on the same behavioral effects following for each a comprehensive review of the scientific literature. Prior to its publication, the FCC rule received endorsements from the U.S. Environmental Protection Agency (EPA), the U.S. Food and Drug Administration (FDA), and the U.S. Occupational Safety and Health Administration (OSHA). The EPA reaffirmed its opinion in letters written in 1999 and 2002.

There are four aspects of the Sage Report that are examined in the ensuing discussions within this section. The first three relate to the basis for the FCC rule, as follows: (1) averaging exposure over time (2) averaging exposure across space, and (3) **reflections**. The 4th item concerns the Sage Report's understanding of the most recent exposure standards as published by IEEE, as they relate to specific anatomic sites, namely the eyes and testes.

Time Averaging

FCC OET Bulletin 65 states:

> ...exposures, in terms of **power density**...may be averaged over certain periods of time with the average not to exceed the limit for continuous exposure...the averaging time for occupational/controlled exposures is 6 minutes, while the averaging time for general population/uncontrolled exposures is 30 minutes. (page 10)

The OET further states:

> Time-averaging provisions may not be used in determining typical exposure levels for devices intended for use by consumers in general population/uncontrolled environments. However, "source-based" time-averaging based on an inherent property or duty-cycle of a device is allowed. (page 74)

In this context, smart meters fall into the "source-based" category, and time averaging is completely appropriate. The Sage Report claims that time averaging does not apply to assessing exposures from smart meters, and continuous operation should be assumed for compliance assessment, which represents a misinterpretation of the FCC rule. The applicability of time averaging to smart meters was reaffirmed in a letter dated August 6, 2010 to Ms. Sage from the FCC's Julius Knapp, Chief, Office of Engineering and Technology, stating:

> For exposure evaluations, however, the average power is relevant, which is determined by taking into account how often these devices [smart meters] will transmit.

To illustrate the amount of time a meter may actually transmit, data were collected from the transmitting records from almost 47,000 meters over a nearly three month period, amounting to more than four million readings in all. The capability to accomplish this was enabled by special software developed by the smart meter manufacturer (Itron) to acquire transmit data. The analysis enumerated the data

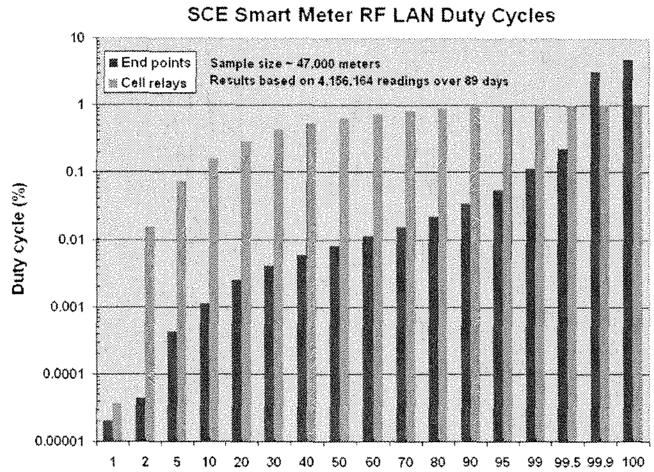

Figure 1

Analysis of SCE daily average duty cycle distribution for different percentiles based on 4,156,164 readings of transmitter activity from an average of 46,698 Itron Smart Meters over a period of 89 consecutive days. Analysis based on estimated transmitter activity during a day. (From EPRI Technical Report 1021126, December 2010)

"packets" associated with uplink and downlink communication to and from end-point and cell relay meters to serve as surrogates for transmission time. The study estimated (Figure 1) a maximum duty cycle of under 5%, with 99.5% of the sample operating at a duty cycle of about 0.22% or less, a value that translates to 3 minutes and 10 seconds of transmitting over a day (a 5% duty cycle, worst case in this study, translates to 72 minutes of transmitting). The duty cycle for cell relays within the same sample did not exceed 1%. Assuming these data are representative of smart meter function in general, the Sage Report using a 100% duty cycle, over-estimates exposure by no less than 20-fold and more typically more than 400-fold. In a smaller study of over 6,800 meters, end-point and cell relay meters were monitored for the number of bytes of data transmitted over an observation period of one day. This method provided a direct (exact) measure of time, and reported duty cycles even lower than those in the larger sample, with no one-day average duty cycle exceeding 1%.

Thus, as an example of examining smart meter duty cycie from the compliance perspective, the EPRI study estimated a nominal exposure of about 12 microwatts per square centimeter ($\mu W/cm^2$) for a person a foot from a 250-mW **end-point meter** while the meter is transmitting. Assuming the worst case duty cycle of 5% for that meter, the "source-based" time-averaged exposure would be 0.6 $\mu W/cm^2$, which is 0.1% of the FCC's **MPE** (maximum permissible exposure); for a 1% duty cycle, the average exposure would be 0.02% of the FCC limit. This value does not yet account for the FCC's stipulation for spatial averaging dealt with in the next discussion.[2]

Spatial Averaging

FCC OET Bulletin 65 states:

> Limits for General Population/Uncontrolled exposure: 0.08 W/kg as averaged over the whole-body and spatial peak **SAR** not exceeding 1.6 W/kg as averaged over any 1 gram of tissue (defined as a tissue volume in the shape of a cube). (page 75)

Exceptions are made for the extremities that have higher SAR permitted. Earlier in the document, FCC states as a general principle:

> A fundamental aspect of the exposure guidelines is that they apply to power densities or the squares of the electric and magnetic field strengths that are spatially averaged over the body dimensions. Spatially averaged RF field levels most accurately relate to estimating the

[2] The FCC rule is not specified to account for the fraction of transmitting time over the course of a day that a person would actually traverse the area within a given distance to the meter. Using the example in the text, a person doing yardwork for 2 hours and 24 minutes (one-tenth of a day) close, say a foot (30 centimeters) from a single meter operating with a 5% duty cycle mounted on the external wall of a residence, would nominally receive an exposure equivalent to 0.01% of the FCC exposure limit for the general public (one-ten thousandth of the exposure limit).

> whole body averaged SAR that will result from the exposure and the MPEs ... (page 10)

The Sage Report presumes a uniform exposure level across the volume of an exposed person that corresponds to the maximum level in the wavefront at a given distance. However, in fact, the exposure level varies across the dimensions of a body. Figure 2 depicts the general idea of averaging across a body's volume in which 10 or more measurements along the body's axis are averaged in terms of their power density (often measured as the electric field, which is then squared to represent power density).

According to measurements reported in the EPRI study, power densities vary across the measurements' angle of elevation. Figure 3 illustrates how the power density varies along a circular trajectory from above to below the meter. The color coded graphic on the right-hand panel of the figure indicates that, in the case of the meter characterized, power density may be lower at the top by roughly a factor of 3 (~5 dB), and at the bottom by up to a factor of about 10 (~10 dB). In a crude fashion, one could liken the variation of power to the beam from a flashlight, which is maximal head on and diminishes as one moves further from the center of the beam (Figure 4). Qualitatively, it is fairly apparent that the power density in the center of the beam can significantly overestimate the power density averaged over one's body dimensions. An example of a vertical profile measured 1 foot in front of a continuously transmitting 900-MHz, 250-mW end-point smart meter (i.e., transmitting to the **LAN**), as reported in the EPRI study cited above, is shown in Figure 5. Note that at its peak the emission is just below 2% of the FCC's MPE for 900 MHz, but the vertical average, which is the basis for the FCC rule is 0.44% of the FCC MPE, more than 4 times less than the peak.

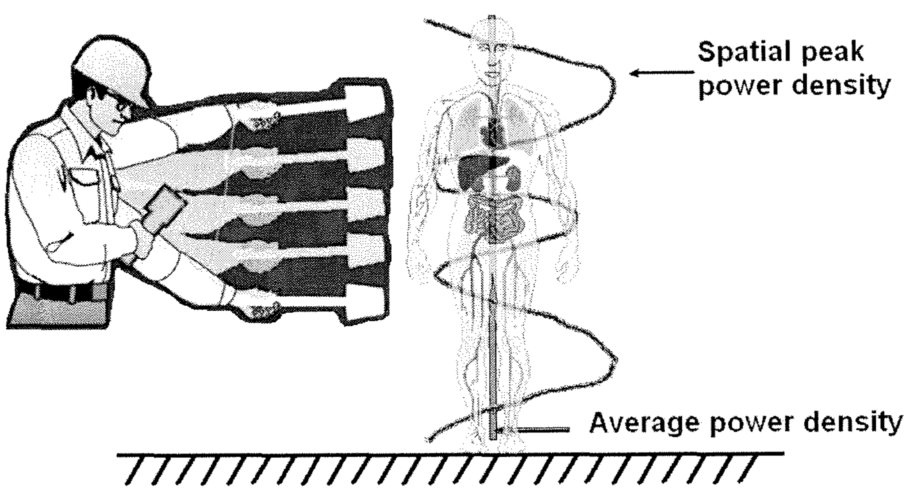

Figure 2

Estimating whole-body SAR with measurements of the power density along the axis of a person in the location to be occupied. (adapted from EPRI Resource paper 1014950, December 2007)

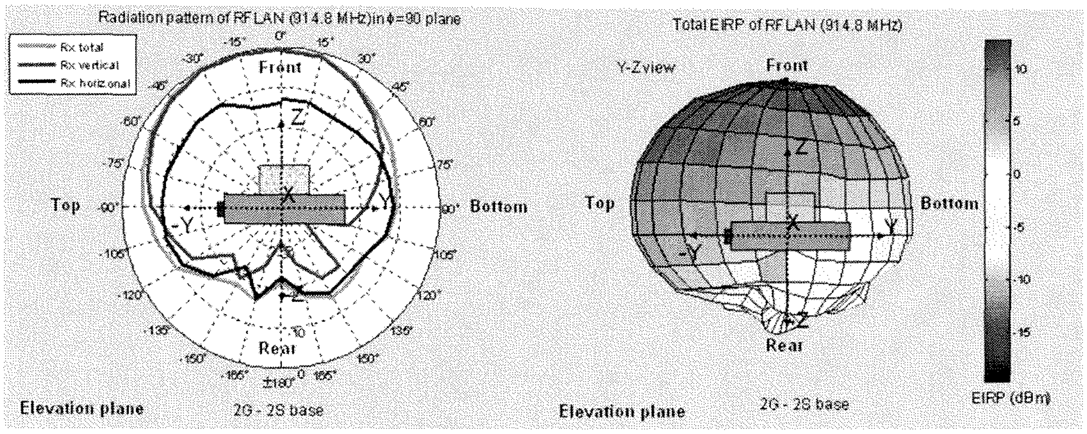

Figure 3
Left: Elevation plane pattern of the 900 MHz RF LAN transmitter in an end point meter showing the horizontal, vertical and total pattern. The scale is in dB with the maximum field at the outer edge of the pattern circle. Right: Elevation plane view of the total EIRP of the 900 MHz RF LAN transmitter in an end point meter. (From EPRI Technical Report 1021126, December 2010)

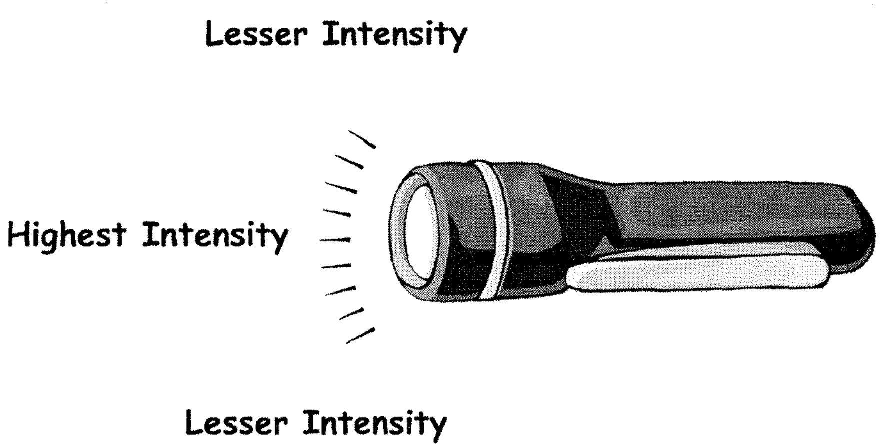

Figure 4
Depiction of beam from a flashlight as a crude analogy of the vertical gradient of the power density from a smart meter

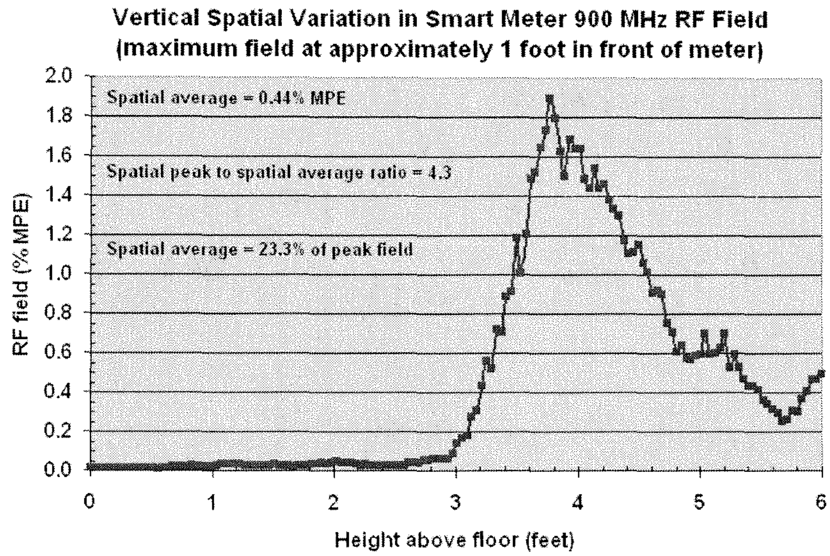

Figure 5

Vertical spatial variation in Smart Meter 900 MHz RF LAN field from 0 to 6 feet above the floor at a lateral distance from the Smart Meter of approximately 1 foot. (From EPRI Technical Report 1021126, December 2010)

Reflections

Electromagnetic waves may reflect off surfaces (Figure 6), which enables us to use rear- and side-view mirrors, which are highly reflective surfaces, to observe traffic traveling behind us. Though visible light is electromagnetic energy that propagates at frequencies 5 to 6 orders of magnitude greater than RF emissions from smart meters, the latter may likewise be reflected to some extent from floors, ceilings and walls depending on their reflective properties. However, most of the environments inhabited by people consist largely of indoor surfaces (wood or carpeted floors, plaster walls and ceilings, windows) and outdoor surfaces (exterior walls, lawns, sidewalks) of moderate reflectivity that may also absorb (and thus attenuate) or pass electromagnetic energy much as light passes through glass. Further, given that smart meters are very frequently on building exteriors facing open space (Figure 7), reflections in those cases would be very small contributors to overall exposure.

The extent of an added exposure due to reflection depends on the reflectivity of the surface (e.g., metallic surfaces are highly reflective; carpeted and wood floors are more absorptive and less reflective), the antenna's beam characteristics (e.g., its angular width and direction) the angle of reflection, and the distance traveled by the wave to an exposed person. For an analysis of RF fields that will result in a conservative estimate of the actual field, the FCC OET 65 Bulletin states:

> For a truly worst-case prediction of power density at or near a surface, such as at ground level or on a rooftop, 100% reflection of incoming radiation can be assumed, resulting in a potential doubling of predicted field strength and a four-fold increase in (far-field equivalent) power density. (Page 20)[3]

The Sage Report interpreted several studies to justify that a worst-case analysis would require increasing the power density of the free-space emissions to account for reflections. This approach was based primarily on a paper by Hondou et al. (J Phys Soc Jap 75:084801, 2006), which reported power density levels for an enclosure made entirely of perfectly reflective surfaces, as depicted in Figure 8 (right). Using the light analogy, this would be equivalent to an enclosed space whose walls, floor and ceiling were made entirely of mirrors. The Hondou et al. (2006) result adapted by the Sage Report is shown in Figure 8 (left), which shows the power density along a path leading away from the antenna.

[3] Reflection values are expressed in terms of the electric field. Thus, as power density is proportional to the electric field squared, a 100% reflection at a particular point in space corresponds to an enhancement of the power density by a factor of $(1+100/100)^2 = 4$. A more common upper bound estimate of 60% for reflection results in a power density enhancement of $(1+60/100)^2 = 2.56$.

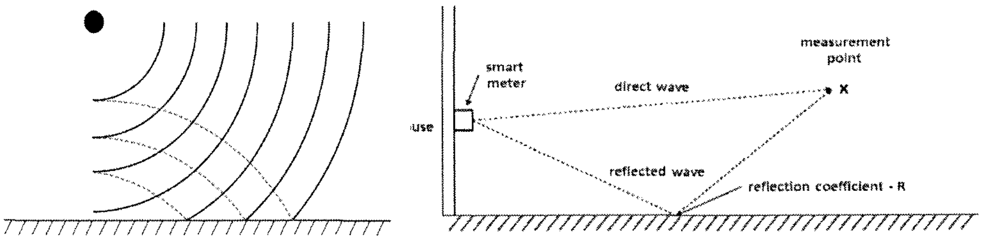

Figure 6
RF Reflections. Left: Wavefronts emitted (solid lines) by source (black dot) and reflected (dashed lines) from the ground. Far from the source (far field), these waves become nearly "plane waves." (From EPRI Technical Report 1014950, Dec 2007); Right: Exposure to incident and reflected wave as would occur at a measurement point; the two contributions may reinforce or cancel one another depending on their mutual phase relationships (Compliments of R.G. Olsen and R.A. Tell)

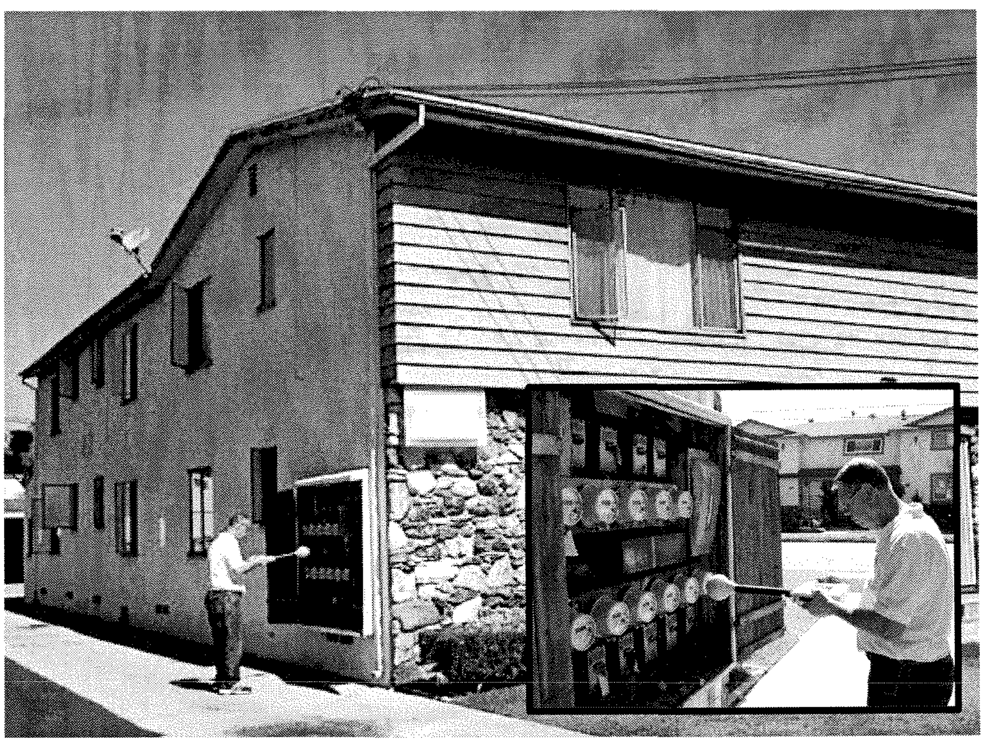

Figure 7
Measuring RF power densities in front of an outdoor bank of smart meters

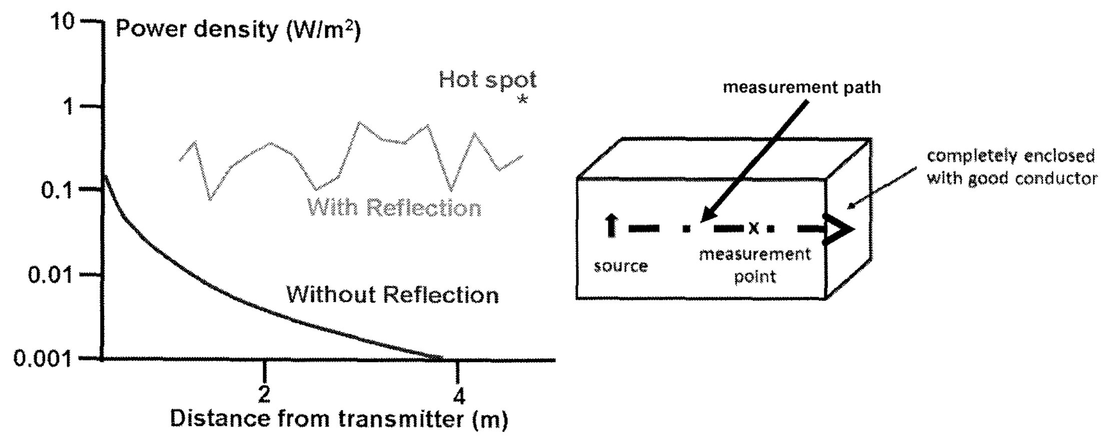

Figure 8

Right: Conceptualization of measurements conducted by Hondou et al. (Compliments of R.G. Olsen and R.A. Tell); Left: Measured power density in the conductive enclosure (red), and calculated free-space value (adapted from Hondou et al., 2006)

At a distance of about 4 meters the power density in this enclosure is between 100 to 1,000 times greater than would be the calculated free space value (blue curve), with a "hot-spot" noted with a power density about 2,000 times greater than the free space scenario. Also note in Figure 8 that as the distance to the antenna decreases, the discrepancy between the reflected and free-space values also decreases (see below for further discussion of reflections versus distance from an antenna). The Sage Report introduced enhancement factors of 1,000% and 2,000%, which translate to, respectively, 121- and 441-fold enhancements of the incident power density (see footnote 3). Despite the claim of adopting "conservative" reflection values based on Hondou et al., the Sage Report, nonetheless used power density enhancements roughly 30 to 110 times greater than the FCC's worst-case scenario, and, moreover, applied the enhancements uniformly to every point in space, which violates the laws of physics. In addition, there are no practical scenarios that simulate the conditions of the enclosure tested by Hondou et al. whereby an individual would be in a space occupied by a smart meter that was also entirely enclosed by conductive surfaces on all sides (floor, walls and ceiling).

Looking further at a realistic indoor case, one might consider rooms in the home (such as a bedroom) to be nearly fully enclosed; doors and windows do represent openings in the enclosure. But, even if this is said, there are two fundamental problems (see Figure 9). First, the source (i.e., the smart meter) is not within the room. It is possible for some of the RF electromagnetic waves to "leak" into the room, but only if the wall is partially transparent to electromagnetic waves from the meter on the exterior of the residence or in the garage. The leakage is small because a smart meter does not radiate much in the direction of the house; its radiation is intentionally directed away from the house. As an added note, though the HAN "Zigbee" antennas are designed to communicate to devices within a residence's interior, their transmission pattern measured in the EPRI study was also more heavily weighted outward much like the end-point meter's pattern. In addition, as the RF passes through the wall it is attenuated. The second problem is since the room is not completely enclosed and the enclosure is not a perfect (or nearly perfect) conductor, it will not behave nearly like the resonant cavity used by Hondou et. al. As a final note, if the wall is more transparent to RF so that attenuation of the RF into the room is small, then the room will look even less like a resonant cavity because its walls are more "leaky."[4]

Although the power density values in the Hondou paper in all likelihood correctly represent the experimental conditions they describe, the results were not utilized appropriately in the Sage Report. The Sage Report calculates the field at

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[4] It is worth noting that Hondou et al. reported another scenario simulating an elevator with a mounted antenna. The "elevator" enclosure used by Hondou et. al. also has metallic sides floor and ceiling. It does have an open door, but given the orientation of the source antenna, only smaller fields are radiated towards the door opening. Thus the door does not degrade the properties of the elevator as a resonant cavity as much as it could if the source was oriented in a different direction.

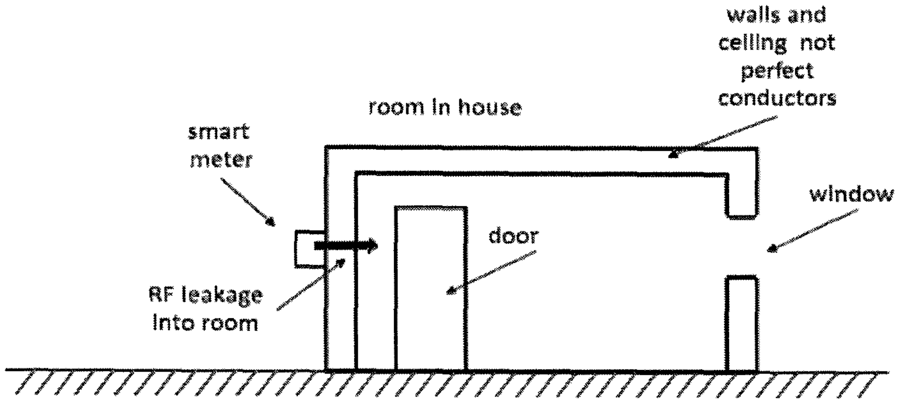

Figure 9

RF leakage into a room in a house which is not a good resonant cavity due both to openings in the walls and the imperfectly conducting enclosure. (Compliments of R.G. Olsen and R.A. Tell)

(for example) 0.15 meters (i.e., 6 inches) from the source and then increases the field by 1000% or 2000% to calculate an "actual" power density at that point. This is not a correct use of Hondou's data. The author of the Sage report incorrectly assumes that the factor of 1,000% or 2000% (10 or 20 fold enhancement of the electric field) may apply at every point in space as a multiplier to the "free space" value of the field. Based on fundamental laws of physics, it can be unequivocally stated that the closer the field point is to the source, the smaller any increase in the field due to reflections. In fact, this ratio approaches 1.0 as the field point becomes arbitrarily close to the source.

This aspect of exposure regarding reflections close to a source, included in the EPRI Technical Report, is illustrated in Figure 10 (left), which represents a calculated power density one foot from a smart meter placed at a height of 5 feet with and without a reflection. The values with reflections present (wavy blue curve) were calculated with a technique called "method of moments" that utilizes realistic characteristics of a ground surface to calculate reflected power density. With a reflection present in this model, the average power density over the vertical axis of a six-foot person standing one foot from the meter was 3.2% greater than the average with no reflections. Also, note how much smaller the exposure levels would be for a person shorter than 4-5 feet. Figure 10 (right) charts the contribution of reflections to the free space power density as distance from the meter increases. Though the relative contribution of reflection is shown to increase with distance from the meter, the total incident power density is simultaneously falling by a greater relative amount with increasing distance from a source. A key finding from this analysis of reflections is that for the distance range modeled, from 1 foot to 20 feet from the meter, the greatest enhancement in power density caused by reflections was only 65%, far smaller than the 256% value provided by FCC for conservatively estimating RF fields when reflections occur. Furthermore, these higher enhancements occurred for points furthest from the source for which the incident field is already smaller. A previous EPRI White Paper, "A Perspective on Radio-Frequency Exposure Associated With Residential Automatic Meter Reading Technology" (1020798), described 60% as a realistic upper bound reflection.

The Sage Report cites another paper (Vermeeren et al., Phys Med Biol 55:5541, 2010) in the context of supporting its enhancement factors which, in fact, it does not. This study models SAR resulting from a rooftop exposure to a base station antenna in the presence of a reflective rooftop (or ground plane) and wall. It reports that at 900 MHz – close to the frequency of the RF LAN (915 MHz) in the wireless smart meter under discussion here – the SAR (proportional to power density at any given frequency) could increase by as much as a factor of about 3.6 (5.5 dB) on a localized basis in 10 grams of tissue, and by a factor of about 2.8 (4.5dB) on a whole body basis, both of these values being consistent with the FCC OET 65 cited above (Figure 11, vertical blue bars). At the same time, reflections modeled at 900 MHz may also result in a reduction of SAR compared to the free-space scenario. At lower frequencies (300 and 450 MHz) reflections were slightly greater, and at higher frequencies, including 2,100 MHz, roughly a home area network's (**HAN**) operating frequency, the reflections were lower (vertical red bars).

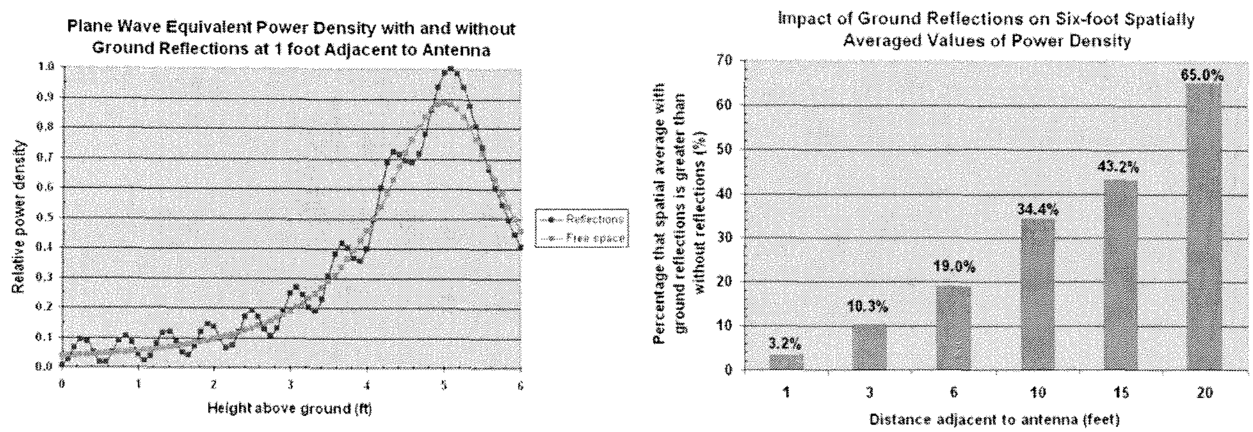

Figure 10
Left: Relative calculated plane wave equivalent power density along a six-foot vertical path, one foot adjacent from a 900 MHz half-wave dipole positioned at five feet above the ground. Power density values are compared with and without ground reflections. Right: Impact of ground reflections on six-foot spatial average of power density for different distances lateral to a 900 MHz dipole antenna mounted at five feet above ground. Vertical axis represents the percentage that the spatially averaged power density that includes any ground reflected fields is greater than the spatially averaged power density in free space (without any ground reflected fields). Ground reflection estimated by method of moments as described in the EPRI Report. (From EPRI Technical Report 1021126, December 2010)

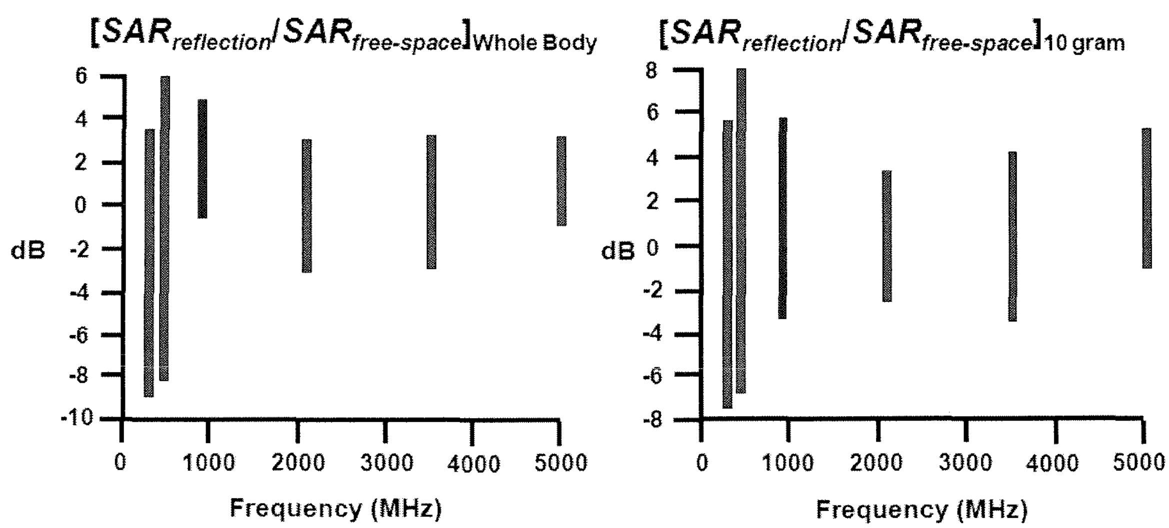

Figure 11
The range of whole-body and 10-gram SAR in the rooftop scenario with reflective ground and wall. Each frequency includes combinations of distance and reflective surface (ground, wall, ground + wall). The blue vertical bar corresponds to the power density range for 900 MHz. (adapted from Vermereen et al., 2010)

Worthy of note was that the Vermeeren et al. study modeled a vertical panel antenna that would intercept much of the body's dimension, leading to a much greater opportunity for whole body exposure than the case of the much smaller smart meter relative to the body's dimension.

Sage Report Interpretation of IEEE Standard Concerning Eyes and Testes

The Sage Report states the following:

> The ANSI/IEEE C95.1-1999 standard specifically excludes exposure of the eyes and testes from the peak power limit of 4000 uW/cm2* [asterisk is a reference to a footnote]. However, nowhere in the ANSI/IEEE nor the FCC OET 65 documents is there a lower, more protective peak power limit given for the eyes and testes.

However, in 2005, IEEE published a revised standard covering RF electromagnetic fields, "IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz (IEEE Std C95.1™-2005). The 2005 revision, working with additional research results available after the 1999 standard was published, removed the language and the intent of language in the 1999 standard regarding an exclusion for eyes and testes. IEEE Std C95.1™-2005 remains the current IEEE standard for RF exposures. The basis for the removal of the 1999 language regarding eyes and testes was extensively documented in the 2005 standard, with brief excerpts as follows:

> ...localized exposure at the upper limit (10 W/kg averaged over 10 g of tissue) is protective against all adverse effects including those occurring in the fetus and testes, the two targets identified as most sensitive to thermal damage. (p. 86)
>
> In summary, adverse effects of RF exposure of the eye, i.e., cataracts, are associated with significant temperature increases due to the absorption of RF energy. The maximal permissible RF exposures in this standard are therefore protective against the significant temperature increases that can result in adverse effects on the eye, such as cataracts. There is no evidence of other significant ocular effects, including cancer, which would support a change in the adverse effect threshold of 4 W/kg. (p 60)

Thus, given that revised standards are designed to override their predecessors, the Sage Report relied on an outdated document to suggest an exclusion for eyes and testes.

Section III: Sage Report Calculation of Exposure Levels

The formula used by the FCC for estimating emission levels from an RF source is:

$$S = \frac{P_t \times G_{\max} \times \delta \times R}{4\pi r^2}$$

Where,

S is plane wave equivalent power density (W/m^2)
P_t is maximum transmitter output power (W)
G_{max} is the maximum possible antenna power gain (a dimensionless factor); this means that the transmission has directionality with maximum power transmitted in one particular direction.[5]
δ is the duty cycle of the transmitter (dimensionless)
r is the radial distance between the transmitter and the point of interest (meters)
R is a dimensionless factor that accounts for possible ground reflections that could enhance the resultant field. For a 60% reflection of the electric field, a value typically used for assessing compliance, the power density, S, would increase of $(1.6)^2$ or 2.56 in the power density since it is proportional to the square of the electric field.[6]

The Sage Report used this formula to calculate RF power density levels as they compare to the FCC general public compliance levels under the assumptions that:

[5] The power density transmitted in this direction at a given distance is greater – by a factor, G_{max} - than the power density at the same distance were it transmitted symmetrically in all directions (or omnidirectionally) in a spherical pattern as from an isotropic source. This also means that there are areas near the antenna with transmitted power density lower than the power density from an omnidirectional source.

[6] The inclusion of the ground reflection factor of 2.56 makes this formula conservative since it assumes that the meter's signal emitted by a power meter is also reflected from the ground causing an enhancement of the resultant RF field due to what is called phase addition of the direct and reflected signals. If this occurs, it will only happen at very specific points above the ground while at other points, the signals will add destructively, reducing the signal intensity. Hence, when considering the body as a whole, the ground reflection will generally not affect the body's average exposure. Nonetheless, it is common when performing FCC compliance analyses to include the possibility of ground reflections.

1. Duty cycle need not be taken into account, and that continuous exposure should be assumed.

2. Implicitly, space averaging across the volume of an individual is unnecessary, with a uniform exposure at the maximum value occurring across all exposure space.

3. Reflections that may range from 60% to 2000% are uniform across the entire exposure volume.

4. Power densities from multiple meters can be added to calculate a cumulative power density, which can then be compared to the FCC limit.

Taking these in sequence:
(1) The discussion above clarified that as a source-based exposure, incorporating the duty cycle into the estimate of average power density (and average SAR) is appropriate.

(2) Furthermore, the FCC OET 65 indicates that exposure levels should be averaged over the volume of a person presumed to occupy the space where exposure occurs.

(3) In estimating the potential effect reflections may play, 60% is a highly conservative estimate for smart meters, with 100% a worst-case estimate. The reflective enclosure case modeled by Hondou et al. (2006) does not apply to any practical real world situations yet identified (see footnote 3 above concerning Hondou et al.'s elevator model). Uniform enhancement cannot be assumed because close to and in front of an emitter, where the emission is maximum, is exactly where the effect of reflections is at a minimum.

(4) When one is very close to a bank of meters (the Sage Report uses exposure to four meters), one cannot be in the direct path of the maximum emission for each, because (again using the crude flashlight model), the power density decreases to some degree with the azimuthal angle from the center of a propagated field. At the very closest distance in front of one emitter, the azimuthal angle from other emitters predicts lower exposures than derived from simple addition. With respect to this point, it should be pointed out that the exposure level in the 4-meter scenario in the Sage Report was unexplainedly not the 4-fold value expected; rather it was less (for example, see Sage Report, Tables 2 & 3). In Sage Report, Table 1, upper panel, the author reports values at 9 inches, rather than the stated 6 inches, such that the 4-meter scenario in the bottom pane is over 7 times the 1-meter scenario, which is clearly not possible even under the report's assumptions.

In terms of compliance assessment, when more than one source is present, each is weighted according to its frequency dependent FCC limit, as shown below Table 1 on the following page Thus, the Sage Report's approach of reporting a simple sum of power densities from sources at different frequencies is inappropriate in terms of assessing compliance.

In fact, the RF field levels from smart meters, even when grouped together, are not expected to exceed FCC limits. The graph in Figure 12 shows expected exposure levels, in terms of the fraction of the FCC limits appropriately weighted by relative contributions from each source. The specifications for the meters in these calculations, shown here in Table 1, correspond to those used in the Sage Report. The graph considers four end-point meters and three end-point meters combined with a cell relay for 60% and 100% reflections. The smart meters include both the end-point LAN emitter, and the HAN transmitting at 2,405 MHz. The Cell Relay includes these two transmitters, as well as a third transmitter for communicating over a wireless wide area network (**WWAN**) back to the utility company. The calculation assumes a duty cycle of 1%, which was applicable to over 99.5% of the readings from the data shown in Figure 1. Furthermore, the graph is extremely conservative in applying the reflection factor at every distance, and assuming that the peak power density in the wavefront is uniform in space (neither of these applies in actuality). These factors more than compensate for the fact that a small fraction of meters may operate at duty cycles up to 5%. Even at a distance of 8 cm (~3 inches) the power density is well below the FCC MPE.

Section IV: Conclusion

In assessing potential RF exposure levels from smart meters, the Sage Report misapplied the practices prescribed by the FCC in "Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields" (OET Bulletin 65, Edition 97-01, August 1997). Both space and time-averaging are appropriate and reflections of 60% or even 100% may be included to provide conservative estimates. In addition, the Sage Report's author did not evaluate cumulative exposure weighted by MPE at the frequency of each source as instructed by the FCC. A more realistic estimate, even allowing for assumptions that overestimate exposure levels

Table 1

Antenna Values for Figure 12

Antenna	*TPO* (dBm)	*G* (dBi)	*EIRP* (dBm)	*EIRP* (mW)	*f* (MHz)	*MPE* (mW/cm²)
RF LAN	24.27	2.2	26.47	443.6	915	0.610
Zigbee	18.71	1	19.71	93.5	2405	1.0
Cell Relay	31.8	-1	30.8	1202.3	850	0.567

Fraction of FCC Limit = $n_1 S_{LAN}/0.610 + n_2 S_{Zig}/1.0 + n_3 S_{CR}/0.567$

Within a residence:

n_1=number of LAN meters; n_2=number of Zigbee meters; n_3=1=number of cell relays

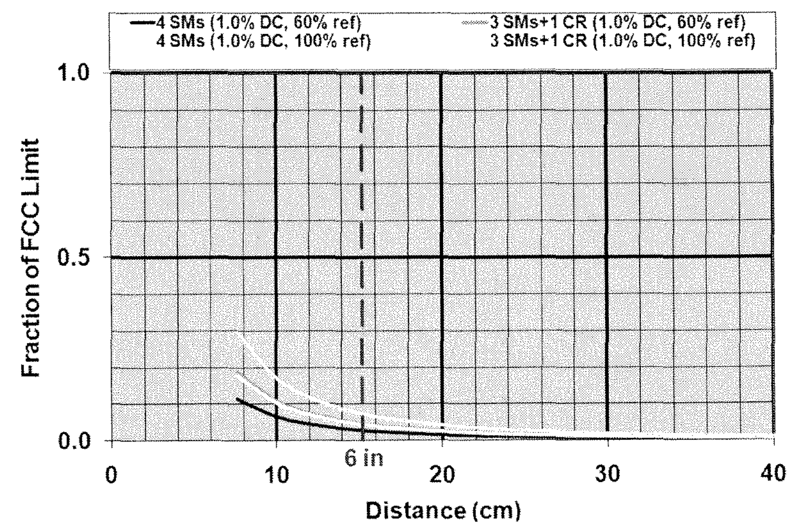

Figure 12

Calculated exposure levels from combinations of meters operating at 1% duty cycle with reflection values of 60% and 100% (see text)

by ignoring space averaging and declining RF levels at positions lateral to the center of a wavefront, reveals that FCC MPEs are very unlikely to be exceeded, even at distances very close to the source. This conclusion also applies to regions behind a meter bank owing to lower emissions in that direction and the attenuating properties of wall materials. These points were supported by measurements described in the EPRI Report, in which power density was measured in front of a rack of 10 ¼ watt (nominal power) continuously operating (i.e., 100% duty cycle) smart meters starting at a distance of 1 foot[7]. Under these circumstances, the frequency-weighted power density was 8% of the FCC MPE for the general public. For a realistic duty cycle of 1%, this would translate to 0.08% of the FCC MPE. For measurements taken immediately behind the rack, the field level for continuous transmission was 0.6% of the FCC MPE at a distance of 8 inches. It should also be pointed out that while the testing was conducted with end-point meters rated nominally at ¼-watt (~250 mW), the manufacturer's data illustrated in the EPRI Report allow one to estimate that, based on a sample of 200,000 meters, 99.9% operate at powers between 150 and 475 mW, with a possible maximum of 500 mW for no more than 0.05% of units. However, were all 10 meters rated at 1 W with the same spatial transmission pattern as the quarter-watt meters actually measured, the exposure at 1 foot would still be less than the FCC limit by a factor of three. Therefore, the Sage Report, for the reasons enumerated in this commentary, has over-estimated

[7] The meters were specially programmed to operate continuously for the measurement study. They do not operate in this manner when actually deployed, transmitting intermittently for very brief periods, as explained in the text.

exposures from smart meters using assumptions and calculations that are inconsistent with the FCC's rule and that do not recognize the basic physical characteristics of RF emissions.

Glossary

Cell relay: A form of Smart Meter that provides the normal function of an end point meter but also allows for data connectivity with the electric utility company via a wireless wide area network that functions in the cellular telephone or personal communications service (PCS) bands.

Duty Cycle: a measured of the percentage or fraction of time that an RF device is in operation. A duty cycle of 1.0, or 100%, corresponds to continuous operation. Also called duty factor. A duty cycle of 0.01 or 1% corresponds to a transmitter operating on average only 1% of the time.

End point meter: A term used to designate a Smart Meter that is installed on a home or business to record and transmit electric energy consumption but that does not provide access point features such as those provided by a cell relay.

EPRI, Electric Power Research Institute, Inc.: EPRI conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies. EPRI's members represent more than 90 percent of the electricity generated and delivered in the United States, and international participation extends to 40 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; and Lenox, Mass.

FCC, Federal Communications Commission: the Federal Communications Commission (FCC) is an independent agency of the US Federal Government and is directly responsible to Congress. The FCC was established by the Communications Act of 1934 and is charged with regulating interstate and international communications by radio, television, wire, satellite, and cable. The FCC also allocates bands of frequencies for non-government communications services (the NTIA allocates government frequencies). The guidelines for human exposure to radio frequency electromagnetic fields as set by the FCC are contained in the Office of Engineering and Technology (OET) Bulletin 65, Edition 97-01 (August 1997). Additional information is contained in OET Bulletin 65 Supplement A (radio and television broadcast stations), Supplement B (amateur radio stations), and Supplement C (mobile and portable devices).

Gain, antenna: a measure of the ability of an antenna to concentrate the power delivered to it from a transmitter into a directional beam of energy. A search light exhibits a large gain since it can concentrate light energy into a very narrow beam while not radiating very much light in other directions. It is common for cellular antennas to exhibit gains of 10 dB (dB is a form of expressing power density on a logarithmic scale) or more in the elevation plane, i.e., concentrate the power delivered to the antenna from the transmitter by a factor of 10 times (10 dB = 10x; 20 dB = 100x) in the direction of the main beam giving rise to an effective radiated power greater than the actual transmitter output power. In other directions, for example, behind the antenna, the antenna will greatly decrease the emitted signals. Gain is often referenced to an isotropic antenna, that is one that transmits uniformly in all directions (spherical wavefront).

HAN, Home Area Network: In the context of Smart Meters, a local area network for communication between a personal computer and various electrical appliances, equipment or systems to accomplish optimized electric energy consumption at the home. Small sensors with low power radio transmitters are attached to the various electrical appliances for communication in the HAN.

LAN, Local Area Network: The wireless mesh (see below) network that interconnects end-point meters, which transmit data to the cell relay (collection point) for transmittal to the local utility. (**Mesh Network**: A term describing a network, typically wireless, in which multiple nodes communicate among themselves and data can be relayed via various nodes to some access point. Mesh networks are self healing in that should a particular pathway become nonfunctional for some reason, alternative paths are automatically configured to carry the data. Mesh networks can expand beyond the normal range of any single node (Smart Meter) by relaying of data among the different meters.)

MPE, Maximum Permissible Exposure: The value of an exposure that should not be exceeded. These include the electromagnetic field, expressed in terms of power density, or as either the electric or magnetic field, and induced or contact currents.

Power Density: The power per unit area, denoted by the symbol *S*, of an RF electromagnetic field normal (perpendicular) to its direction of propagation, usually expressed in units of watts per square meter (W/m^2) or, for convenience, milliwatts per square centimeter (mw/cm^2) or microwatts per square centimeter ($\mu w/cm^2$). For plane waves (i.e., those beyond the immediate proximity of an antenna operating in the frequency range of a smart meter), power density, electric field strength, *E*, and magnetic field strength, *H*, are related by the impedance of free space, whose value is 120π (377) ohms. In particular, the power density, $S = E^2/120\pi = 120\pi H^2$ (where *E* and *H* are expressed in units of V/m and A/m, respectively).

Reflection: An electromagnetic wave (the "reflected" wave) caused by a change in the electrical properties of the environment in which an "incident" wave is propagating. This wave usually travels in a different direction than the incident wave. Generally, the larger and more abrupt the change in the electrical properties of the environment, the larger the reflected wave.

SAR, Specific Absorption Rate: The time derivative of the incremental energy absorbed by (dissipated in) an incremental mass contained in a volume of a given density. SAR is expressed in units of watts per kilogram, W/kg (or milliwatts per gram, mW/g). Guidelines for human exposure to radio frequency fields are based on SAR thresholds for potential adverse biological effects. When the human body is exposed to a radio frequency field, the SAR experienced is proportional to the squared value of the electric (or magnetic) field strength induced in the body.

WWAN, Wireless Wide Area Network: WWANs are provided by several cellular telephone companies for wireless connectivity directly to the Internet for data transmission. WWANs are different from so-called wireless "hot spots" such as found in cyber cafés and operate in either the 850 MHz cellular or 1900 MHz PCS bands.

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The Electric Power Research Institute, Inc. (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies. EPRI's members represent more than 90 percent of the electricity generated and delivered in the United States, and international participation extends to 40 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; and Lenox, Mass.

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APPENDIX E
Canadian Cancer Statistics 2012, Statistics Canada et al., May 2012

See attached.

Canadian Cancer Society | Société canadienne du cancer

Public Health Agency of Canada | Agence de la santé publique du Canada

Statistics Canada | Statistique Canada

CANADIAN **CANCER** STATISTICS 2012

Produced by: Canadian Cancer Society, Statistics Canada, Provincial/Territorial Cancer Registries, Public Health Agency of Canada

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Citation: Material appearing in this publication may be reproduced or copied without permission; however, the following citation must be used to indicate the source: Canadian Cancer Society's Steering Committee on Cancer Statistics. *Canadian Cancer Statistics 2012*. Toronto, ON: Canadian Cancer Society; 2012.

May 2012
ISSN 0835-2976

The development of this publication over the years has benefited considerably from the comments and suggestions of readers. The Steering Committee appreciates and welcomes such comments. To be notified about next year's publication or to offer ideas on how the publication can be improved, please complete the *Evaluation form* or e-mail stats@cancer.ca.

Cette publication est disponible en Français.

1. Incidence and mortality by cancer type

- An estimated 186,400 new cases of cancer (excluding 81,300 non-melanoma skin cancers) and 75,700 deaths from cancer will occur in Canada in 2012.
- Of the newly diagnosed cases, more than one-half will be lung, colorectal, prostate and breast cancers.
- Over one-quarter (27%) of all cancer deaths are attributed to lung cancer.
- Colorectal cancer has a significant impact on mortality for men and women combined, with an estimated 9,200 deaths (12% of all cancer deaths).

2. Incidence and mortality by geographic region

- Generally, both incidence and mortality rates are higher in Atlantic Canada and Quebec. They are lowest in British Columbia.
- In both men and women, lung cancer incidence rates are highest in Quebec and lowest in British Columbia.
- The highest colorectal cancer incidence rates among men and women occur in Newfoundland and Labrador. For women, high rates also occur in Prince Edward Island and Nova Scotia. The lowest rates for both sexes are in British Columbia.
- The prostate cancer mortality rate is highest in Saskatchewan.
- Little variation is seen in breast cancer incidence and mortality rates across Canada.

3. Incidence and mortality by age and sex

- Age is a key factor in cancer burden, with 69% of new cases and 62% of cancer deaths occurring among those 50 to 79 years of age.
- Incidence and mortality rates for males surpass those for females around age 55.
- Mortality is declining for males in most age groups and for females under 70.

4. Time trends in incidence and mortality

- Increases in the number of new cancer cases are due mainly to a growing and aging population.
- Between 1998 and 2007 for males and between 2002 and 2007 for females, thyroid cancer incidence rates rose an average of almost 7% per year. Liver cancer rates rose nearly 4% per year for males and more than 2% per year for females between 1998 and 2007. Kidney cancer rates rose nearly 3% per year for males since 2003.
- Between 1998 and 2007, incidence rates declined, on average, by at least 2% per year for stomach cancer in males and for larynx cancer in both sexes.

HIGHLIGHTS

- Between 2001 and 2007 for males and between 1998 and 2007 for females, overall mortality rates declined significantly. The rates declined, on average, by at least 2% per year for the following cancers:
    - prostate cancer (since 2001), lung cancer (since 1998), larynx (since 2001) and colorectal cancer (since 2003) in males
    - breast and cervical cancers (since 1998) in females
    - stomach cancer (since 1998) and non-Hodgkin lymphoma (since 2000) in both sexes
- Between 1998 and 2007, the liver cancer mortality rate increased more than 2% per year in males.

ABOUT THIS PUBLICATION

Canadian Cancer Statistics is part of an annual series that began in 1987 and has been developed by members of the Steering Committee on Cancer Statistics, which is supported by the Canadian Cancer Society. The Steering Committee is responsible for developing content, reviewing statistical information, interpreting data and writing the text. The Steering Committee includes individuals from the Canadian Cancer Society, the Public Health Agency of Canada (PHAC), Statistics Canada, the Canadian Council of Cancer Registries, US Centers for Disease Control and Prevention as well as researchers based in universities and provincial or territorial cancer agencies.

Purpose and intended audiences

The aim of this annual publication is to provide health professionals, researchers and policy-makers with detailed information regarding incidence, mortality and other measures of cancer burden for the most common types of cancer, presented by age, sex, time period and province or territory. These data can help stimulate new research as well as assist decision-making and priority-setting at the community, provincial/territorial and national levels. Educators, the media and members of the public who have an interest in cancer may also find value in this report.

Format

This publication has recently undergone an evaluation, and we extend our thanks to all our readers who participated in the evaluation process.

In 2013, we will launch a revised version of the publication based on the feedback we received through the evaluation and on current testing of a possible future format. To make this process possible, the 2012 edition has been shortened so that we may dedicate our resources to improving future editions. The 2012 publication therefore does not include the sections on five-year relative survival, prevalence, probability of developing or dying from cancer, cancer in children and youth, or a special topic. Similarly, we will not produce a printed (hard copy) edition for 2012. The publication will continue to be available at no charge through the Canadian Cancer Society's website at www.cancer.ca/statistics.

Data sources (see *Appendix II* for detailed information)

The Canadian Cancer Registry (CCR), National Cancer Incidence Reporting System (NCIRS), Canadian Vital Statistics – Death Database (CVS: D) and population censuses and forecasts are the main sources of data for this publication.

- Provincial and territorial cancer registries collect clinical and demographic data on newly diagnosed cancer cases for people residing in the province or territory. These data are reported annually to Statistics Canada and added to the CCR.
- Provincial and territorial registrars of vital statistics collect demographic and cause of death information for people residing in the province or territory at the time of death. These data are reported annually to Statistics Canada and added to the CVS: D.
- Cancers included in this publication are defined according to the groupings listed in Table A1, unless otherwise noted.
- The following types of tumours are not included:
    - non-melanoma skin cancers (basal and squamous): Most provincial and territorial cancer registries do not collect non-melanoma skin cancer incidence

data. Canada-wide non-melanoma skin cancer estimates are based on data from three provinces and are shown only in Tables 1.1 and 1.2.

- benign tumours and carcinomas in situ: The exception is in situ carcinomas of the bladder, which are included for provinces and territories other than Ontario.

Actual and estimated data (see *Appendixes I* and *II* for detailed information)

- The information provided in this publication includes both actual and estimated data.
- Actual cancer incidence data used in this publication cover the period of 1983 to 2009 (except for Quebec, for which data in the CCR were available to 2007 in time for this publication).
- Actual mortality data used in this publication cover the period of 1983 to 2007 for all provinces and territories. However, at press time, data for 2008 became available and can be obtained through Statistics Canada (see *Appendix I*).
- Incidence data for 2010 to 2012 and mortality data for 2008 to 2012 are estimated (see *Appendix II*).

Review and analysis

- The Chronic Disease Surveillance and Monitoring Division of the Centre for Chronic Disease Prevention and Control (CCDPC), part of the Public Health Agency of Canada (PHAC), conducted the data analysis. The analysts were supported by Ms. Brenda Branchard, who updated the tables and figures.
- Provincial and territorial cancer registries were consulted regarding the cancer incidence and mortality estimates for their own jurisdictions. The results of this consultation are noted in Tables A3 and A4.
- The French version of this publication was reviewed by Rabia Louchini of the Ministère de la Santé et Services sociaux and Jean-Marc Daigle of the Institut national de santé publique du Québec.

Special topic

For a complete list of previously published special topics, see *Appendix III*. Special topics (1988–2011) are available online at www.cancer.ca/statistics or can be obtained in hard copy by e-mailing stats@cancer.ca.

Production and distribution

The Canadian Cancer Society supports the production of this publication with charitable funds. Ms. Monika Dixon coordinated the production process and provided administrative support from the initial planning through to distribution.

How to access the contents of this publication

All figures from this publication and some additional tables and figures are available on the Canadian Cancer Society's website at www.cancer.ca/statistics. This material may be used without permission. Please refer to the front of this publication for proper citation information.

For additional resources related to cancer surveillance in Canada, please refer to the section entitled *For further information*.

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TABLE OF CONTENTS

1. INCIDENCE AND MORTALITY BY CANCER TYPE

In 2012, Canada will continue to see an increase in the number of individuals diagnosed with cancer. Every hour of every day, an average of 21 people will be diagnosed with some type of cancer, and nine people will die from cancer.

Incidence describes the number of new cases of cancer diagnosed in a year, while mortality indicates the number of deaths attributed to cancer. Together, these statistics (outlined in Tables 1.1 and 1.2) provide a fundamental understanding of the cancer burden.

An estimated 186,400 new cases of cancer and 75,700 cancer deaths are expected in Canada in 2012. More men than women will be diagnosed with a new cancer and will die from cancer (52% of all new cases and deaths in men vs. 48% in women). In addition, 81,300 new cases and 320 deaths from non-melanoma skin cancer (basal and squamous) are expected in 2012. Although non-melanoma skin cancer represents the most common cancer diagnosed among Canadians, it is reported separately because it accounts for very few deaths, and most cancer registries do not routinely collect information on these cases.

Prostate cancer remains the most common cancer diagnosed in men, with 26,500 cases expected in 2012. Breast cancer continues to be the most frequently diagnosed cancer in women, with 22,700 new cases expected. In men and women combined, lung cancer is the second most common cancer (14%), and colorectal cancer is the third most common (13%). In 2012, four cancers (breast, lung, colorectal and prostate) will account for 53% of all cancers diagnosed in Canada.

Lung cancer remains the leading cause of cancer death in both men (27%) and women (26%), as shown in Figures 1.1 and 1.2. While prostate cancer is the most common cancer diagnosed in men, it ranks third in terms of mortality for men, with approximately 4,000 deaths. Breast cancer, which represents 26% of all newly diagnosed cancer cases in women, ranks second in mortality for women at 14%. Colorectal cancer has a significant impact on mortality for men and women combined, with 9,200 deaths expected (12% of all cancer deaths).

Every day, over 500 Canadians are diagnosed with cancer and 200 die from this disease.

1. INCIDENCE AND MORTALITY BY CANCER TYPE

Table 1.1
Estimated New Cases and Age-Standardized Incidence Rates for Cancers by Sex, Canada, 2012

	New Cases			Cases per 100,000		
	Total*	M	F	Total*	M	F
All Cancers	**186,400**	**97,600**	**88,800**	**406**	**456**	**368**
Prostate	26,500	26,500	—	—	121	—
Lung	25,600	13,300	12,300	54	62	49
Colorectal†	23,300	13,000	10,300	49	60	40
Breast	22,900	200	22,700	50	1	96
Non-Hodgkin Lymphoma	7,800	4,300	3,500	17	20	14
Bladder‡	7,800	5,800	2,000	16	27	8
Melanoma	5,800	3,100	2,700	13	15	12
Kidney	5,600	3,500	2,200	12	16	9
Leukemia	5,600	3,200	2,400	13	16	10
Thyroid	5,600	1,250	4,400	14	6	22
Body of Uterus	5,300	—	5,300	—	—	22
Pancreas	4,600	2,200	2,300	10	10	9
Oral	4,000	2,700	1,350	9	12	5
Stomach	3,300	2,100	1,150	7	10	5
Brain	2,800	1,600	1,200	7	8	6
Ovary	2,600	—	2,600	—	—	11
Multiple Myeloma	2,400	1,350	1,050	5	6	4
Liver	2,000	1,500	470	4	7	2
Esophagus	1,850	1,400	450	4	6	2
Cervix	1,350	—	1,350	—	—	7
Larynx	1,050	860	180	2	4	1
Hodgkin Lymphoma	940	510	430	3	3	2
Testis	940	940	—	—	6	—
All Other Cancers	16,700	8,400	8,400	36	40	33
Non-Melanoma Skin	81,300	44,800	36,500	—	—	—

— Not applicable.
* Column totals may not sum to row totals due to rounding.
† Definition for this cancer has changed; see Table A2.
‡ Ontario does not currently report in situ bladder cases.
Note: "All Cancers" excludes the estimated new cases of non-melanoma skin cancer (basal and squamous).
Analysis by: Chronic Disease Surveillance and Monitoring Division, CCDPC, Public Health Agency of Canada.
Data source: Canadian Cancer Registry database at Statistics Canada.

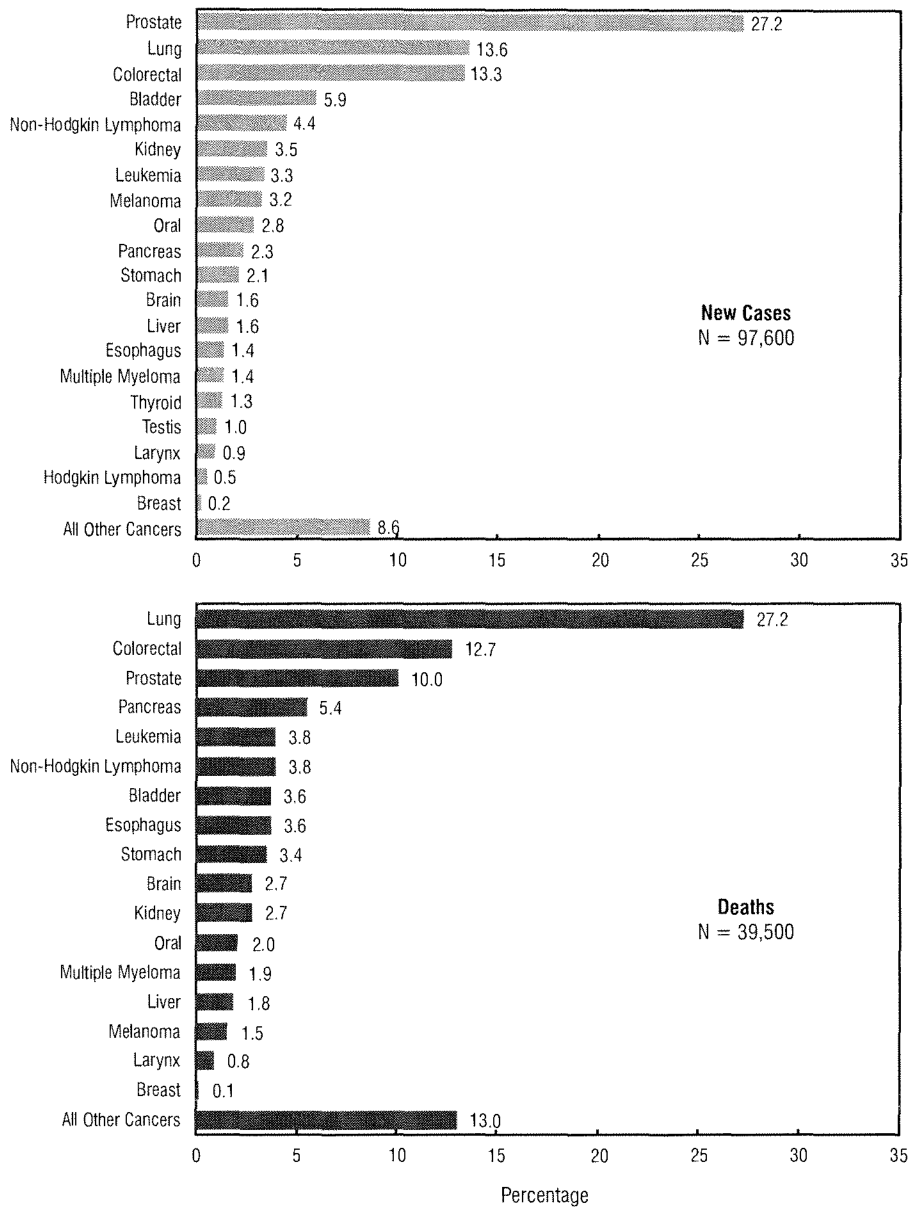
Table 1.2
Estimated Deaths and Age-Standardized Mortality Rates for Cancers by Sex, Canada, 2012

	Deaths			Deaths per 100,000		
	Total*	M	F	Total*	M	F
All Cancers	**75,700**	**39,500**	**36,200**	**156**	**184**	**135**
Lung	20,100	10,800	9,400	42	50	36
Colorectal†	9,200	5,000	4,200	19	23	15
Breast	5,200	55	5,100	11	<0.5	19
Pancreas	4,300	2,100	2,100	9	10	8
Prostate	4,000	4,000	—	—	19	—
Non-Hodgkin Lymphoma	2,800	1,500	1,300	6	7	5
Leukemia	2,600	1,500	1,100	5	7	4
Stomach	2,100	1,350	790	4	6	3
Bladder	2,100	1,450	670	4	7	2
Esophagus	1,850	1,450	410	4	7	1
Brain	1,850	1,050	760	4	5	3
Ovary	1,750	—	1,750	—	—	7
Kidney	1,700	1,050	650	4	5	2
Multiple Myeloma	1,400	750	620	3	4	2
Oral	1,150	780	380	2	4	1
Melanoma	970	600	370	2	3	1
Liver	900	690	210	2	3	1
Body of Uterus	900	—	900	—	—	3
Cervix	390	—	390	—	—	2
Larynx	390	300	80	1	1	<0.5
All Other Cancers	10,100	5,200	5,000	20	24	18

— Not applicable.
* Column totals may not sum to row totals due to rounding.
† Definition for this cancer has changed; see Table A2.
Note: "All Other Cancers" includes 320 deaths from non-melanoma skin cancer (basal and squamous).
Analysis by: Chronic Disease Surveillance and Monitoring Division, CCDPC, Public Health Agency of Canada.
Data source: Canadian Vital Statistics Death database at Statistics Canada.

1. INCIDENCE AND MORTALITY BY CANCER TYPE

Figure 1.1
Percentage Distribution of Estimated New Cases and Deaths for Selected Cancers, Males, Canada, 2012

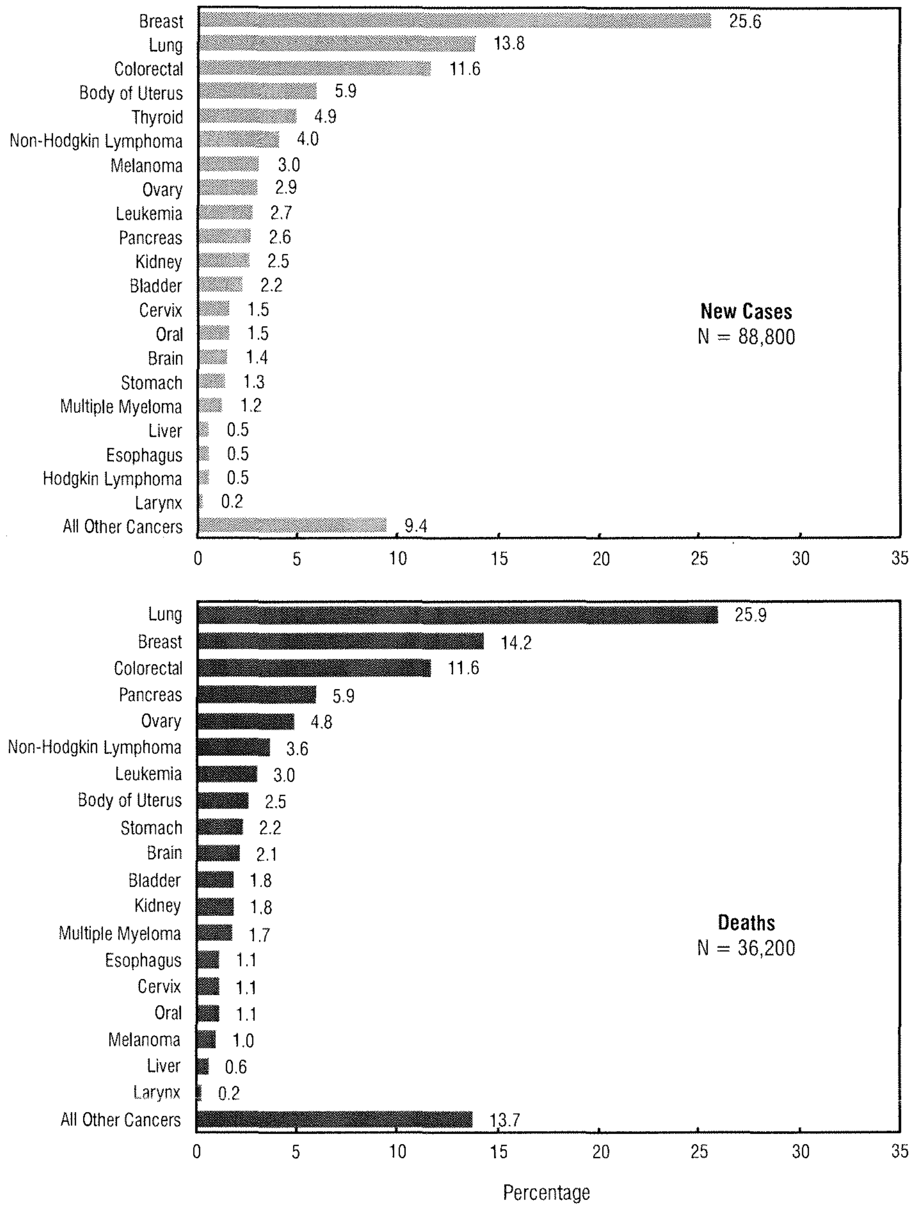


Note: New cases exclude an estimated 44,800 cases of non-melanoma skin cancer (basal and squamous). The number of deaths for "All Other Cancers" includes about 200 deaths with underlying cause "other malignant neoplasms" of skin.

Analysis by: Chronic Disease Surveillance and Monitoring Division, CCDPC, Public Health Agency of Canada.

Data sources: Canadian Cancer Registry and Canadian Vital Statistics Death databases at Statistics Canada.

Figure 1.2
Percentage Distribution of Estimated New Cases and Deaths for Selected Cancers, Females, Canada, 2012



Note: New cases exclude an estimated 36,500 cases of non-melanoma skin cancer (basal and squamous). Deaths for "All Other Cancers" includes about 110 deaths with underlying cause "other malignant neoplasms" of skin.

Analysis by: Chronic Disease Surveillance and Monitoring Division, CCDPC, Public Health Agency of Canada.

Data sources: Canadian Cancer Registry and Canadian Vital Statistics Death databases at Statistics Canada.

2. INCIDENCE AND MORTALITY BY GEOGRAPHIC REGION

Table 2.1 presents population projections and estimates of new cases and deaths for all cancers combined, by sex and province/territory for 2012. Tables 2.2 and 2.3 present estimates of the number of new cases and the age-standardized incidence rates for selected cancers by sex and province for 2012. The corresponding estimates of the number of cancer deaths and the age-standardized mortality rates are presented in Tables 2.4 and 2.5. *Appendix I* provides references to the most recent actual numbers and rates.

Since the risk of developing cancer increases with age, age standardization (also called age adjustment) is used to adjust for differences in the age profiles of different populations. This allows for better comparison among populations that are quite different. Thus, cancer rates among the provinces and territories are compared using age-standardized rates. The calculation of age-standardized rates, using the 1991 Canadian population as the standard, is described in the *Glossary* and in more detail in *Appendix II*.

Incidence

The estimated incidence rates for all cancers combined in males is highest in the Atlantic Provinces, Quebec and Ontario (Table 2.3). For females, highest rates occur in Quebec, Nova Scotia, Ontario and New Brunswick. Lowest rates for males and females are in British Columbia. It should be noted that rates in Newfoundland and Labrador are considered to be lower than actual figures due to missing data (see *Appendix II*).

Prostate cancer incidence rates continue to show large provincial differences. Variation in the use of prostate-specific antigen (PSA) testing is generally believed to account for the difference in provincial prostate cancer incidence rates.

In both men and women, lung cancer incidence rates are highest in Quebec and lowest in British Columbia.

The highest colorectal cancer incidence rates among men and women are in Newfoundland and Labrador. For women, high rates also occur in Prince Edward Island and Nova Scotia. The lowest rates for both sexes are in British Columbia.

Female breast cancer incidence rates appear to be fairly consistent across the country, with no discernible geographic pattern.

Mortality

For males, the estimated mortality rates for all cancers combined continue to be higher in Atlantic Canada, Quebec and Manitoba, with lower rates in Western Canada (Table 2.5). The pattern is similar for females, although overall differences across the country are smaller than for males.

Among males, the lung cancer mortality rate is highest in Quebec and Nova Scotia and lowest in British Columbia. Among females, the lung cancer mortality rate is highest in Quebec and lowest in Ontario.

Colorectal cancer mortality rates for both sexes are highest in Newfoundland and Labrador, almost twice that in British Columbia.

The mortality rate for prostate cancer continues to be highest in Saskatchewan.

Female breast cancer mortality rates appear to be fairly consistent across the country, with no discernible geographic pattern.

2. INCIDENCE AND MORTALITY BY GEOGRAPHIC REGION

Interpretation

The population-based provincial/territorial and national cancer registries serve as important resources that enable geographic comparisons of cancer trends. Interpretation of geographic differences should, however, be approached with caution since there may be a number of explanations for the variation. True differences in incidence or mortality rates among provinces and territories may be due to the variation in any one of several factors, including the following:

- the prevalence of cancer risk factors (e.g., higher historic smoking rates in Quebec and Atlantic Canada as the likely cause of higher rates of lung cancer)
- the early detection of cancer due to different rates of participation in formal screening programs (e.g., mammographic screening for breast cancer) or other screening procedures (e.g., PSA testing for prostate cancer)
- the availability of diagnostic services
- access to and quality of health services, most notably treatment
- cancer registry practices

However, even if the above situations apply, it cannot be assumed that they are the cause of the variation in cancer rates across Canada. Such a determination can be made only after conducting more detailed studies involving individual people. It is also important to note that for many cancers the interval between exposure to a risk factor and the occurrence of the disease is quite long, making it difficult to collect detailed information on the prevalence of past exposure to risk factors. Where true differences in cancer risk exist and can be causally attributed to modifiable risk factors, these findings can be used in planning cancer control programs that aim to reduce the burden of cancer.

When interpreting interprovincial variation, it should be kept in mind that the number of cases and the annual rates in a given province or territory may be unreliable and vary considerably from year to year when a cancer is rare or the population is small.

While the completeness of registration of new cancer cases is generally very good across the country, there are exceptions. Death certificate information has not been available for registry purposes in Newfoundland and Labrador until very recently and was not available for this publication. This has led to an underestimation of the actual data and therefore the projected number of newly diagnosed cases, mainly among those cancers with a poor prognosis, such as lung and pancreas (see *Appendix II*). The degree to which death certificate information is checked against hospital records also varies across provinces and territories, and this affects the accuracy of incidence data (e.g., year of diagnosis). In Quebec, because of the registry's dependence on hospital data, the numbers of prostate, melanoma and bladder cases are believed to be under-reported.[1]

- The method of projection selected by the provincial registries for 2012 estimates (Nordpred Power5 regression model or a five-year averaging) varies across provinces and cancer type (see *Methods* in *Appendix II*).
- The large interprovincial differences seen in bladder cancer incidence rates are likely due to differences in reporting of in situ cases, particularly in Ontario, where such cases were not collected until recently and were not available for this publication.

2. INCIDENCE AND MORTALITY BY GEOGRAPHIC REGION

There continues to be large variation in reported incidence and mortality rates across Canada.

Canada is one of the few nations in the world with a cancer registry system that allows cancer patterns to be monitored and compared across the entire population. Such comparisons can provide valuable information for research, knowledge exchange, planning and decision-making.

2. INCIDENCE AND MORTALITY BY GEOGRAPHIC REGION

Table 2.1

Estimated Population, New Cases and Deaths for All Cancers by Sex and Geographic Region, Canada, 2012

	Population (in thousands)			New Cases			Deaths		
	Total*	M	F	Total*	M	F	Total*	M	F
CANADA	**34,922**	**17,324**	**17,598**	**186,400**	**97,600**	**88,800**	**75,700**	**39,500**	**36,200**
British Columbia (BC)	4,671	2,317	2,354	23,300	12,500	10,800	9,800	5,200	4,600
Alberta (AB)	3,841	1,957	1,883	16,100	8,800	7,400	6,300	3,300	2,900
Saskatchewan (SK)	1,048	521	527	5,500	2,900	2,600	2,400	1,250	1,100
Manitoba (MB)	1,261	628	633	6,200	3,100	3,000	2,800	1,500	1,350
Ontario (ON)	13,598	6,706	6,892	72,300	37,300	35,000	27,900	14,500	13,400
Quebec (QC)†	8,025	3,980	4,045	47,600	24,500	23,100	20,000	10,200	9,700
New Brunswick (NB)	759	373	386	5,000	2,700	2,200	1,900	1,000	910
Nova Scotia (NS)	953	463	490	6,100	3,200	2,800	2,700	1,450	1,200
Prince Edward Island (PE)	145	71	74	890	510	370	370	190	190
Newfoundland and Labrador (NL)†	509	249	260	3,100	1,750	1,400	1,400	790	630
Yukon (YT)	34	17	17	130	65	65	75	45	35
Northwest Territories (NT)	44	23	22	140	75	65	60	30	30
Nunavut (NU)	33	17	16	70	35	35	50	25	20

* Column totals may not sum to row totals due to rounding.

† The actual data used to calculate the projected overall 2012 estimates were underestimated for some cancers for this province.

Note: The Canada and provincial/territorial totals exclude non-melanoma skin cancer (basal and squamous).

Analysis by: Chronic Disease Surveillance and Monitoring Division, CCDPC, Public Health Agency of Canada.

Data sources: Canadian Cancer Registry and Canadian Vital Statistics Death databases, and Census and Demographics Branch at Statistics Canada.[2]

Table 2.2
Estimated New Cases for Selected Cancers by Sex and Province, Canada, 2012

	New Cases										
	Canada*	BC	AB	SK	MB	ON	QC†	NB	NS	PE	NL†
Males											
All Cancers	**97,600**	**12,500**	**8,800**	**2,900**	**3,100**	**37,300**	**24,500**	**2,700**	**3,200**	**510**	**1,750**
Prostate	26,500	3,700	2,500	880	750	10,900	5,400	860	920	160	490
Lung	13,300	1,550	1,000	360	430	4,400	4,300	410	480	70	250
Colorectal‡	13,000	1,600	1,100	420	490	4,800	3,400	340	470	60	310
Bladder§	5,800	820	550	180	210	1,500	2,000	170	210	30	85
Non-Hodgkin Lymphoma	4,300	590	410	120	140	1,750	930	110	110	15	60
Kidney	3,500	320	330	100	130	1,300	920	120	150	20	65
Leukemia	3,200	430	320	110	120	1,300	720	70	75	15	30
Melanoma	3,100	490	270	80	85	1,500	350	90	140	20	45
Oral	2,700	340	220	60	110	1,100	630	65	90	15	45
Pancreas	2,200	300	200	65	70	810	610	60	70	10	25
Stomach	2,100	270	190	60	85	750	550	55	65	5	50
Brain	1,600	180	150	45	45	620	440	35	45	10	25
Liver	1,500	240	150	25	40	600	410	15	30	5	10
Esophagus	1,400	180	150	35	45	540	320	40	55	10	20
Multiple Myeloma	1,350	160	130	35	40	540	350	30	40	10	15
Thyroid	1,250	95	110	15	30	600	290	30	30	5	15
Females											
All Cancers	**88,800**	**10,800**	**7,400**	**2,600**	**3,000**	**35,000**	**23,100**	**2,200**	**2,800**	**370**	**1,400**
Breast	22,700	3,000	1,950	690	800	9,100	5,500	550	740	95	330
Lung	12,300	1,500	1,000	390	400	4,100	3,800	370	450	60	200
Colorectal‡	10,300	1,250	830	310	380	3,900	2,800	250	390	55	220
Body of Uterus	5,300	720	480	150	210	2,200	1,200	120	140	20	85
Thyroid	4,400	260	350	50	90	2,200	1,150	95	85	5	40
Non-Hodgkin Lymphoma	3,500	460	330	110	130	1,350	820	100	120	15	65
Melanoma	2,700	420	240	60	75	1,350	280	85	130	20	35
Ovary	2,600	300	190	75	95	1,150	650	65	65	10	30
Leukemia	2,400	300	230	80	85	1,050	540	45	60	10	20
Pancreas	2,300	280	210	75	75	780	720	70	75	10	20
Kidney	2,200	190	190	70	85	840	600	70	95	10	45
Bladder§	2,000	270	180	65	70	510	740	60	65	10	35
Cervix	1,350	160	160	45	50	550	280	30	45	10	25
Oral	1,350	170	100	35	50	570	320	25	35	5	15
Brain	1,200	130	100	35	35	470	340	35	40	5	20
Stomach	1,150	130	75	35	40	470	300	35	40	5	30
Multiple Myeloma	1,050	120	100	30	30	440	280	25	25	5	10

* Column totals may not sum to row totals due to rounding. Canada totals include provincial and territorial estimates. Territories are not listed separately due to small numbers.

† The actual data used to calculate the projected overall 2012 estimates were underestimated for some cancers for this province.

‡ Definition for this cancer has changed; see Table A2.

§ Interprovincial variation. Ontario does not currently report in situ bladder cases.

Note: New cases for "All Cancers" exclude non-melanoma skin cancer (basal and squamous).

Analysis by: Chronic Disease Surveillance and Monitoring Division, CCDPC, Public Health Agency of Canada.

Data source: Canadian Cancer Registry database at Statistics Canada.

Table 2.3

Estimated Age-Standardized Incidence Rates for Selected Cancers by Sex and Province, Canada, 2012

	Cases per 100,000										
	Canada*	BC	AB	SK	MB	ON	QC†	NB	NS	PE	NL†
Males											
All Cancers	**456**	**413**	**442**	**449**	**425**	**459**	**474**	**523**	**498**	**528**	**485**
Prostate	121	119	127	136	101	131	100	157	136	156	129
Lung	62	49	52	55	58	53	83	78	73	74	68
Colorectal‡	60	53	57	64	65	58	65	65	72	63	86
Bladder§	27	27	29	28	28	19	38	33	32	32	25
Non-Hodgkin Lymphoma	20	20	21	19	19	22	18	22	17	17	17
Kidney	16	11	16	16	18	16	18	22	22	21	17
Leukemia	16	15	16	17	16	17	15	14	13	16	9
Melanoma	15	17	13	13	12	19	7	18	22	21	13
Oral	12	11	10	9	14	13	12	12	13	15	13
Pancreas	10	10	10	10	10	10	12	12	10	12	7
Stomach	10	9	9	9	11	9	11	10	10	7	15
Brain	8	6	7	7	7	8	9	8	8	9	8
Liver	7	8	7	4	5	7	8	3	5	4	3
Thyroid	6	4	5	3	4	8	6	6	5	5	5
Esophagus	6	6	7	6	6	6	6	8	8	8	6
Multiple Myeloma	6	5	6	5	5	7	7	6	6	9	4
Females											
All Cancers	**368**	**324**	**335**	**354**	**354**	**382**	**383**	**379**	**383**	**337**	**359**
Breast	96	92	88	98	97	100	94	95	100	89	84
Lung	49	42	46	52	45	43	60	59	57	51	49
Colorectal‡	40	35	36	39	41	39	42	38	48	48	54
Body of Uterus	22	21	21	22	26	23	19	19	19	18	21
Thyroid	22	10	17	9	14	29	25	21	15	9	13
Non-Hodgkin Lymphoma	14	14	15	15	15	15	14	17	16	12	16
Melanoma	12	14	11	9	9	16	5	16	19	17	10
Ovary	11	9	8	11	11	13	11	11	8	9	7
Leukemia	10	9	11	11	10	12	9	9	9	9	6
Kidney	9	5	9	9	10	9	10	12	12	10	11
Pancreas	9	8	9	9	8	8	11	10	9	8	4
Bladder§	8	7	8	9	8	5	12	10	8	8	9
Cervix	7	6	8	9	8	7	6	7	9	9	8
Brain	6	5	5	6	5	6	7	6	6	5	5
Oral	5	5	5	5	6	6	5	4	4	6	4
Stomach	5	4	3	4	4	5	5	5	5	5	8
Multiple Myeloma	4	3	4	4	3	4	4	4	3	4	3

* Canada totals include provincial and territorial estimates. Territories are not listed separately due to small numbers.

† The actual data used to calculate the projected overall 2012 estimates were underestimated for some cancers for this province.

‡ Definition for this cancer has changed; see Table A2.

§ Interprovincial variation. Ontario does not currently report in situ bladder cases.

Note: Rates for "All Cancers" exclude non-melanoma skin cancer (basal and squamous). Rates are age-standardized to the 1991 Canadian population.

Analysis by: Chronic Disease Surveillance and Monitoring Division, CCDPC, Public Health Agency of Canada.

Data source: Canadian Cancer Registry database at Statistics Canada.

Table 2.4
Estimated Deaths for Selected Cancers by Sex and Province, Canada, 2012

	Deaths										
	Canada*	BC	AB	SK	MB	ON	QC	NB	NS	PE	NL
Males											
All Cancers	**39,500**	**5,200**	**3,300**	**1,250**	**1,500**	**14,500**	**10,200**	**1,000**	**1,450**	**190**	**790**
Lung	10,800	1,250	790	290	350	3,600	3,400	330	420	60	210
Colorectal†	5,000	630	390	150	180	1,900	1,300	110	200	25	130
Prostate	4,000	530	370	210	180	1,500	830	100	120	25	70
Pancreas	2,100	320	180	65	75	760	540	60	75	10	35
Non-Hodgkin Lymphoma	1,500	200	140	60	65	570	330	45	55	5	20
Leukemia	1,500	190	130	55	60	610	350	30	55	10	20
Bladder	1,450	220	120	45	55	540	340	35	50	5	25
Esophagus	1,450	230	140	40	55	560	290	40	55	5	25
Stomach	1,350	140	110	35	50	510	360	35	50	5	45
Brain	1,050	150	110	30	30	360	300	30	35	5	20
Kidney	1,050	120	85	35	50	380	270	35	45	5	25
Oral	780	100	75	20	35	300	180	20	25	5	15
Multiple Myeloma	750	100	65	25	25	300	180	20	25	5	10
Liver	690	120	55	5	20	290	170	10	15	—	5
Melanoma	600	90	55	15	15	270	110	10	25	5	10
Females											
All Cancers	**36,200**	**4,600**	**2,900**	**1,100**	**1,350**	**13,400**	**9,700**	**910**	**1,200**	**190**	**630**
Lung	9,400	1,150	720	260	340	3,200	2,800	280	330	45	170
Breast	5,100	630	390	160	210	2,000	1,350	110	160	30	90
Colorectal†	4,200	520	330	130	150	1,550	1,150	100	160	30	100
Pancreas	2,100	290	200	65	70	740	600	60	70	10	25
Ovary	1,750	240	150	60	80	690	380	45	60	5	30
Non-Hodgkin Lymphoma	1,300	170	100	45	60	490	340	30	50	10	15
Leukemia	1,100	140	100	40	45	420	260	30	40	5	10
Body of Uterus	900	100	75	25	25	410	200	20	25	5	10
Stomach	790	90	60	20	30	280	220	20	30	5	30
Brain	760	100	70	25	25	250	220	20	25	5	15
Bladder	670	80	45	15	15	290	180	10	20	5	10
Kidney	650	70	55	25	25	250	160	20	25	5	15
Multiple Myeloma	620	80	60	20	30	240	150	15	25	—	10
Esophagus	410	80	35	15	20	170	80	10	15	—	5
Cervix	390	45	50	10	20	160	65	10	20	—	10
Oral	380	55	35	10	15	150	95	5	10	—	5
Melanoma	370	60	35	10	10	160	65	10	15	—	5

— Fewer than three deaths.

* Column totals may not sum to row totals due to rounding. Canada totals include provincial and territorial estimates. Territories are not listed separately due to small numbers.

† Definition for this cancer has changed; see Table A2.

Analysis by: Chronic Disease Surveillance and Monitoring Division, CCDPC, Public Health Agency of Canada.

Data source: Canadian Vital Statistics Death database at Statistics Canada.

Table 2.5

Estimated Age-Standardized Mortality Rates for Selected Cancers by Sex and Province, Canada, 2012

	Deaths per 100,000										
	Canada*	BC	AB	SK	MB	ON	QC	NB	NS	PE	NL
Males											
All Cancers	**184**	**167**	**174**	**187**	**197**	**177**	**198**	**193**	**223**	**195**	**230**
Lung	50	41	42	44	47	44	65	64	65	64	60
Colorectal†	23	20	20	22	24	23	25	22	31	24	39
Prostate	19	17	20	29	24	18	16	19	19	26	22
Pancreas	10	10	9	10	10	9	10	12	12	10	9
Leukemia	7	6	7	8	8	8	7	7	9	10	6
Non-Hodgkin Lymphoma	7	7	7	9	9	7	7	9	8	7	5
Bladder	7	7	6	7	7	6	7	7	8	7	8
Esophagus	7	7	7	6	7	7	5	7	8	6	6
Stomach	6	4	6	5	7	6	7	7	8	5	12
Brain	5	5	5	5	4	5	6	6	6	5	5
Kidney	5	4	4	5	6	5	5	7	7	6	7
Multiple Myeloma	4	3	3	3	4	4	3	4	4	5	3
Oral	4	3	3	3	4	4	3	4	4	3	4
Melanoma	3	3	3	3	2	3	2	2	4	3	4
Liver	3	4	3	1	3	3	3	1	2	—	2
Females											
All Cancers	**135**	**125**	**127**	**137**	**144**	**131**	**146**	**138**	**145**	**152**	**149**
Lung	36	33	33	34	37	32	45	43	41	40	40
Breast	19	17	17	21	22	20	20	17	20	24	22
Colorectal†	15	13	14	15	14	14	16	14	18	22	24
Pancreas	8	8	9	7	7	7	9	9	9	6	6
Ovary	7	7	7	8	9	7	6	8	7	5	7
Non-Hodgkin Lymphoma	5	4	4	6	6	5	5	5	6	6	4
Leukemia	4	4	4	5	5	4	4	4	5	5	3
Body of Uterus	3	3	3	3	3	4	3	3	3	2	3
Brain	3	3	3	3	3	3	4	3	4	5	4
Stomach	3	2	3	2	3	3	3	3	3	4	7
Kidney	2	2	2	3	3	2	2	3	3	5	3
Multiple Myeloma	2	2	3	2	3	2	2	2	3	—	2
Bladder	2	2	2	2	2	3	2	1	2	2	2
Cervix	2	1	2	2	2	2	1	2	3	—	2
Esophagus	1	2	1	2	2	2	1	2	2	—	1
Melanoma	1	2	2	1	1	2	1	1	2	—	1
Oral	1	1	1	1	2	1	1	1	1	—	1

— Fewer than three deaths.

* Canada totals include provincial and territorial estimates. Territories are not listed separately due to small numbers.

† Definition for this cancer has changed; see Table A2.

Note: Rates are age-standardized to the 1991 Canadian population.

Analysis by: Chronic Disease Surveillance and Monitoring Division, CCDPC, Public Health Agency of Canada.

Data source: Canadian Vital Statistics Death database at Statistics Canada.

3. INCIDENCE AND MORTALITY BY AGE AND SEX

Trends by age

Canadians aged 50–79 years will represent almost 70% of all new cancer cases and 62% of cancer deaths in 2012. The highest proportion of new cancer cases (28%) will occur in the 60–69 age group, while the highest proportion of deaths from cancer (34%) is expected in the 80 and older age group (Table 3.1). Cancer continues to affect Canadians of all ages:

- The youngest Canadians, between the ages of 0 and 49, will account for an estimated 12% (21,700 cases) of all new cancer diagnoses and 5% (3,680 deaths) of all cancer deaths in 2012.
- In 2012, there will be about 51,200 new cancer cases in Canadians in the 60–69 age range, which is the highest burden of new cancer diagnoses (28%), and approximately 16,900 cancer deaths (22%).
- Canadians aged 80 years and older will experience the highest proportion of cancer deaths at 34% (25,400 deaths). They will account for 19% of all new cancer diagnoses (35,400 cases) in 2012.

The burden of cancer in older Canadians remains significant. Table 3.1 indicates that Canada's population is estimated at 35 million. According to Statistics Canada, the number of people aged 65 or older is now close to 5 million, or 14% of the total population.[3] This proportion is expected to continue to grow as the baby boomers begin to reach age 65.[2]

Figure 3.1 displays age-specific rates of cancer incidence and mortality by five-year age groups. Cancer incidence and mortality rates increase with age for both sexes. The incidence rate for males surpasses that for females around age 55, and a similar pattern is observed for mortality.

Age and sex distributions for the most common cancers among Canadians in 2012 are presented in Table 3.2, which shows the following:

- Four major cancers (breast, lung, colorectal and prostate) represent the majority (53%) of newly diagnosed cancers in both men and women. Prostate cancer is the most common cancer in men (27%), while breast cancer (26%) is the most common cancer in women.
- Half of all newly diagnosed lung and colorectal cancer cases will occur among people aged 70 years or older.
- Breast cancer occurs primarily in females 50–69 years of age. Thirty percent of breast cancer cases will be diagnosed among women over the age of 69, while 19% will occur in those under age 50. It is notable that although over half of the new cases of breast cancer occur between ages 50 and 69, more deaths from breast cancer will occur in females 80 years and older than in any other age group, reflecting the benefits of screening and treatment in prolonging life in middle-aged women.
- Prostate cancer will be diagnosed most frequently in males aged 60–69 years, but more prostate cancer deaths will occur in males 80 years and older. This pattern likely reflects the effect of screening men for prostate cancer in their 60s and the long natural history of the disease.
- Unlike other major cancers, for which the number of deaths increases with age, deaths for lung cancer peak at age 70–79 for both males and females.

Trends by sex

Trends in age-standardized incidence and mortality rates for all cancers combined for males and females are shown in Figure 3.2.

Cancer is more common in males than females among those 19 years and younger and 60 years and older, but this trend reverses between ages 20 and 50, with a higher incidence in females. In the 50–59 age group, male and female rates are very similar. Sex-specific cancers (breast and cervical cancer in particular) as well as melanoma and thyroid cancer account for the higher cancer incidence in younger females.

Breast cancer is the most common cancer in females over the age of 20. Deaths from breast cancer are more frequent than deaths from other common cancers only in women 30–39 years of age.

The overall cancer incidence rate in males over age 69 has been dropping, primarily due to a declining rate of lung cancer from decreased tobacco use.[4] The overall incidence rate in females has only recently begun to level off. Lung cancer remains the most common cause of cancer death in both sexes.

Since 1989, the mortality rate for all cancers combined has been dropping for males up to age 79 and for females up to age 69. But for females, this rate begins to increase from age 70. Mortality rates for males and females in the youngest age groups (0–19, 20–29) are very similar in recent years and show limited variation up to age 59, after which male mortality rates are notably higher than those for females.

Table 3.1
Estimated New Cases and Deaths for All Cancers by Age Group and Sex, Canada, 2012

Age Group	Population (in thousands)			New Cases			Deaths		
	Total*	M	F	Total*	M	F	Total*	M	F
All Ages	**34,922**	**17,324**	**17,598**	**186,400**	**97,600**	**88,800**	**75,700**	**39,500**	**36,200**
0–19	7,878	4,043	3,836	1,400	760	650	160	85	75
20–29	4,858	2,476	2,383	2,100	970	1,100	190	99	85
30–39	4,721	2,364	2,357	4,900	1,700	3,200	630	260	370
40–49	5,087	2,563	2,524	13,300	4,700	8,600	2,700	1,150	1,500
50–59	5,139	2,555	2,584	33,300	16,300	17,000	9,000	4,500	4,500
60–69	3,707	1,808	1,899	51,200	29,600	21,600	16,900	9,300	7,600
70–79	2,113	981	1,132	44,800	25,800	18,900	20,700	11,600	9,100
80+	1,418	534	883	35,400	17,700	17,700	25,400	12,500	12,900

* Column totals may not sum to row totals due to rounding. Canada totals include provincial and territorial estimates.

Note: New cases exclude non-melanoma skin cancer (basal and squamous).

Analysis by: Chronic Disease Surveillance and Monitoring Division, CCDPC, Public Health Agency of Canada.

Data sources: Canadian Cancer Registry and Canadian Vital Statistics Death databases, and Census and Demographics Branch at Statistics Canada.[2]

Table 3.2

Estimated New Cases and Deaths for the Most Common Cancers by Age Group and Sex, Canada, 2012

Age Group	Lung			Colorectal			Prostate	Breast
	Total	M	F	Total	M	F	M	F
New Cases								
All Ages	**25,600**	**13,300**	**12,300**	**23,300**	**13,000**	**10,300**	**26,500**	**22,700**
0–19	5	5	—	10	5	5	—	5
20–29	20	10	10	70	35	35	—	110
30–39	95	40	55	260	140	120	5	850
40–49	810	340	460	1,100	580	520	460	3,300
50–59	3,800	1,800	2,000	3,500	2,000	1,450	4,600	5,600
60–69	7,400	3,900	3,500	6,100	3,800	2,300	10,500	6,000
70–79	7,900	4,300	3,600	6,500	3,800	2,700	7,100	4,000
80+	5,500	2,900	2,700	5,800	2,600	3,200	3,800	2,800
Deaths								
All Ages	**20,100**	**10,800**	**9,400**	**9,200**	**5,000**	**4,200**	**4,000**	**5,100**
0–19	—	—	—	—	—	—	—	—
20–29	5	5	5	10	10	5	—	5
30–39	45	15	30	55	30	25	—	90
40–49	530	240	280	260	140	120	10	410
50–59	2,600	1,300	1,300	940	550	390	120	920
60–69	5,400	2,900	2,400	1,900	1,150	710	500	1,100
70–79	6,300	3,500	2,800	2,500	1,500	970	1,100	1,000
80+	5,300	2,800	2,500	3,600	1,650	2,000	2,200	1,600

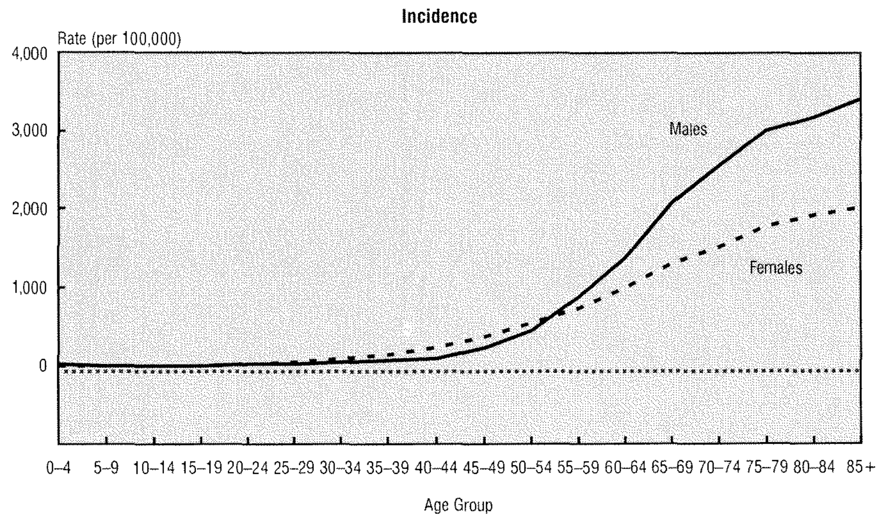
— Fewer than three cases or deaths.

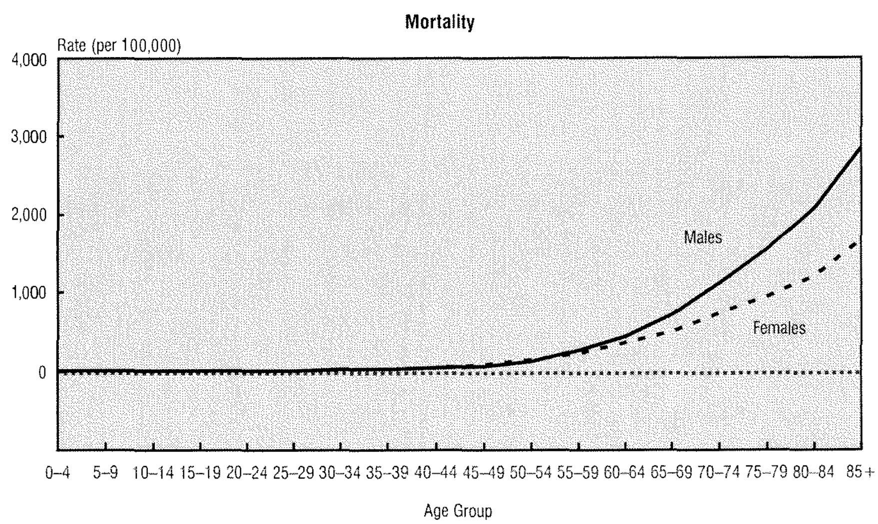
Analysis by: Chronic Disease Surveillance and Monitoring Division, CCDPC, Public Health Agency of Canada.

Data sources: Canadian Cancer Registry and Canadian Vital Statistics Death databases at Statistics Canada.

Cancer risk increases with age, and the number of new cancer diagnoses will continue to increase as the baby boomer population begins to reach age 65. Notable declines in mortality rates for all cancers combined have occurred in both sexes and in most age groups.

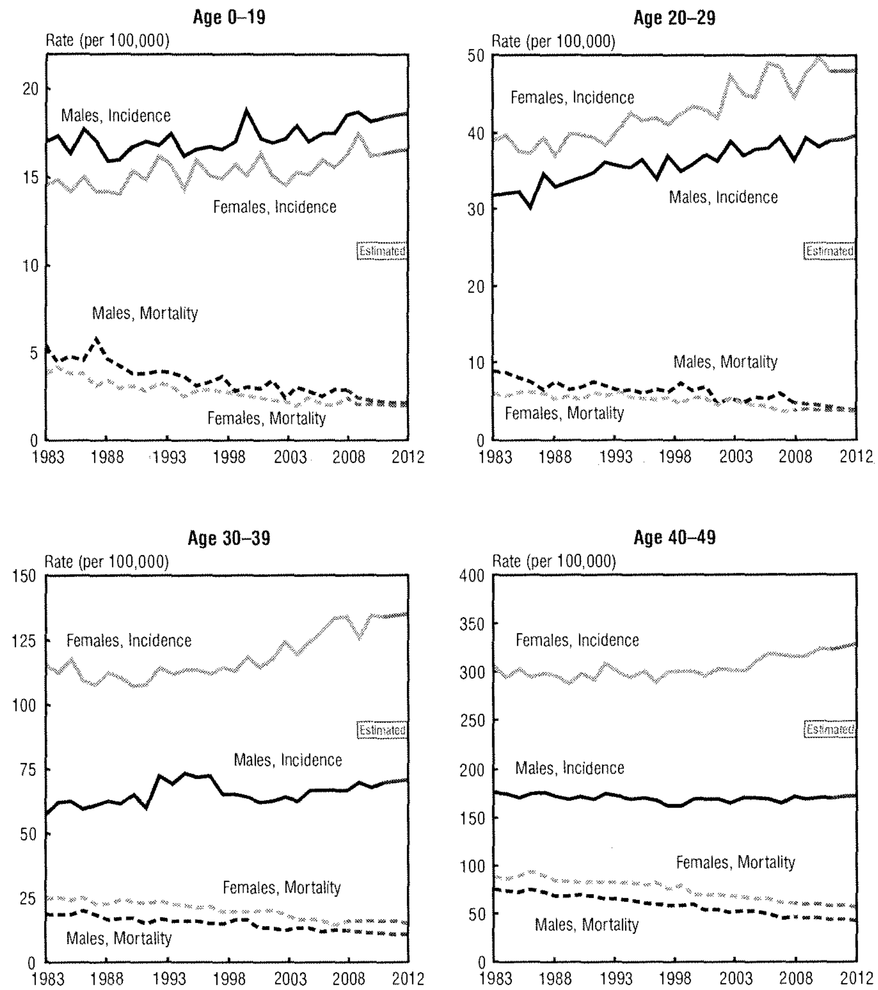
Figure 3.1
Age-Specific Incidence and Mortality Rates for All Cancers by Sex, Canada, 2007





Note: Incidence rates exclude non-melanoma skin cancer (basal and squamous).
Analysis by: Chronic Disease Surveillance and Monitoring Division, CCDPC, Public Health Agency of Canada.
Data sources: Canadian Cancer Registry and Canadian Vital Statistics Death databases at Statistics Canada.

Figure 3.2
Age-Standardized Incidence and Mortality Rates for All Cancers by Age Group, Canada, 1983–2012



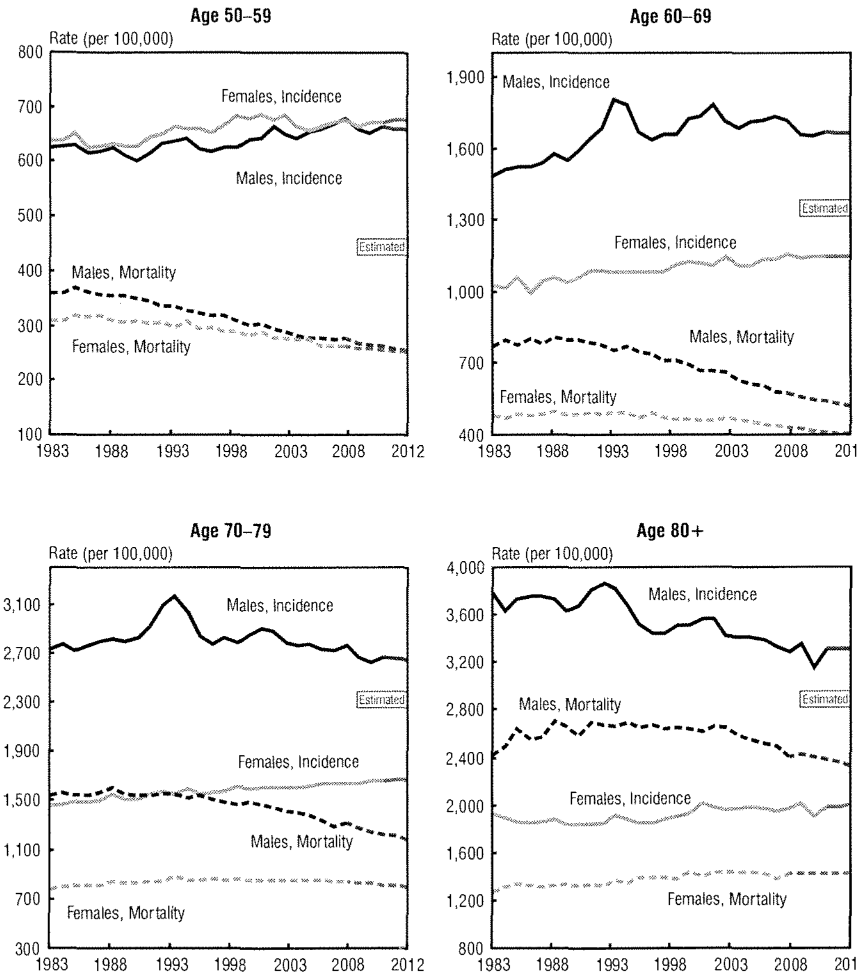
Note: The range of the rate scales differs widely among the four age groups. Incidence rates exclude non-melanoma skin cancer (basal and squamous). Actual incidence data were available to 2009 for all provinces except Quebec (2007), and actual mortality data were available to 2007.

Analysis by: Chronic Disease Surveillance and Monitoring Division, CCDPC, Public Health Agency of Canada.

Data sources: Canadian Cancer Registry, National Cancer Incidence Reporting System and Canadian Vital Statistics Death databases at Statistics Canada.

Figure 3.2 *(continued)*

Age-Standardized Incidence and Mortality Rates for All Cancers by Age Group, Canada, 1983–2012



Note: The range of the rate scales differs widely among the four age groups. Incidence rates exclude non-melanoma skin cancer (basal and squamous). Actual incidence data were available to 2009 for all provinces except Quebec (2007), and actual mortality data were available to 2007.

Analysis by: Chronic Disease Surveillance and Monitoring Division, CCDPC, Public Health Agency of Canada.

Data sources: Canadian Cancer Registry, National Cancer Incidence Reporting System and Canadian Vital Statistics Death databases at Statistics Canada.

4. TIME TRENDS IN INCIDENCE AND MORTALITY

The numbers of new cases and deaths are important measures of cancer burden on the Canadian population and healthcare system. Incidence trends generally signal changes in population structure or the prevalence of risk factors, or they may indicate changes in screening or diagnostic practices. Incidence trends are one statistic that can be directly used to indicate how many new people may seek diagnosis, primary treatment, potential further treatment or palliative care in the future. Trends in mortality rates reflect changes in disease incidence, survival or both. A decreasing trend in mortality indicates progress in cancer control.

Trends in incidence and mortality are often assessed by comparing annual age-standardized rates. Age standardization results in more meaningful comparisons of changes in cancer risk or diagnostic practices over place and time because it adjusts for variation in the age distribution and growth of populations. Unless otherwise specified, this section reports average annual percent changes over 10 years.

Trends for all cancers combined

Figure 4.1 presents the number of new cases for all cancers combined, together with the corresponding age-standardized incidence rates for 1983 to 2009, with estimates to the year 2012. Figure 4.2 presents the number of deaths and age-standardized mortality rates for 1983 to 2007, with estimates to 2012. Despite the relative stability in age-standardized rates, the number of new cancer cases continues to rise steadily as the Canadian population grows and ages. In 2012, the number of new cancer cases is estimated to be 186,400, and the number of cancer deaths is estimated to be 75,700.

Among males, the overall cancer incidence rate rose in the early 1990s and then declined sharply (Figure 4.1). This reflects a similar trend in the incidence of prostate cancer, the leading type of cancer in men, during the same period. Since 1993, there has been a decline in the overall cancer incidence rate in males. In contrast, the cancer mortality rate in males, after reaching a peak in 1988, has been declining steadily because of decreases in mortality rates for prostate, lung, colorectal and other cancers (Figure 4.2).

Among females, the overall cancer incidence rate has been increasing slowly since the early 1990s (Figure 4.1), while the mortality rate has been declining slowly since the mid-1990s (Figure 4.2).

Figures 4.3 and 4.4 show the relative contributions to the changes in the total number of new cases and deaths that can be attributed to changes in cancer risk or diagnostic practices, population size and aging of the population. The major contributors to the rising number of new cancer cases are population growth and the aging of the population:

- The lowest solid line represents the total number of new cancer cases (or deaths) that would have occurred each year if the population size and age structure had remained the same as they were in 1983. This line reflects the impact of changes in cancer risk or diagnostic practices.
- The middle line represents the number of new cases (or deaths) that would have occurred if the age structure of the population had remained the same as it was in 1983. This line reflects the impact of changes in cancer risk and population growth.

- The top line represents the number of new cases (or deaths) that actually occurred and thus reflects the combined impact of changes in risk, population growth and aging of the population.

These figures indicate that the increase in the number of cancer cases and deaths that has occurred over the last 30 years is primarily the result of an aging population and, to a lesser extent, an increase in population size. As long as current demographic trends continue, there will be a corresponding annual increase in the number of new cases and deaths from cancer.

Trends for selected cancers

Trends in annual rates for selected cancers over the past 30 years are presented in Figures 4.5 to 4.8, with the data provided in Tables 4.1 to 4.4.

The annual percent change (APC) in cancer-specific incidence rates and mortality rates (1998–2007) is listed in Table 4.5. The overall incidence rate increased significantly for females between 1998 and 2007 (0.3% per year). The overall mortality rate declined significantly between 1998 and 2007 for females (-0.8% per year) and between 2001 and 2007 for males (-2.0% per year). It should be noted that these short-term trends do not necessarily reflect the longer term or earlier trends evident in Tables 4.1 to 4.4 and Figures 4.5 to 4.8. The descriptions that follow should be interpreted with this in mind.

For the cancers listed in Table 4.5, several statistically significant increases or decreases of 2% or more per year are observed:

- increases in incidence rate
  - liver cancer in both males (3.6%) and females (2.4%)
  - thyroid cancer in both males (6.8%) and females (6.9%)
  - kidney cancer in males (2.6%)
- decreases in incidence rate
  - larynx cancer in both males (-3.8%) and females (-3.4%)
  - stomach cancer in males (-2.0%)
- increases in mortality rate
  - liver cancer in males (2.2%)
- decreases in mortality rate
  - in males, deaths from all cancers combined (-2.0%), lung cancer (-2.3%), colorectal cancer (-2.6%), non-Hodgkin lymphoma (-2.6%), stomach cancer (-3.0%), prostate cancer (-4.3%) and larynx cancer (-6.2%)
  - in females, breast cancer (-2.2%), non-Hodgkin lymphoma (-2.7%), stomach cancer (-2.9%) and cervical cancer (-2.9%)

Discussion of leading and selected cancers with significantly changing trends

Breast cancer

Breast cancer incidence rates rose from 1983 through the early 1990s, in part because of increased mammography screening. Reasons for the pattern of modest declines and increases observed since then are unclear but likely relate to factors such as the continuing rise in mammography screening throughout the 1990s, along with the fluctuating patterns of hormone replacement therapy use among post-menopausal women during this time.

Female breast cancer mortality rates have been declining since the mid-1980s. The mortality rate has fallen by almost 40% since peaking in 1986, from 32.0 to 19.5 per 100,000 (Table 4.4). The downward trend has accelerated to 2.2% per year in recent years. This is likely the result of a combination of increased mammography screening and the use of more effective adjuvant therapies following breast cancer surgery. The breast cancer mortality rate is the lowest it has been since 1950. Similar declines have also occurred in the United States, United Kingdom and Australia.[5]

Cervical cancer

Incidence and mortality rates have continued declining for cervical cancer, by 1.4% and 2.9% per year, respectively, since 1998 (Table 4.5). This is largely due to widespread, regular screening with the Papanicolaou (Pap) test, which detects pre-malignant and malignant lesions early so that they can be treated.

The immunization of school-aged children with the vaccine for human papillomavirus (HPV) is anticipated to further reduce incidence and mortality over the longer term but will not eliminate cervical cancer. The continuation of Pap screening is still a necessary and important part of preventive healthcare.

Colorectal cancer

Colorectal cancer incidence rates between 1983 and 2000 were relatively stable in men and declined slightly in females. In both sexes, the incidence rate has declined significantly (0.8% per year) since 2000 (Table 4.5).

Mortality rates continue to decline in both sexes—by 2.6% per year in males since 2003 and 1.8% per year in females since 1998 (Table 4.5). This is likely the result of improvements in treatment, such as chemotherapy.

Screening for colorectal cancer can reduce both incidence (by identifying and removing precancerous polyps) and mortality. Screening has already been occurring in several provinces, which may partly account for the decline in mortality, though screening rates are low. All provinces have announced or have started implementing organized screening programs.

Kidney cancer

Figure 4.5 indicates that incidence rates of kidney cancer in Canadian men increased during the 1980s, stabilized between 1988 and 1998 and rose again thereafter. During the period from 2003 to 2007, kidney cancer incidence rates among males increased significantly by 2.6% per year (Table 4.5). Between 1998 and 2007, the incidence increased significantly among women by 1.9% per year.

The rising incidence of kidney cancer is consistent with trends observed in several developed countries.[6–8] The upward trend in kidney cancer in Canada may be partly explained by the increasing use of high-tech diagnostic imaging, increase in cigarette smoking (prior to its decline) and increased obesity over the past 25 years.[9]

Mortality rates for kidney cancer have decreased slightly by 0.8% per year for men and by 0.9% for women during the period of 1998 to 2007.

Larynx cancer

Incidence rates of larynx cancer (1998–2007) have decreased for both males (-3.8% per year) and females (-3.4% per year), while mortality rates for males showed a significant decline of 6.2% since 2001 (Table 4.5).

Cancer of the larynx is most strongly associated with smoking[10] and alcohol use.[11] Incidence and mortality rates reflect the decreasing trends in these risk factors.[4,12]

Liver cancer

In males, the incidence rate of liver cancer increased by 3.6% per year, and the mortality rate increased by 2.2% per year (Table 4.5) between 1998 and 2007. Both increases were statistically significant. In females, the incidence rate increased by 2.4% per year (Table 4.5).

Some of the observed increase may be explained by the rising immigration of people from world regions where risk factors for liver cancer, such as hepatitis B virus infection and exposure to aflatoxins, are prevalent.[13]

Other factors include increased rates of hepatitis C infection and alcohol abuse, which both increase the risk of liver cirrhosis and therefore liver cancer.[14]

Lung cancer

In males, incidence and mortality rates for lung cancer began to level off in the mid-1980s and have been declining ever since (Tables 4.1 and 4.2). Rates have dropped significantly, by 1.8% per year for incidence and by 2.3% per year for mortality (Table 4.5).

In females, the incidence rate has been increasing since 1983, with a significant upward trend of 1.1% per year between 1998 and 2007. The mortality rate for females shows a slight (0.7%) but statistically significant increase.

Despite the diverging trends, males are projected to continue to have higher incidence and mortality rates than females in 2012 (incidence: 62 vs. 49 per 100,000; mortality: 50 vs. 36 per 100,000).

The differences between male and female lung cancer trends reflect past differences in the patterns of tobacco use. In males, the drop in tobacco consumption began in the mid-1960s, preceding the decline in lung cancer rates by approximately 20 years. In females, tobacco consumption began to decline in the mid-1980s.

Non-Hodgkin lymphoma

Incidence rates for non-Hodgkin lymphoma have increased modestly in males (0.8%) and stabilized in females since 1998.

The observed incidence patterns likely result from a combination of improved detection and classification of this complex set of diseases, as well as changes in risk factors. The clearest risk factor for non-Hodgkin lymphoma is immunosuppression, which can result from immune disorders, immunosuppressive therapy or infection with human immunodeficiency virus (HIV). Other factors that increase risk are poorly understood but may include occupational exposure to pesticides and organochlorines, such as phenoxy herbicides and dioxins.

Mortality rates have declined for males (-2.6% per year) and females (-2.7% per year) since 2000 (Table 4.5).

Declines in mortality may reflect recent improvements in treatment, such as immunotherapy (e.g., rituximab). As well, the introduction of anti-retroviral treatment for HIV infection in the second half of the 1990s has resulted in a decline in the proportion of particularly aggressive forms of non-Hodgkin lymphoma attributable to HIV infection.

Oral cancer

This group of cancers includes cancers of the lip, tongue, salivary gland, mouth, nasopharynx and oropharynx. Slight declines have occurred in the incidence rate (-1.0% per year) and mortality rate (-1.8% per year) for males since 1998 (Table 4.5).

A decline in smoking, which is a major risk factor for most oral cancers in Canada, likely accounts for the downward trends in oral cancer incidence and mortality.

Decreases in heavy alcohol use may also be relevant. The contributions of other risk factors, including HPV infection, diet and sun exposure (linked to lip cancer), are unclear.

Prostate cancer

The two peaks in the incidence of prostate cancer that occurred in 1993 and 2001, each followed by a decline (Figure 4.5), are compatible with two waves of intensified screening activity with the PSA test for early prostate cancer detection. The first peak follows the introduction of PSA as a screening test. The second may be explained by the publicity around the 2001 prostate cancer diagnosis of the then federal minister of health, as a result of serial PSA tests. The first decline was followed by resumption of the earlier, more gradual increase, whereas the second decline has been followed by a stabilizing of the trend.

Although the long-term, ongoing increase in incidence may be due to gradual changes in early detection, changes in the prevalence of risk factors might also be partly responsible. However, little is known about what these factors are for prostate cancer.

In contrast to incidence, mortality rates for prostate cancer rose much more slowly from 1980 and started to decline in the mid-1990s. Mortality declined significantly by 4.3% per year between 2001 and 2007 (Table 4.5), which likely reflects improved treatment over time.

In 2009, two large randomized trials of PSA testing and its possible relation to reducing mortality in men over age 55 produced conflicting results.[15,16] Ongoing follow-up of men in these studies may help clarify the role of PSA testing in reducing deaths from prostate cancer.

Stomach cancer

Incidence rates of stomach cancer are declining in both sexes by 2.0% per year in males and 1.6% per year in females between 1998 and 2007 (Table 4.5). This decline may be due to changes in diet, decreases in smoking and heavy alcohol use (which can increase the impact of smoking on stomach cancer risk) and increased recognition and treatment of infection with the bacterium *Helicobacter pylori*, which is associated with stomach cancer.

Mortality rates from this cancer have also declined significantly, by 3.0% per year in males and by 2.9% per year in females (Table 4.5).

Thyroid cancer

The incidence rate of thyroid cancer is the most rapidly increasing of all cancers (6.8% per year in males since 1998 and 6.9% per year in females since 2002; Table 4.5). Similar increases have been noted in Europe and the United States.

There are two proposed explanations for the rising rates of thyroid cancer. More frequent use of diagnostic testing (ultrasound, computed tomography [CT] and magnetic resonance imaging) may be detecting earlier stage, asymptomatic thyroid cancers more frequently than was possible in the past.[17] Alternatively, a true increase in the risk over time of this cancer could be possible as at least one US research study has found increases in thyroid tumours of all sizes and stages.[18]

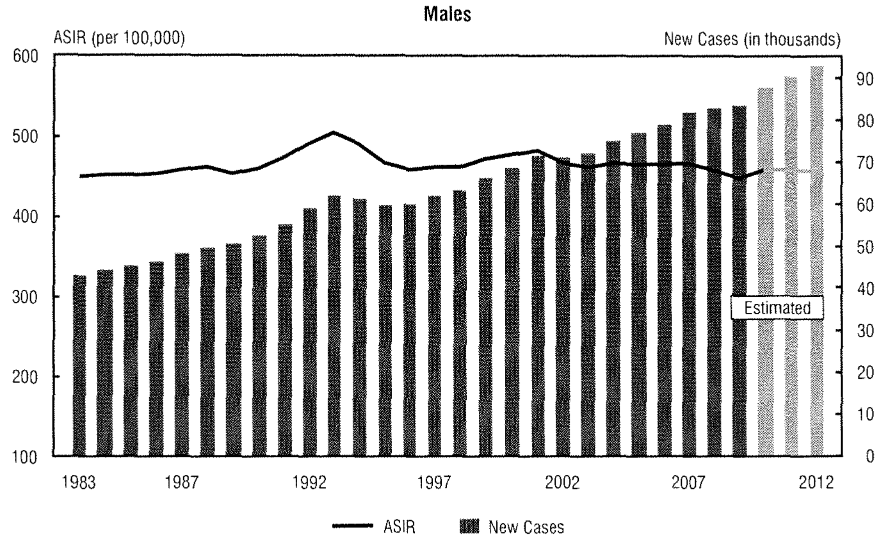
Mortality rates have remained stable, most likely because modern treatment is highly effective in the management of early thyroid cancers.

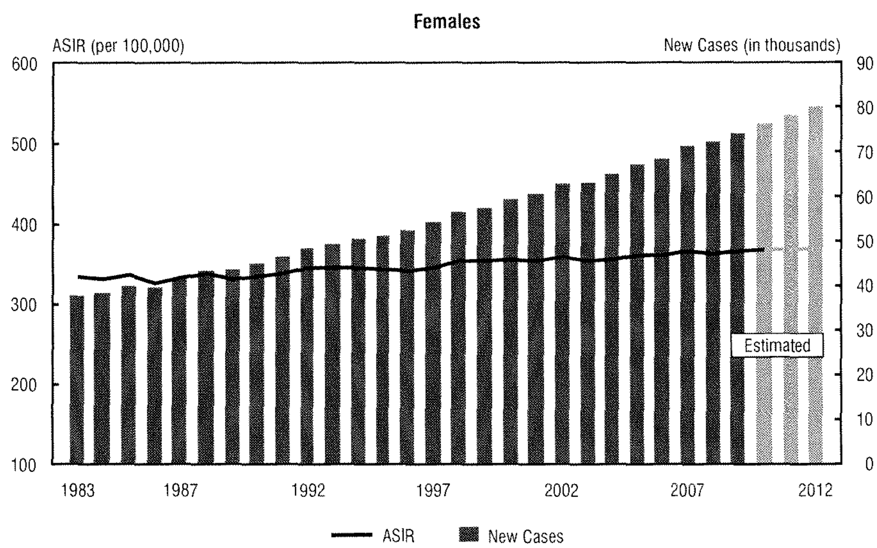
Implications

The strong declines in mortality rates for several cancers suggest that there has been important progress in cancer control, specifically due to early detection and treatment, as seen in improved five-year relative survival in the most recent time period for the leading cancers.[19] However, the increasing or stable trends in incidence rates for many cancers suggest a need for more primary prevention. Furthermore, Figure 4.1 and Figure 4.2 highlight the fact that the rise in new cases of cancer will place an increasing burden on Canadian society, largely independent of the trend in incidence and mortality rates. This vividly illustrates why cancer prevention and health promotion programs are so vital. There is a need to enhance capacity for primary prevention, early detection and treatment to further reduce overall cancer incidence and mortality.

Incidence and mortality are measures of disease burden, and their trends can inform the need for clinical services. Overall, incidence rates are stable (males) or show modest increases (females), but mortality rates are declining, suggesting better survival for some cancers. The trends call for an enhancement of primary prevention efforts; a sustained focus on screening for breast, colorectal and cervical cancers; more emphasis on early detection measures and public education on the early signs of cancer; and improved treatment options and health promotion.

Figure 4.1
New Cases and Age-Standardized Incidence Rates (ASIRs) for All Cancers, Canada, 1983–2012



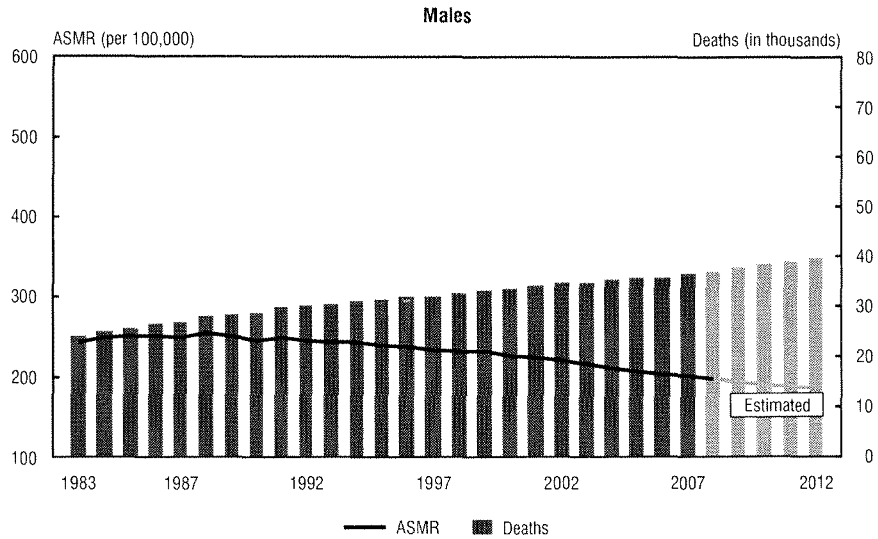


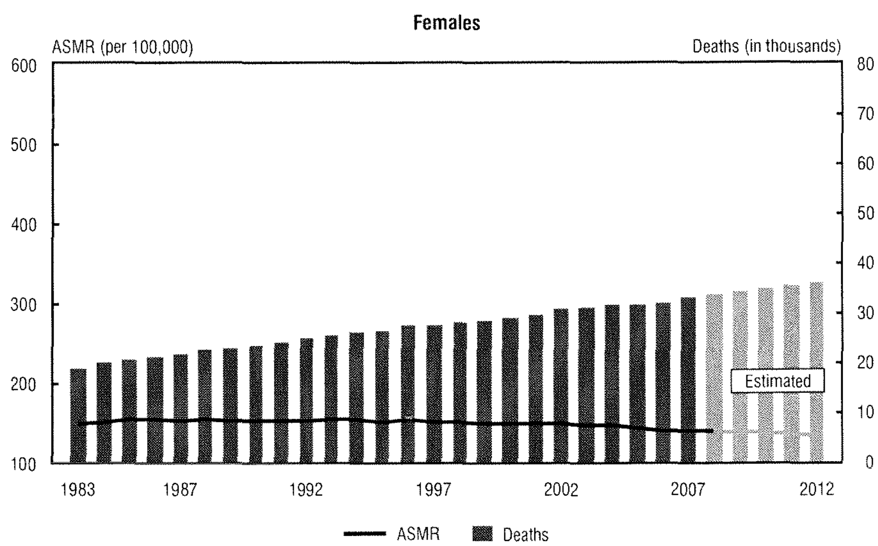
Note: "All cancers" excludes non-melanoma skin cancer (basal and squamous). Rates are age-standardized to the 1991 Canadian population. Actual incidence data were available to 2009 except for Quebec (2007). Please refer to *Appendix II: Data sources and methods* for further details.

Analysis by: Chronic Disease Surveillance and Monitoring Division, CCDPC, Public Health Agency of Canada.

Data sources: Canadian Cancer Registry and National Cancer Incidence Reporting System databases at Statistics Canada.

Figure 4.2
Deaths and Age-Standardized Mortality Rates (ASMRs) for All Cancers, Canada, 1983–2012

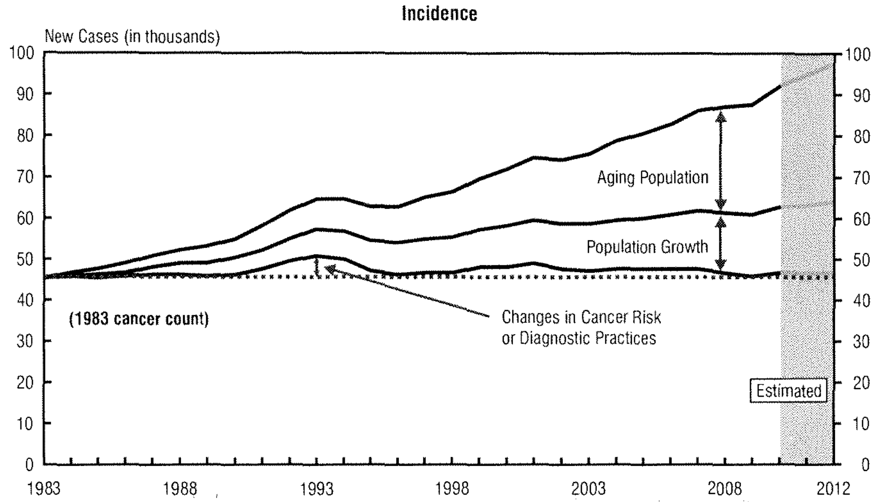


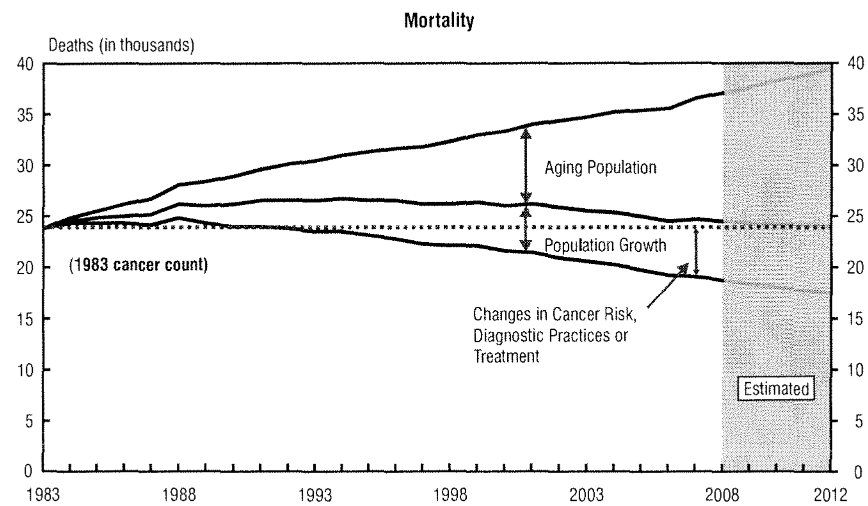


Note: Rates are age-standardized to the 1991 Canadian population. Actual data were available to 2007.
Analysis by: Chronic Disease Surveillance and Monitoring Division, CCDPC, Public Health Agency of Canada.
Data source: Canadian Vital Statistics Death database at Statistics Canada.

Figure 4.3

Trends in New Cases and Deaths for All Cancers and Ages, Attributed to Cancer Rate, Population Growth and Aging Population, Males, Canada, 1983–2012





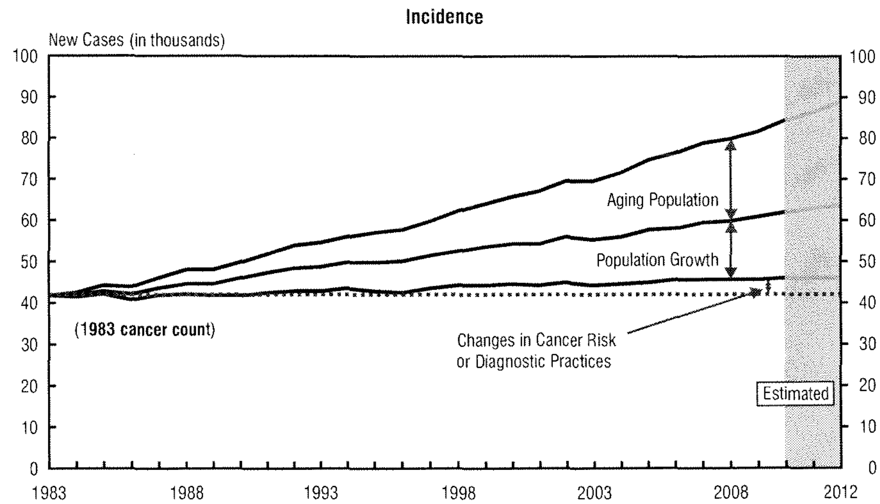
Note: New cases excludes non-melanoma skin cancer (basal and squamous). Actual incidence data were available to 2009 for all provinces except Quebec (2007), and actual mortality data were available to 2007. The range of scales differs between the figures.

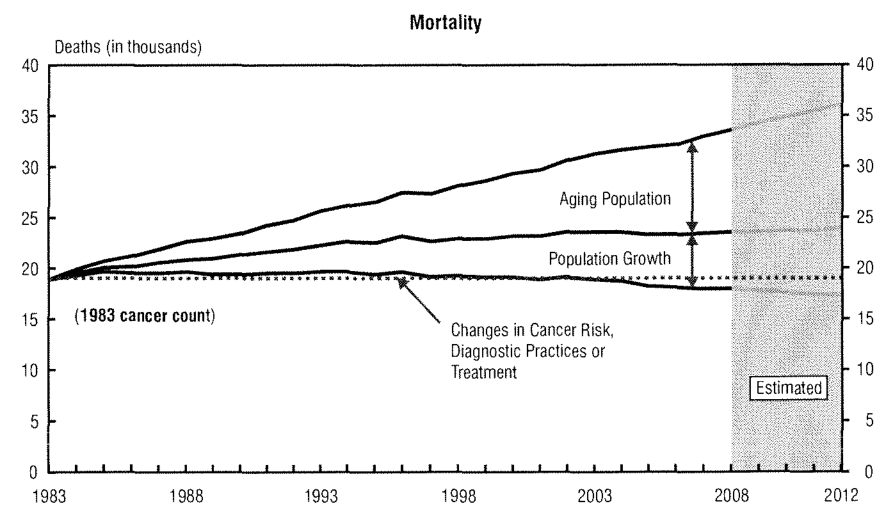
Analysis by: Chronic Disease Surveillance and Monitoring Division, CCDPC, Public Health Agency of Canada.

Data sources: Canadian Cancer Registry, National Cancer Incidence Reporting System and Canadian Vital Statistics Death databases at Statistics Canada.

Figure 4.4

Trends in New Cases and Deaths for All Cancers and Ages, Attributed to Cancer Rate, Population Growth and Aging Population, Females, Canada, 1983–2012



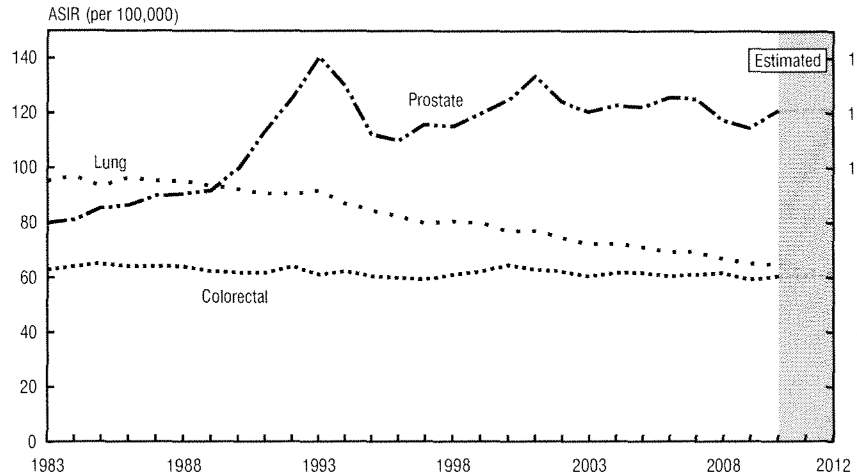


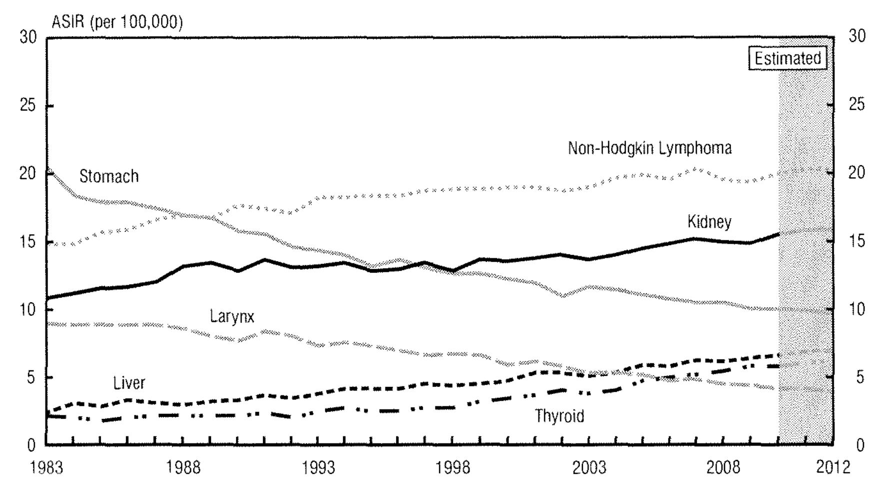
Note: New cases exclude non-melanoma skin cancer (basal and squamous). Actual incidence data were available to 2009 for all provinces except Quebec (2007), and actual mortality data were available to 2007. The range of scales differs between the figures.

Analysis by: Chronic Disease Surveillance and Monitoring Division, CCDPC, Public Health Agency of Canada.

Data sources: Canadian Cancer Registry, National Cancer Incidence Reporting System and Canadian Vital Statistics Death databases at Statistics Canada.

Figure 4.5
Age-Standardized Incidence Rates (ASIRs) for Selected* Cancers, Males, Canada, 1983–2012





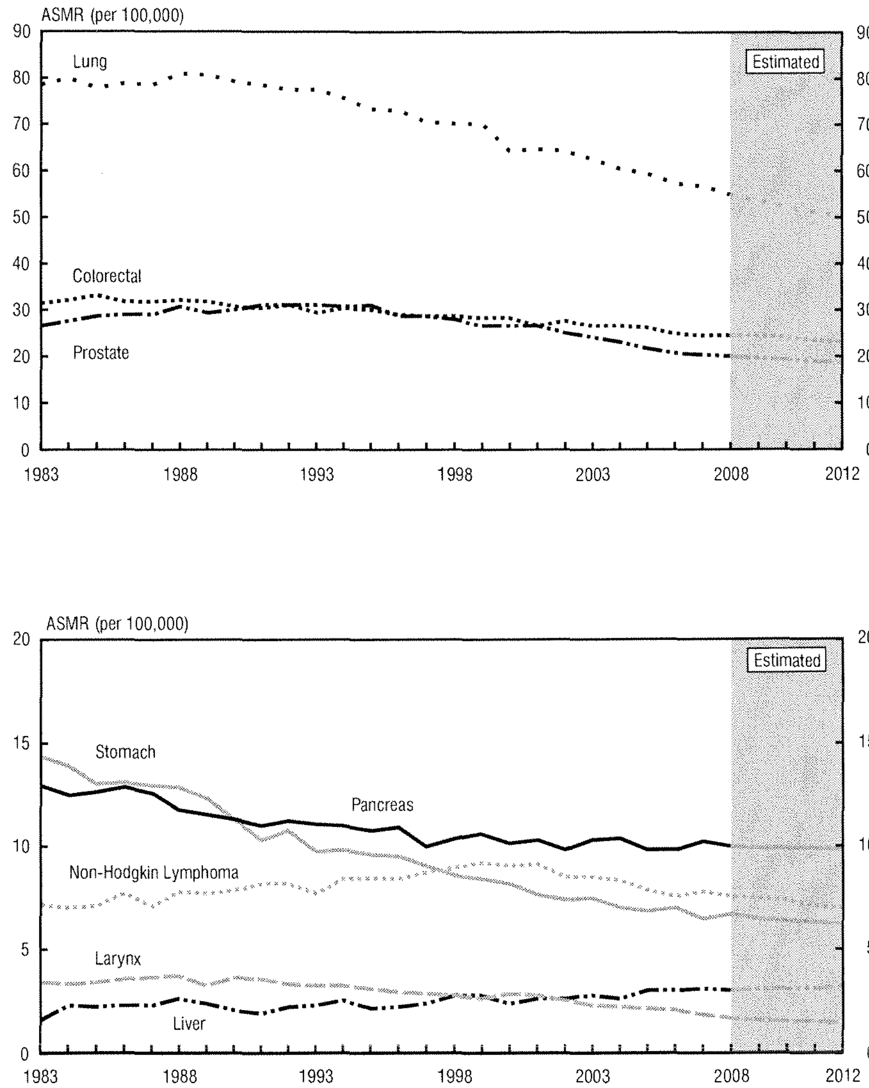
* Five most frequent cancers (both sexes combined) and cancers with a statistically significant change in incidence rate of at least 2% per year (see Table 4.5).

Note: Rates are age-standardized to the 1991 Canadian population. See Table 4.1 for data points. Actual data for incidence were available to 2009 except for Quebec (2007). The range of scales differs widely between the figures.

Analysis by: Chronic Disease Surveillance and Monitoring Division, CCDPC, Public Health Agency of Canada.

Data sources: Canadian Cancer Registry and National Cancer Incidence Reporting System databases at Statistics Canada.

Figure 4.6
Age-Standardized Mortality Rates (ASMRs) for Selected* Cancers, Males, Canada, 1983–2012



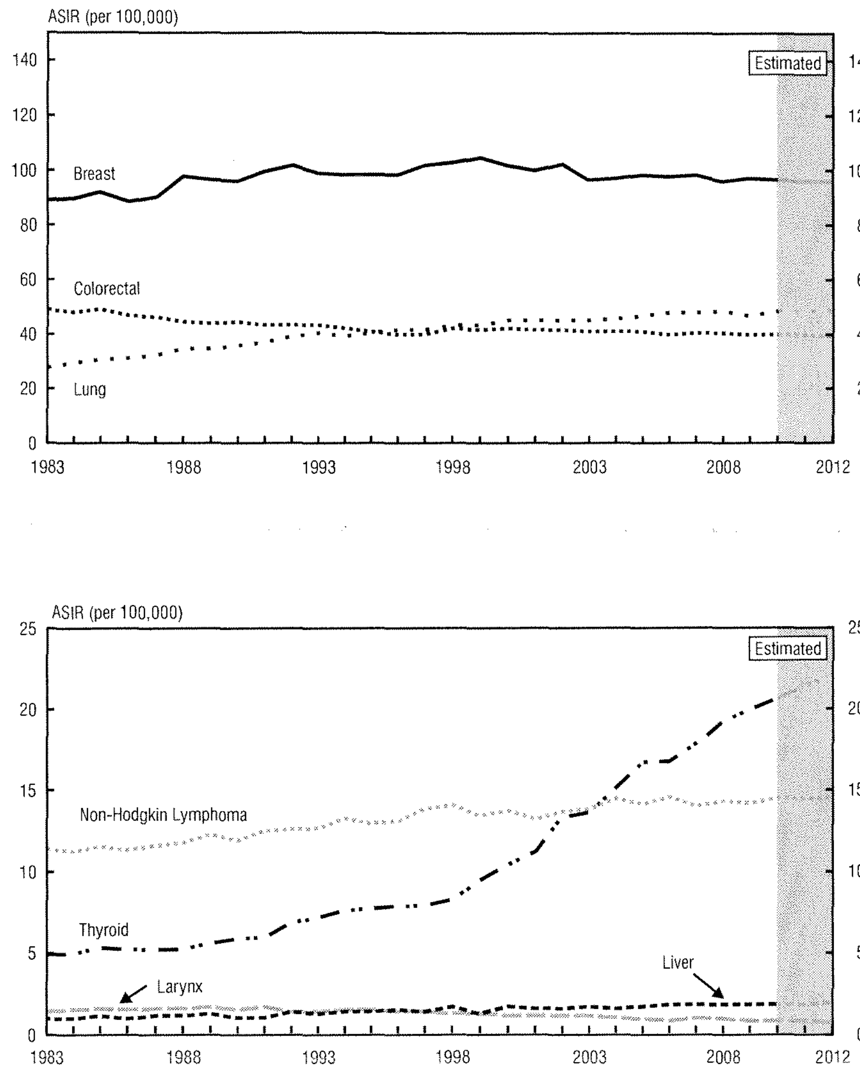
* Five most frequent causes of cancer deaths (both sexes combined) and cancers with a statistically significant change in mortality rate of at least 2% per year (see Table 4.5).

Note: Rates are age-standardized to the 1991 Canadian population. See Table 4.2 for data points. Actual data for mortality were available to 2007. The range of scales differs widely between the figures.

Analysis by: Chronic Disease Surveillance and Monitoring Division, CCDPC, Public Health of Agency of Canada.

Data source: Canadian Vital Statistics Death database at Statistics Canada.

Figure 4.7
Age-Standardized Incidence Rates (ASIRs) for Selected* Cancers, Females, Canada, 1983–2012



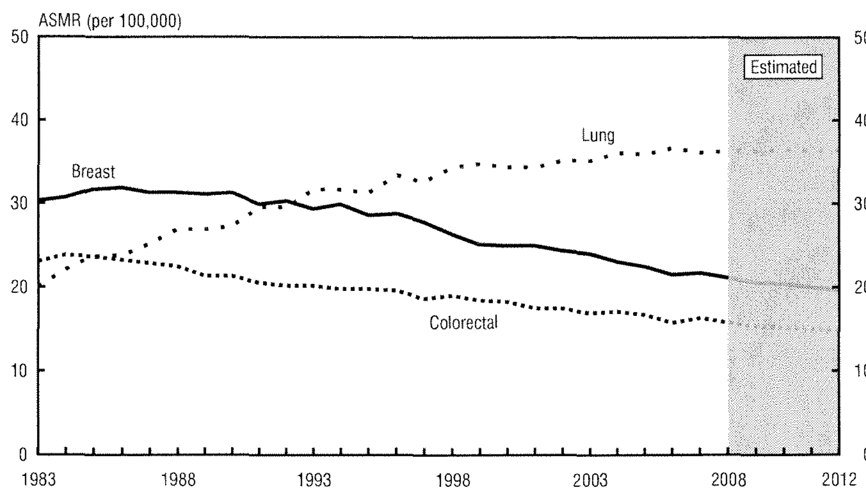
* Five most frequent cancers (both sexes combined) and cancers with a statistically significant change in incidence rate of at least 2% per year (see Table 4.5).

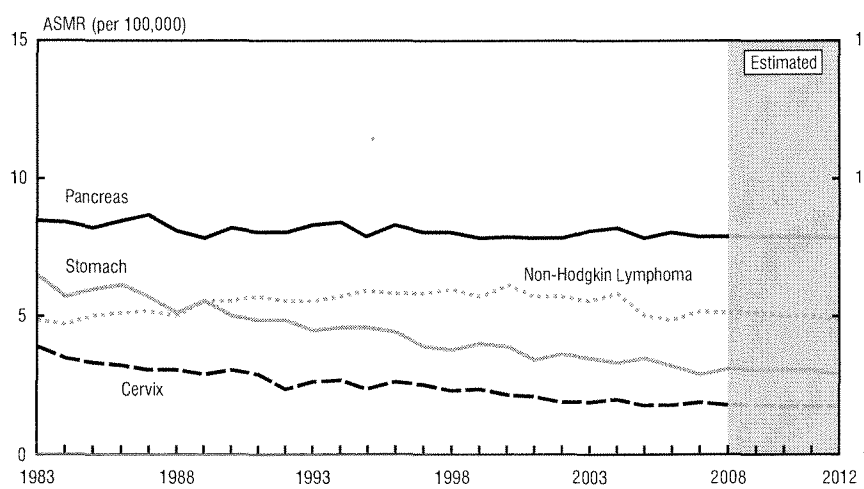
Note: Rates are age-standardized to the 1991 Canadian population. See Table 4.3 for data points. Actual data for incidence were available to 2009 except for Quebec (2007). The range of scales differs widely between the figures.

Analysis by: Chronic Disease Surveillance and Monitoring Division, CCDPC, Public Health Agency of Canada.

Data sources: Canadian Cancer Registry and National Cancer Incidence Reporting System databases at Statistics Canada.

Figure 4.8
Age-Standardized Mortality Rates (ASMRs) for Selected* Cancers, Females, Canada, 1983–2012





* Five most frequent causes of cancer deaths (both sexes combined) and cancers with a statistically significant change in mortality rate of at least 2% per year (see Table 4.5).

Note: Rates are age-standardized to the 1991 Canadian population. See Table 4.4 for data points. Actual data for mortality were available to 2007. The range of scales differs widely between the figures.

Analysis by: Chronic Disease Surveillance and Monitoring Division, CCDPC, Public Health Agency of Canada.

Data source: Canadian Vital Statistics Death database at Statistics Canada.

Table 4.1
Age-Standardized Incidence Rates for Selected* Cancers, Males, Canada, 1983–2012

Year	Cases per 100,000									
	All Cancers	Prostate	Lung	Colorectal	Non-Hodgkin Lymphoma	Kidney	Stomach	Liver	Thyroid	Larynx
1983	450.5	79.7	95.0	62.9	14.9	10.8	20.5	2.4	2.1	9.0
1984	452.3	81.0	96.9	63.8	14.9	11.3	18.4	3.1	2.0	8.9
1985	452.3	85.1	93.0	65.2	15.7	11.5	18.0	2.8	1.8	8.8
1986	453.9	86.1	96.1	63.5	16.0	11.6	18.0	3.3	2.0	8.8
1987	458.5	89.5	94.8	63.4	16.6	12.0	17.4	3.1	2.2	8.8
1988	460.9	90.4	95.1	63.4	17.0	13.3	17.0	3.0	2.1	8.6
1989	453.8	91.8	93.3	62.0	16.7	13.4	16.7	3.2	2.1	8.1
1990	460.2	99.8	92.4	61.9	17.7	12.9	15.8	3.4	2.2	7.7
1991	472.4	112.5	90.5	61.8	17.4	13.6	15.6	3.6	2.4	8.4
1992	490.6	125.7	90.6	63.3	17.2	13.1	14.6	3.5	2.0	8.1
1993	503.1	140.7	91.5	61.0	18.2	13.2	14.3	3.8	2.6	7.4
1994	491.3	129.8	86.8	62.1	18.2	13.4	14.1	4.2	2.7	7.5
1995	467.1	111.8	84.7	60.5	18.3	12.8	13.3	4.2	2.6	7.4
1996	458.1	110.1	82.2	59.4	18.3	13.0	13.6	4.2	2.6	6.9
1997	461.0	115.6	79.4	59.1	18.8	13.4	13.1	4.5	2.7	6.6
1998	460.8	115.0	80.5	61.2	18.9	12.9	12.6	4.4	2.7	6.7
1999	471.9	119.6	79.5	62.2	18.9	13.6	12.6	4.6	3.2	6.6
2000	476.5	124.8	77.1	64.2	19.0	13.5	12.3	4.7	3.5	5.9
2001	482.3	133.2	77.0	63.2	19.0	13.8	11.9	5.3	3.6	6.1
2002	466.7	123.8	74.5	62.6	18.8	14.0	11.0	5.3	4.0	5.8
2003	462.4	120.4	72.4	60.3	19.0	13.6	11.7	5.1	3.7	5.4
2004	466.4	122.6	72.3	61.5	19.7	14.0	11.4	5.4	4.0	5.3
2005	465.3	121.9	71.1	61.4	20.0	14.4	11.1	5.9	4.7	5.2
2006	464.9	126.1	69.1	60.4	19.5	14.9	10.7	5.8	5.0	4.7
2007	467.1	125.5	68.9	60.8	20.4	15.3	10.5	6.3	5.2	4.8
2008	458.0	117.2	67.0	61.4	19.6	15.0	10.5	6.1	5.5	4.5
2009	448.8	114.6	65.1	59.2	19.3	14.9	10.1	6.4	5.8	4.4
2010†	458.0	121.2	64.2	60.6	20.1	15.6	10.0	6.6	5.8	4.2
2011†	457.0	121.2	63.0	60.5	20.2	15.8	9.9	6.8	6.0	4.1
2012†	456.1	121.2	61.8	60.5	20.2	15.9	9.7	6.9	6.1	3.9

* Five most frequent cancers (both sexes combined) and cancers with a statistically significant change in incidence rate of at least 2% per year (see Table 4.5).

† Actual data were available to 2009 except for Quebec (2007). Estimated rates for all provinces/territories. These estimates are based on long-term trends and may not reflect recent changes.

Note: Rates for "All Cancers" exclude non-melanoma skin cancer (basal and squamous). Rates are age-standardized to the 1991 Canadian population.

Analysis by: Chronic Disease Surveillance and Monitoring Division, CCDPC, Public Health Agency of Canada.

Data sources: Canadian Cancer Registry and National Cancer Incidence Reporting System databases at Statistics Canada.

Table 4.2
Age-Standardized Mortality Rates for Selected* Cancers, Males, Canada, 1983–2012

Year	Deaths per 100,000								
	All Cancers	Lung	Colorectal	Prostate	Pancreas	Non-Hodgkin Lymphoma	Stomach	Liver	Larynx
1983	243.1	78.4	31.7	26.7	12.9	7.2	14.3	1.6	3.4
1984	248.1	80.2	32.4	27.5	12.5	7.0	13.9	2.3	3.3
1985	249.2	78.0	33.3	28.9	12.7	7.1	13.0	2.2	3.4
1986	249.0	78.8	31.9	29.4	12.8	7.7	13.1	2.3	3.5
1987	248.1	78.5	31.9	29.4	12.6	7.1	12.9	2.3	3.6
1988	254.6	81.2	32.3	30.7	11.8	7.8	12.8	2.6	3.7
1989	249.4	81.0	31.9	29.7	11.5	7.7	12.3	2.4	3.2
1990	246.4	79.4	30.8	30.1	11.3	7.9	11.3	2.0	3.6
1991	247.5	78.7	30.3	31.2	11.0	8.1	10.3	1.9	3.5
1992	245.2	77.6	31.0	31.1	11.2	8.1	10.7	2.2	3.3
1993	243.2	77.9	29.6	31.1	11.1	7.7	9.7	2.3	3.2
1994	242.3	75.6	30.2	30.8	11.0	8.4	9.8	2.5	3.2
1995	239.3	73.3	30.0	31.1	10.7	8.4	9.6	2.1	3.1
1996	236.6	72.9	29.4	29.0	10.9	8.4	9.5	2.2	2.9
1997	232.3	70.5	28.8	28.8	10.0	8.7	9.0	2.4	2.8
1998	230.7	70.2	28.8	28.1	10.4	8.9	8.6	2.7	2.7
1999	229.8	70.4	28.4	26.9	10.6	9.2	8.4	2.7	2.6
2000	225.8	64.3	28.4	26.9	10.1	9.0	8.1	2.4	2.8
2001	224.3	64.7	27.0	26.7	10.3	9.1	7.6	2.6	2.7
2002	220.3	64.5	27.6	25.1	9.8	8.5	7.3	2.6	2.5
2003	215.4	62.7	26.7	24.0	10.3	8.5	7.4	2.7	2.3
2004	212.1	60.6	26.7	23.4	10.4	8.3	7.0	2.6	2.2
2005	207.7	59.8	26.4	21.9	9.8	7.9	6.8	3.0	2.1
2006	201.5	57.5	24.8	20.8	9.8	7.5	7.0	3.0	2.0
2007	200.1	57.0	24.4	20.4	10.2	7.8	6.5	3.1	1.8
2008†	196.4	55.1	24.6	20.3	10.0	7.5	6.6	3.0	1.7
2009†	193.3	53.8	24.3	19.8	9.9	7.4	6.5	3.1	1.6
2010†	190.3	52.6	24.0	19.4	9.9	7.3	6.4	3.1	1.5
2011†	187.2	51.3	23.7	18.9	9.9	7.1	6.3	3.1	1.5
2012†	184.4	50.2	23.4	18.5	9.8	7.0	6.2	3.2	1.4

* Five most frequent causes of cancer deaths (both sexes combined) and cancers with a statistically significant change in mortality rate of at least 2% per year (see Table 4.5).

† Actual data were available to 2007. Estimated rates for all provinces/territories. These estimates are based on long-term trends and may not reflect recent changes.

Note: Rates are age-standardized to the 1991 Canadian population.

Analysis by: Chronic Disease Surveillance and Monitoring Division, CCDPC, Public Health Agency of Canada.

Data source: Canadian Vital Statistics Death database at Statistics Canada.

Table 4.3
Age-Standardized Incidence Rates for Selected* Cancers, Females, Canada, 1983–2012

Year	Cases per 100,000							
	All Cancers	Breast	Lung	Colorectal	Thyroid	Non-Hodgkin Lymphoma	Liver	Larynx
1983	333.1	89.3	28.2	49.1	4.8	11.5	0.9	1.3
1984	329.9	90.3	29.5	47.8	4.9	11.3	0.9	1.4
1985	336.1	92.2	30.8	49.5	5.3	11.4	1.1	1.5
1986	325.4	88.6	31.5	47.1	5.2	11.3	0.9	1.4
1987	331.6	91.1	33.2	46.7	5.2	11.5	1.1	1.5
1988	336.8	97.8	34.6	45.0	5.1	11.7	1.1	1.5
1989	330.6	96.4	34.9	44.3	5.6	12.2	1.2	1.6
1990	333.6	96.0	36.3	44.5	5.8	12.1	1.0	1.4
1991	338.0	100.2	37.5	43.2	5.9	12.5	1.0	1.6
1992	343.8	101.9	39.7	43.3	6.8	12.6	1.3	1.3
1993	343.3	99.2	40.5	43.1	7.1	12.7	1.2	1.3
1994	343.8	99.0	39.8	42.5	7.6	13.3	1.3	1.4
1995	342.1	98.9	40.7	41.4	7.7	13.1	1.3	1.4
1996	340.0	98.7	42.0	40.1	7.8	13.1	1.4	1.3
1997	344.3	102.3	41.9	40.4	7.9	13.8	1.3	1.3
1998	352.0	103.4	43.6	42.8	8.2	14.0	1.6	1.2
1999	352.8	105.4	43.5	41.9	9.4	13.5	1.2	1.2
2000	354.8	101.7	45.1	42.9	10.4	13.8	1.6	1.1
2001	352.6	100.4	45.1	42.3	11.2	13.3	1.5	1.1
2002	358.6	102.4	45.7	42.1	13.3	13.6	1.5	1.1
2003	351.4	96.9	45.6	41.2	13.6	13.7	1.6	1.1
2004	354.2	97.2	46.3	41.6	15.1	14.4	1.5	1.0
2005	360.9	98.5	47.6	41.5	16.7	14.0	1.6	0.9
2006	361.0	98.3	47.9	40.3	16.8	14.5	1.8	0.8
2007	364.3	98.6	47.7	40.9	17.9	13.9	1.8	1.0
2008	361.9	96.2	48.6	40.7	19.2	14.2	1.8	0.9
2009	364.2	97.6	47.4	39.9	20.0	14.2	1.8	0.8
2010†	365.7	96.5	48.4	40.1	20.6	14.4	1.8	0.8
2011†	366.8	96.2	48.6	39.9	21.4	14.4	1.8	0.8
2012†	367.9	95.9	48.7	39.8	22.2	14.5	1.9	0.7

* Five most frequent cancers (both sexes combined) and cancers with a statistically significant change in incidence rate of at least 2% per year (see Table 4.5).

† Actual data were available to 2009 except for Quebec (2007). Estimated rates for all provinces/territories. These estimates are based on long-term trends and may not reflect recent changes.

Note: Rates for "All Cancers" exclude non-melanoma skin cancer (basal and squamous). Rates are age-standardized to the 1991 Canadian population.

Analysis by: Chronic Disease Surveillance and Monitoring Division, CCDPC, Public Health Agency of Canada.

Data sources: Canadian Cancer Registry and National Cancer Incidence Reporting System databases at Statistics Canada.

Table 4.4
Age-Standardized Mortality Rates for Selected* Cancers, Females, Canada, 1983–2012

Year	Deaths per 100,000							
	All Cancers	Lung	Breast	Colorectal	Pancreas	Non-Hodgkin Lymphoma	Stomach	Cervix
1983	149.4	19.9	30.4	23.0	8.5	4.9	6.5	3.9
1984	151.8	22.1	30.7	23.8	8.4	4.7	5.7	3.5
1985	154.8	23.7	31.8	23.6	8.2	5.0	6.0	3.3
1986	154.4	23.9	32.0	23.3	8.5	5.1	6.1	3.2
1987	154.0	25.3	31.3	22.8	8.7	5.2	5.7	3.0
1988	155.3	26.9	31.4	22.6	8.1	5.0	5.1	3.0
1989	153.0	26.9	31.2	21.2	7.8	5.5	5.5	2.9
1990	152.9	27.5	31.3	21.2	8.2	5.5	5.0	3.0
1991	153.7	29.5	30.1	20.6	8.0	5.7	4.9	2.9
1992	153.1	29.6	30.4	20.1	8.0	5.5	4.9	2.4
1993	154.9	31.7	29.4	20.2	8.3	5.5	4.5	2.6
1994	155.2	31.9	30.0	19.8	8.4	5.7	4.6	2.7
1995	152.0	31.3	28.7	19.7	7.9	5.9	4.6	2.4
1996	155.2	33.6	28.9	19.6	8.3	5.8	4.4	2.6
1997	150.4	32.6	27.8	18.7	8.0	5.8	3.9	2.5
1998	151.3	34.5	26.4	19.1	8.0	6.0	3.8	2.3
1999	149.8	34.9	25.2	18.5	7.8	5.7	4.0	2.4
2000	149.8	34.4	25.0	18.1	7.9	6.1	3.9	2.2
2001	148.2	34.4	25.0	17.6	7.8	5.7	3.4	2.1
2002	149.2	35.2	24.4	17.5	7.8	5.7	3.6	1.9
2003	148.1	35.3	24.1	16.9	8.1	5.5	3.5	1.9
2004	147.0	36.1	23.1	17.1	8.2	5.8	3.3	2.0
2005	143.7	35.9	22.6	16.7	7.8	5.0	3.5	1.8
2006	141.5	36.8	21.5	15.7	8.0	4.9	3.2	1.8
2007	141.2	36.1	21.8	16.3	7.9	5.2	2.9	1.9
2008†	140.3	36.4	21.1	15.7	7.9	5.1	3.1	1.8
2009†	139.1	36.5	20.7	15.4	7.9	5.1	3.0	1.8
2010†	137.9	36.6	20.3	15.2	7.9	5.0	3.0	1.7
2011†	136.7	36.5	19.9	15.0	7.9	5.0	3.0	1.7
2012†	135.5	36.3	19.5	14.8	7.8	4.9	2.9	1.7

* Five most frequent causes of cancer deaths (both sexes combined) and cancers with a statistically significant change in mortality rate of at least 2% per year (see Table 4.5).

† Actual data were available to 2007. Estimated rates for all provinces/territories. These estimates are based on long-term trends and may not reflect recent changes.

Note: Rates are age-standardized to the 1991 Canadian population.

Analysis by: Chronic Disease Surveillance and Monitoring Division, CCDPC, Public Health Agency of Canada.

Data source: Canadian Vital Statistics Death database at Statistics Canada.

Table 4.5

Annual Percent Change (APC) in Age-Standardized Incidence and Mortality Rates for Selected Cancers, Canada, 1998–2007

	Incidence				Mortality			
	Males		Females		Males		Females	
	APC	Change-point†	APC	Change-point†	APC	Change-point†	APC	Change-point†
All Cancers	**0.1**	**2003**	**0.3****		**–2.0****	**2001**	**–0.8****	
Prostate	–0.6	2001	—		–4.3**	2001	—	
Lung	–1.8**		1.1**		–2.3**		0.7**	
Colorectal	–0.8**	2000	–0.8**	2000	–2.6**	2003	–1.8**	
Breast	—		–0.7**		—		–2.2**	
Non-Hodgkin Lymphoma	0.8**		0.5		–2.6**	2000	–2.7**	2000
Bladder	–0.7*		–0.1		–1.1**		0.4	
Melanoma	1.4**		1.4**		0.3		0.1	
Kidney	2.6*	2003	1.9**		–0.8		–0.9*	
Leukemia	0.6		1.2**		–1.2**		–0.9	
Thyroid	6.8**		6.9**	2002	—		—	
Body of Uterus	—		0.7*		—		–0.1	
Pancreas	–0.3		0.4		–0.4		0.1	
Oral	–1.0*		0.2		–1.8*		–1.8	
Stomach	–2.0**		–1.6**		–3.0**		–2.9**	
Brain	–0.4		–0.8		–0.7		–1.4**	
Ovary	—		–0.2		—		–2.2	2003
Multiple Myeloma	0.4		0.0		–1.5*		–0.9	
Liver	3.6**		2.4*		2.2**		1.1	
Esophagus	0.6		–0.7		–0.1		–1.5*	
Cervix	—		–1.4**		—		–2.9**	
Larynx	–3.8**		–3.4**		–6.2**	2001	–2.8	
Hodgkin Lymphoma	0.4		0.9		—		—	
Testis	1.4*		—		—		—	

— Not applicable or small number of deaths.
* Significant, $p<0.05$.
** Significant, $p<0.01$.
† Changepoint indicates the baseline year, if the slope of the trend changed after 1998 for incidence or mortality. Changepoints were fit to rates from 1986 to 2007 for both incidence and mortality.

Note: APC is calculated assuming a log linear model; "All Cancers" incidence rates include cancers not found in the table but exclude non-melanoma skin cancer (basal and squamous). When there is no changepoint in the most recent 10 years, the APC was obtained by running a separate changepoint analysis on the most recent 10 years. If there is a changepoint, the APC was taken from the last segment. See *Appendix II: Data sources and methods* for further details.

Analysis by: Chronic Disease Surveillance and Monitoring Division, CCDPC, Public Health Agency of Canada.

Data sources: Canadian Cancer Registry and Canadian Vital Statistics Death databases at Statistics Canada.

APPENDIX I: ACTUAL DATA FOR NEW CASES AND DEATHS

The focus of this publication is current year estimates obtained by analyzing actual data and making short-term projections using statistical techniques (see *Appendix II*).

However, summaries of actual incidence and mortality statistics based on the most recently available data are available:

- Information on cancer incidence is available from the following websites:
    - Statistics Canada
      www.statcan.gc.ca/bsolc/olc-cel/olc-cel?catno=82-231-X&lang=eng
    - Public Health Agency of Canada, Chronic Disease Infobase Cubes
      www.infobase.phac-aspc.gc.ca
- Information on causes of death—including cancer mortality—is available from Statistics Canada:
  www.statcan.gc.ca/bsolc/olc-cel/olc-cel?catno=84-208-x&lang=eng
- The most up-to-date data for individual provinces and territories can be obtained by contacting the provincial or territorial cancer registries (see *For further information*).

APPENDIX II: DATA SOURCES AND METHODS

DATA SOURCES

Incidence data: The Canadian Cancer Registry (CCR)

Actual cancer incidence data used in this publication cover the period of 1983 to 2009 (except for Quebec, for which data in the CCR were available to 2007 in time for this publication). Data for 1992 to 2009 were obtained from the CCR,[20] while data for earlier years were retrieved from its predecessor, the National Cancer Incidence Reporting System (NCIRS). The NCIRS is a fixed, tumour-oriented database containing cases diagnosed as far back as 1969.

- Incidence data originate with the provincial and territorial cancer registries, which provide data annually to Statistics Canada for inclusion in the CCR.
- The CCR is a person-oriented database that includes clinical and demographic information about residents of Canada newly diagnosed with cancer.
- The Health Statistics Division at Statistics Canada maintains the CCR, including linking data internally to track people with tumours diagnosed in more than one province or territory and to identify duplicates. Incidence records are also linked with the mortality data (described below) for the purposes of survival and prevalence analyses.
- Cancer diagnoses are classified according to the *International Classification of Diseases for Oncology, Third Edition* (ICD-O-3).[21]

Mortality data: the Canadian Vital Statistics – Death Database (CVS: D)

- The actual cancer mortality data cover the period of 1983 to 2007 and were obtained from the CVS: D.[22]
- Death records originate with the provincial and territorial registrars of vital statistics and are provided regularly to Statistics Canada for inclusion in the CVS: D.
- The CVS: D includes demographic and cause of death information for all deaths in Canada from 1921 onward.
- Data are also included for Canadian residents who died in some states of the United States. Canada currently receives abstracted death data from approximately 10 states.
- The Health Statistics Division at Statistics Canada maintains the CVS: D.
- Cause of death is classified according to the *International Statistical Classification of Diseases and Related Health Problems, Tenth Revision* (ICD-10).[23]
- Cancer deaths are those for which some form of cancer, as certified by a physician, is the underlying cause of death.

Population data: The Census of Canada

- Population estimates for Canada and the provinces and territories are based on censuses conducted every five years from 1981 through to 2006.
- Intercensal estimates prepared by Statistics Canada are used for the years between these censuses, and postcensal estimates are used for 2006 to 2010.[3]
- Projected population estimates are used for 2011 and 2012, as prepared by Statistics Canada under assumptions of medium growth (scenario M1).[2] The

scenario M1 incorporates medium-growth and historical trends (1981–2008) of interprovincial migration.

- All population estimates include non-permanent residents and are adjusted for net census under-coverage and Canadians returning from abroad.

Cancer definitions

- Cancers are generally defined according to the groupings of ICD-O-3 for incidence and ICD-10 for mortality, as indicated in Table A1.
- Some definitions have changed slightly over time; changes occurring since the 2004 edition of this publication are outlined in Table A2.

METHODS

Incidence and mortality rates

Records from each province or territory were extracted from the relevant incidence or mortality files and then classified by year of diagnosis or death and by sex, five-year age group (0–4, 5–9, ..., 80–84 and 85+ years) and cancer type.

- Rates for each category were calculated by dividing the number of cases or deaths in each category (i.e., province/territory, year, sex, age group, cancer type) by the corresponding provincial or territorial population figure. These formed the basis for calculations of age-standardized rates and for estimates beyond the most recent year of actual data.
- For the section *Incidence and mortality by age and sex*, age-specific rates were computed for broader age groups (0–19, 20–29, ..., 70–79 and 80+ years) in the same way.
- Age-standardized incidence rates (ASIRs) and mortality rates (ASMRs) were calculated using the direct method, which involves weighting the age-specific rates for each five-year age group according to the age distribution of the 1991 Canadian population (see *Glossary*).

Estimation of incidence (new cases) and mortality (deaths) for 2012

Two methods were used to estimate incidence and mortality data: the Nordpred Power5 regression model and five-year averaging.

Nordpred Power5 modelling

The Nordpred Power5 regression model was the primary method for estimating the number of new cases and deaths in 2012 for each cancer type by sex (except new cases of non-melanoma skin cancer; see *Non-melanoma skin cancer incidence* below) reported in Tables 1.1 and 1.2. Nordpred is based on an age-period-cohort Poisson regression model but has enhancements that overcome difficulties in the standard Poisson model and improve projection accuracy.[24] Nordpred was developed into a software package[25] and is now one of the most frequently used methods for cancer projections worldwide.[26–30]

The Nordpred Power5 model was used when the average annual number of cases for a site for the most recent five years was greater than 50. The assumption underlying the Nordpred Power5 regression model is that the annual number of new cases and deaths are independent Poisson random variables with mean values equal to the product of the population size for a particular year and the (true) annual rate.

- A separate Nordpred Power5 regression model was fit for each province, sex and type of cancer for the period of 1985 to 2009 (1983–2007 for Quebec) for incidence and 1983 to 2007 for mortality.
- The Power5 model is $R_{ap} = (A_a + D \cdot p + P_p + C_c)^5$ where a, p and c represent age, period and cohort, respectively, in five-year groups. Input data were aggregated into five-year calendar periods and 18 five-year age groups (described above); cohorts were created synthetically by subtracting age from period. R_{ap} is the incidence/mortality rate in age group a in calendar period p, A_a is the age component for age group a, D is the common drift parameter that summarizes the linear component of the trend that cannot be attributed to either period or cohort.[31] P_p is the nonlinear period component of period p, and C_c is the nonlinear cohort component of cohort c.
- Nordpred uses a goodness of fit test to choose the number of five-year periods to be included in the dataset used for calculating future values (projection base).
- The software determines whether the average trend across all observed values, or the slope for the last 10 years of observed values is used for projection, based on a significance, test for departure from linear trend. This approach serves as an approximate way of looking for significant changes in the observed trend. You can also choose between using the average trend or the trend for the last 10 years for your projection by specifying the value for the "recent" option.
- For each age group, a minimum of five cases in each five-year period was required; for age groups below this limit, the average number of cases in the last two periods is used to calculate future rates.
- To allow for a damping of the impact of current trends in the future time periods, a "cut-trend" option is used, which is a vector of proportions indicating how much to cut the trend estimate for each five-year projection period. A gradual reduction in the drift parameter of 25% and 50% in the second and third five-year period, respectively, was used as the default in this publication.
- Age was included in all models as a factor. Age-specific incidence rate trends were then extrapolated to 2012. The predicted numbers of cancer cases in 2012 were calculated by multiplying these extrapolated incidence rates by the sex-, age- and province-specific population projections for the same year.
- The Nordpred "recent" and "cut-trend" options were modified from the default values for selected sites, including thyroid cancer incidence and prostate cancer mortality, since recent trends are not expected to continue with as large an annual percent change. The values were chosen so that estimates were consistent with the most recent data available to the provincial cancer registries.

Five-year averaging

New cases and deaths in 2012 for each type of cancer were also estimated based on the average of the five most recent years of data. This method may be more realistic for cancers for which there are recent changes in trend (the Nordpred Power5 model results in poor estimates for these cancers because it is based on a medium or longer term trend) or when frequencies are low and result in unstable estimates using the Nordpred model. The average of rates for the most recent five years was calculated for each sex, five-year age group, cancer type and province. The predicted numbers were then obtained by multiplying these rates by the corresponding projected population sizes.

The five-year average was used for prostate cancer incidence because of recent age-specific changes in trend.

Selection of "best" estimates

Estimates from the two methods were compared for each sex, cancer type and geographic region for all ages combined. The "best" estimate for each category was selected in consultation with individual provincial or territorial cancer registries, according to the following guidelines:

- The Nordpred model was preferred except when frequencies were low.
- Five-year average estimates were used when the average annual number of cases during the most recent five years was less than or equal to 50.
- Five-year average estimates were used for the territories and are reported only for "All Cancers" because of small sample sizes.
- The absolute value of the difference between the age-standardized rates estimated by the two methods was calculated and expressed relative to the five-year average estimate. For example, if the Nordpred Power5 model estimated a rate of 4.0 and the five-year average estimated a rate of 4.5, the relative difference would be (4.0 – 4.5) ÷ 4.5, or 11.1%.
- Provinces closely examined estimates for cancers where the absolute value of the relative difference exceeded 15%. Such situations may be indicative of important deviations from the long-term trend.
- Provinces provided feedback based on the availability of in-house projections, knowledge of local trends or access to more current data, which permitted an assessment of the estimates produced by the two different estimation methods.
- Estimates for Canada as a whole were computed as the sum of the estimates for the individual provinces and territories.

Tables A3 and A4 indicate the cancer types that were reported according to the five-year average method for 2012. In these situations, the age-standardized rates for 2012 reported in this publication were calculated using the most recent five years of actual data.

All cancers combined

Provincial estimates of incidence counts for "All Cancers" for males were computed as the sum of the "best" estimates for prostate cancer and all cancers excluding prostate, as estimated by Poisson modelling.

Non-melanoma skin cancer incidence

Only a few provinces routinely collect data on the incidence of basal and squamous cell carcinoma of the skin (generally referred to as non-melanoma skin cancer, or NMSC). The numbers of NMSC in all of Canada, by sex, were estimated using these data.

- Pathology laboratories in British Columbia send all diagnostic reports of NMSC to the provincial registry. The age- and sex-specific incidence rates in British

Columbia for 1992 to 1994 and 2003 were projected to 2012 by the British Columbia Cancer Registry and applied to the projected Canadian population estimates to generate an estimate of the number of cases for Canada as a whole.

- Counts of NMSC for 1989 to 2008 by year, sex and age group were provided by the Manitoba Cancer Registry and by the New Brunswick Cancer Registry. Linear regressions using a logarithmic transformation of the annual rates for each province and age group (0–39, 40–59, 60–79 and 80+ years) were conducted and projected to 2012.
- The predicted numbers of NMSC cases for all of Canada were calculated by multiplying the projected incidence rates for each of Manitoba and New Brunswick by the sex- and age-specific Canadian population projections for 2012.
- Reported new cases of NMSC for all of Canada are the average of 2012 estimates from the British Columbia, Manitoba and New Brunswick registries.

Rounding for reporting

- Estimates of incidence and mortality presented in this publication have been rounded as follows:
  - numbers between 0 and 99 to the nearest 5
  - numbers between 100 and 999 to the nearest 10
  - numbers between 1,000 and 1,999 to the nearest 50
  - numbers greater or equal to 2,000 to the nearest 100
- Percentages, age-standardized rates and age-specific rates were rounded to the nearest 10th, except in Tables 1.1, 1.2, 2.3 and 2.5, where space restrictions forced rounding to the nearest whole number.
- Age-specific and sex-specific numbers or rates were combined before rounding, so it is possible that the totals in the tables do not add up. However, any such discrepancies are within the precision of the rounding units described above.

Precision of 2012 estimates

Estimates of precision (standard errors, coefficients of variation and confidence limits) for 2012 counts and rates are available on request from the Chronic Disease Surveillance and Monitoring Division (Centre for Chronic Disease Prevention and Control, Public Health Agency of Canada). The precision of an estimate depends primarily on the number of observed cases and the population size for each combination of cancer type, age, sex and province or territory.

Annual percent change (APC) in cancer incidence and mortality rates

The estimated APC was calculated for each cancer type by fitting a piecewise linear regression model, assuming a constant rate of change in the logarithm of the annual ASIR or ASMR in each segment. The models incorporated estimated standard errors of the ASIR or ASMR. The tests of significance used a Monte Carlo Permutation method. The estimated slope from this model was then transformed back to represent an annual percentage increase or decrease in the rate.

- Changepoint analysis was applied to annual age-standardized rates over the period of 1986 to 2007 (for incidence and mortality) in order to determine years in which the APC changed significantly; such years are referred to as *changepoints*.
- A minimum of five years of data before and after a changepoint was required for a new trend to be identified. Thus, the most recent possible changepoint is 2003.
- If no changepoint was detected within the period from 1998 to 2007, then the APC was estimated by fitting a model within this time period, in the same way as described above.
- If a changepoint was detected within this decade, then the APC was estimated from the trend in the last segment. Both the changepoint year and the APC for the years beyond the changepoint are indicated in Table 4.5.

Contribution of change in cancer rate, population growth and population age structure to incidence and mortality trends

Figures 4.3 and 4.4 display the determinants of increases in incidence and mortality for males and females, respectively. The section on *Time trends in incidence and mortality* provides a description of the three series. The series were calculated as follows:

- Uppermost series: the annual number of Canadian cancer cases or deaths, for males or females
- Next to uppermost series: annual total population multiplied by the annual age-standardized rate, using the 1983 population distribution for males or females as the standard weights
- Next to baseline series: the 1983 total population multiplied by the annual age-standardized rate, using the 1983 population distribution for males or females as the standard weights
- Baseline (dotted line): the observed number of Canadian cancer cases or deaths during 1983, for males or females

DATA AND METHODS ISSUES

Incidence

Although the Canadian Council of Cancer Registries and its Standing Committee on Data Quality make every effort to achieve uniformity in defining and classifying new cancer cases, reporting procedures and completeness still vary across the country. The standardization of case-finding procedures, including linkage to provincial or territorial mortality files, has improved the registration of cancer cases and comparability of data across the country. Some specific issues remain:

- Benign tumours and carcinomas in situ are not routinely captured or reported except for in situ carcinomas of the bladder; all cancer registries except Ontario report in situ bladder cancers to the CCR.
- The Newfoundland and Labrador Cancer Registry did not receive information on death certificates that mentioned cancer until very recently. This has led to underestimates of the incidence of some cancers because there were no "death certificate only" (DCO) cases. This could result in death counts or rates exceeding those for incidence in a specific year; this especially affects highly fatal cancers.

- The number of DCO cases for 2008 and 2009 in Newfoundland and Labrador was estimated from 2007 data.
- In Quebec, cases diagnosed only through death certificates have not generally been reported to the CCR with the exception of the 2000 to 2006 data years. The number of DCO cases in Quebec for 2007 was estimated from the average of 2002 to 2006. In addition, because of the registry's dependence on hospital data, the numbers of cases of some cancers, particularly those for which pathology reports represent the main source of diagnostic information, are underestimated. Prostate cancer, melanoma and bladder cancers are affected in particular.[1]
- The number of DCO cases for 2008 and 2009 in Ontario was estimated from the average of 2003 to 2007 data.
- The number of DCO cases is less than 2% of total cases.
- Non-melanoma skin cancers are excluded since most provincial and territorial cancer registries do not collect information on these cases. These cancers are difficult to register completely because they may be diagnosed and treated in a variety of settings and are very numerous. Estimates based on the three registries that include these cancers (see *Non-melanoma skin cancer incidence* above) are therefore likely to be underestimates.

Mortality

Although procedures for registering and allocating cause of death have been standardized both nationally and internationally, some lack of specificity and uniformity is inevitable. The description of cancer type provided on the death certificate is usually less accurate than that obtained by the cancer registries from hospital and pathology records.

Although there have been numerous small changes in definitions over the years (see Table A2), there is one major earlier change of note:

- In the versions of this publication published before 2003, mortality due to colorectal cancer was based on the *International Classification of Diseases, Ninth Revision* (ICD-9), codes 153–154, to be consistent with other publications. However, this underestimates colorectal cancer mortality by about 10% because most deaths registered as ICD-9 code 159.0 (intestine not otherwise specified) are cases of colorectal cancer.
- Commencing with the 2003 edition, these deaths were included in the definition of colorectal cancer. As a consequence, mortality figures for colorectal cancer appearing in this publication cannot be directly compared with those appearing in reports prior to 2003.

Table A1
Cancer Definitions

Cancer	ICD-O-3 Site/Histology Type* (Incidence)	ICD-10 (Mortality)
Oral	C00–C14	C00–C14
Esophagus	C15	C15
Stomach	C16	C16
Colorectal	C18–C20, C26.0	C18–C20, C26.0
Liver	C22.0	C22.0, C22.2–C22.7
Pancreas	C25	C25
Larynx	C32	C32
Lung	C34	C34
Melanoma	C44 (Type 8720–8790)	C43
Breast	C50	C50
Cervix	C53	C53
Body of Uterus	C54–C55	C54–C55
Ovary	C56.9	C56
Prostate	C61.9	C61
Testis	C62	C62
Bladder (including in situ)	C67	C67
Kidney	C64.9, C65.9	C64–C65
Brain	C70–C72	C70–C72
Thyroid	C73.9	C73
Hodgkin Lymphoma*	Type 9650–9667	C81
Non-Hodgkin Lymphoma*	Type 9590–9596,9670–9719, 9727–9729 Type 9823, all sites except C42.0,.1,.4 Type 9827, all sites except C42.0,.1,.4	C82–C85,C96.3
Multiple Myeloma*	Type 9731,9732,9734	C90.0, C90.2
Leukemia*	Type 9733,9742,9800–9801,9805, 9820,9826,9831–9837,9840, 9860–9861,9863,9866–9867, 9870–9876,9891,9895–9897,9910, 9920,9930–9931,9940,9945–9946, 9948,9963–9964 Type 9823 and 9827, sites C42.0,.1,.4	C91–C95,C90.1
All Other Cancers	All sites C00–C80, C97 not listed above	All sites C00–C80, C97 not listed above
All Cancers excluding Lung	C00–C97 excluding C34	C00–C97 excluding C34

Table A1 *(continued)*
Cancer Definitions

Cancer	ICD-O-3 Site/Histology Type* (Incidence)	ICD-10 (Mortality)
All Other and Unspecified Cancers	Type 9140,9740,9741,9750–9758, 9760–9769,9950–9962, 9970–9989 C76.0–C76.8 (type 8000–9589) C80.9 (type 8000–9589) C42.0–C42.4 (type 8000–9589) C77.0–C77.9 (type 8000–9589) C44.0–C44.9 excluding type 8050–8084,8090–8110, 8720–8790,9590–9989	C26.1,C44,C46,C76–C80,C88, C96.0–.2,C96.7–.9,C97
All Cancers	All invasive sites	All invasive sites

* Histology types 9590–9989 (leukemia, lymphoma and multiple myeloma) and 9050–9055 (mesothelioma) are excluded from other specific organ sites.

Note: ICD-O-3 refers to the *International Classification of Diseases for Oncology, Third Edition*.[21]

Table A2
Recent Cancer Definition Changes

	Incidence Definition			Mortality Definition		
Cancer	New Definition and Year Changed		Old Definition	New Definition and Year Changed		Old Definition
Bladder	ICD-O-3 C67 (including in situ cancers, except for Ontario since this province does not report in situ bladder cancer)	2006	ICD-O-3, C67 (not including in situ cancers)	—		—
Colorectal	ICD-O-3 C18–C20, C26.0	2011	ICD-O-3 C18–C21,C26.0	ICD-10 C18–C20, C26.0	2012	ICD-10 C18–C21, C26.0
Kidney	ICD-O-3 C64–C65	2008	ICD-O-3 C64–C66,C68	ICD-10 C64–C65	2008	ICD-10 C64–C66, C68
Leukemia	—		—	ICD-10 C91–C95, C90.1	2008	ICD-10 C91–C95
Liver	—		—	ICD-10 C22.0, C22.2–C22.7	2007	ICD-10 C22 (before 2006) ICD-10 C22.0, C22.2–C22.9 (in 2006)
Lung	ICD-O-3 C34	2008	ICD-O-3 C33–C34 (before 2006) ICD-O-3 C34 (in 2006) ICD-O-3 C33–C34 (in 2007)	ICD-10 C34	2008	ICD-10 C33–C34 (before 2006) ICD-10 C34 (in 2006) ICD-10 C33–C34 (in 2007)
Multiple myeloma	—		—	ICD-10 C90.0, C90.2	2008	ICD-10 C88, C90 (before 2007) ICD-10 C90 (in 2007)
Ovary	ICD-O-3 C56	2006	ICD-O-3 C56, C57.0–C57.4	ICD-10 C56	2006	ICD-10 C56, C57.0–C57.4
All other and unspecified cancers	—		—	ICD-10 C44, C46, C76–C80,C88, C96.0–C96.2, C96.7–C96.9, C97	2007	ICD-10 C44,C46, C76–C80, C96.0–C96.2, C96.7–C96.9, C97

Note: According to the *International Classification of Diseases for Oncology, Third Edition* (ICD-O-3),[21] cancer incidence for bladder, kidney, lung and ovary excludes histology types 9590–9989 (leukemia, lymphoma and multiple myeloma) and 9050–9055 (mesothelioma).

Table A3

Use of Five-Year Average Method* for Incidence Projection by Cancer Type and Province, 2012

	BC	AB	SK	MB	ON	QC	NB	NS	PE	NL
All Cancers								F		
Oral			F	F			F	F	M,F	M,F
Esophagus		F	M,F	M,F			M,F	M,F	M,F	M,F
Stomach			F	F			F	F	M,F	F
Pancreas			F						M,F	M,F
Larynx	F	F	M,F	M,F			M,F	M,F	M,F	M,F
Melanoma									M,F	M,F
Breast									F	
Cervix			F	F			F	F	F	F
Body of Uterus									F	
Ovary									F	F
Prostate†	M	M	M	M	M	M	M	M	M	M
Testis			M	M			M	M	M	M
Bladder									M,F	F
Brain			M,F	M,F			M,F	M,F	M,F	M,F
Thyroid			M,F	M			M	M	M,F	M,F
Hodgkin Lymphoma	F	F	M,F	M,F			M,F	M,F	M,F	M,F
Non-Hodgkin Lymphoma									M,F	
Liver		F	M,F	M,F			M,F	M,F	M,F	M,F
Colorectal									F	
Lung									F	
Kidney									M,F	F
Multiple Myeloma			M,F	M,F			M,F	M,F	M,F	M,F
Leukemia		M					F		M,F	M,F

* Nordpred Power5 regression model is the default for all provinces except when the average annual cases for the most recent five years is less than or equal to 50, when the five-year average estimate is the default.

† Five-year average method was used for prostate cancer to better capture the stabilizing trend in incidence observed for this cancer.

Note:

M = males; F = females.

For territories (not shown), five-year average method was used for "All Cancers" because of small numbers.

Table A4
Use of Five-Year Average Method* for Mortality Projection by Cancer Type and Province, 2012

	BC	AB	SK	MB	ON	QC	NB	NS	PE	NL
All Cancers										
Oral		F	M,F	M,F			M,F	M,F	M,F	M,F
Esophagus		F	M,F	M,F			M,F	M,F	M,F	M,F
Stomach		M	M,F	M,F			M,F	M,F	M,F	M,F
Pancreas									M,F	M,F
Larynx	F	M,F	M,F	M,F	F	F	M,F	M,F	M,F	M,F
Melanoma	F	M,F	M,F	M,F			M,F	M,F	M,F	M,F
Breast									F	
Cervix		F	F	F			F	F	F	F
Body of Uterus			F	F			F	F	F	F
Ovary							F		F	F
Prostate									M	
Bladder		F	M,F	M,F			M,F	M,F	M,F	M,F
Brain			M,F	M,F			M,F	M,F	M,F	M,F
Non-Hodgkin Lymphoma			F				M,F	M,F	M,F	M,F
Liver		M,F	M,F	M,F		F	M,F	M,F	M,F	M,F
Colorectal									M,F	
Lung									M,F	
Kidney		F	M,F	M,F			M,F	M,F	M,F	M,F
Multiple Myeloma		F	M,F	M,F			M,F	M,F	M,F	M,F
Leukemia			F	F			M,F	M,F	M,F	M,F

* Nordpred Power5 regression model is the default for all provinces except when the average annual deaths for the most recent five years is less than or to equal 50, when the five-year average estimate is the default.

Note:

M = males; F = females.

For territories (not shown), five-year average method was used for "All Cancers" because of small numbers.

APPENDIX III: PREVIOUS SPECIAL TOPICS

Special topics are related to current or ongoing issues in cancer surveillance or cancer control. In particular, they aim to provide an in-depth look at the Canadian context. Previous special topics are available at www.cancer.ca/statistics and include the following:

2011	Colorectal cancer
2010	End-of-life care Cancer in depth: Esophagus cancer Cancer in depth: Kidney cancer
2009	Cancer in adolescents and young adults (15–29 years)
2008	Childhood cancer (ages 0–14)
2007	Breast cancer
2006	Progress in cancer control: screening
2005	Progress in cancer prevention: modifiable risk factors
2004	International variation in cancer incidence, 1993–1997 Economic burden of cancer in Canada, 1998
2003	Non-Hodgkin's lymphoma
2002	Cancer incidence in young adults Five-year relative cancer survival in Canada, 1992
2001	Colorectal cancer
2000	Progress in cancer control
1999	Factors contributing to the population burden of cancer incidence and mortality A new national cancer surveillance system for Canada
1998	International comparisons
1997	Ten years of Canadian cancer statistics
1996	Prostate cancer Direct costs of cancer in Canada, 1993 Evaluation of cancer estimates: 1987–1991
1995	Prevalence of cancer Colorectal cancer
1993	Female breast cancer
1991	Smoking and lung cancer Cancer among the Inuit and Indians
1990	Cancer of the female breast and genital organs – recent trends Hodgkin's disease and cancer of the testis Cancer mortality by income quintile Economic cost of illness in Canada Cancer control
1989	Cancer incidence and mortality: an international comparison
1988	Tobacco consumption from smoking and mortality from lung cancer Cancer mortality: an international comparison

Age
The age of the person with cancer at the time of diagnosis or death.

Age-standardized incidence rate (ASIR)
The incidence rate that would have occurred if the age distribution in the population of interest was the same as that of the standard population. It is generally expressed per 100,000 population at risk per year. It can be calculated for all ages combined or for specific broad age groups (generally age groupings of greater than 10 years). It is calculated as a weighted average of the actual age-specific rates, where the weights are the proportions of persons in the corresponding age groups of a standard population. In Canada, we use the 1991 Canadian population (males and females combined) as the standard. The potential confounding effect of age is reduced when comparing age-standardized rates computed using the same standard population.

Age-standardized mortality rate (ASMR)
The mortality rate that would have occurred if the age distribution in the population of interest was the same as that of the standard population. It is generally expressed per 100,000 population at risk per year. It can be calculated for all ages combined or for specific broad age groups (generally age groupings of greater than 10 years). It is calculated as a weighted average of the actual age-specific rates, where the weights are the proportions of persons in the corresponding age groups of a standard population. In Canada, we use the 1991 Canadian population (males and females combined) as standard. The potential confounding effect of age is reduced when comparing age-standardized rates computed using the same standard population.

Annual percent change (APC)
The estimated change in the rate of new cases (incidence) or deaths (mortality) from one year to the next over some period of time, reported as a percentage. It is estimated by fitting a linear model to logarithmically transformed annual rates, assuming that the rate is changing over the modelled period of time as a constant percentage of the rate of the previous year.

ICD-10
International Statistical Classification of Diseases and Related Health Problems, Tenth Revision.[23] This is a general system for classifying diseases and causes of death, including cancer.

ICD-O-3
International Classification of Diseases for Oncology, Third Edition.[21] This is the most current system specifically designed for classifying tumours. It is based on ICD-10 but encompasses both the body organ where the tumour arose and the tumour's morphologic type.[23]

Incidence (new cases)
The total number of new cases of cancer diagnosed in a given population during a specific period of time. This counts the cancers, not the number of people; a person can have more than one cancer.

Incidence rate
The number of new cancer cases (of all types or of a specific site or type) occurring in a given population during a year, usually expressed as the number of cancers per 100,000 population at risk. It is calculated as the number of new cases divided by the population size, then multiplied by 100,000. It can be calculated for all ages combined or for specific age groups, when it is referred to as an age-specific rate.

Mortality (deaths)
The number of deaths due to cancer in a given population during a specific period of time, regardless of when the diagnosis of cancer was made (e.g., during or prior to the period of interest, or at the time of death).

GLOSSARY

Mortality rate

The number of cancer deaths (of all types or of a specific site or type) occurring in a given population during a year, usually expressed as the number of cancer deaths per 100,000 population at risk. It is calculated as the number of deaths divided by the population size, then multiplied by 100,000. It can be calculated for all ages combined or for specific age groups, when it is referred to as an age-specific rate.

Province/territory

The province or territory of the person's permanent residence at the time of cancer diagnosis or death. This may not be the same location as where the new case of cancer or the cancer death was registered, or where treatment was delivered.

Standard population

The Canadian population distribution is based on the final postcensal estimates of the July 1, 1991, Canadian population, adjusted for census under-coverage. The age distribution of the population has been weighted and normalized. Data were obtained from the Census and Demographics Branch, Statistics Canada.

1991 Canadian Standard Population

Age Group	Population (per 100,000)
0–4	6,946.4
5–9	6,945.4
10–14	6,803.4
15–19	6,849.5
20–24	7,501.6
25–29	8,994.4
30–34	9,240.0
35–39	8,338.8
40–44	7,606.3
45–49	5,953.6
50–54	4,764.9
55–59	4,404.1
60–64	4,232.6
65–69	3,857.0
70–74	2,965.9
75–79	2,212.7
80–84	1,359.5
85+	1,023.7
Total	100,000

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FOR FURTHER INFORMATION

Data contained in this publication and additional information are available from the following:

- Canadian Cancer Society
  www.cancer.ca
- Public Health Agency of Canada
  www.phac-aspc.gc.ca (select surveillance)
- Statistics Canada
  www.statcan.gc.ca (search "cancer")

Additional information related to this publication can be found in other print sources, including the following:

- reports from provincial and territorial cancer registries
- *Cancer Incidence in Canada,*[20] *Cancer Survival Statistics*[32] and *Health Reports*, published by Statistics Canada
- *Chronic Diseases and Injuries in Canada,* published by Health Canada/Public Health Agency of Canada
- a collaborative monograph entitled *Cancer in North America: 2004–2008*, published by the North American Association of Central Cancer Registries and available at www.naaccr.org/DataandPublications/CINAPubs.aspx
- *Cancer Incidence in Five Continents*, published by the International Agency for Research on Cancer in 2007 and available at: http://www.iarc.fr/en/publications/pdfs-online/epi/sp160/index.php.

Information from the Canadian Cancer Society
For general information about cancer statistics or any other aspect of cancer (such as cancer prevention, screening, diagnosis, treatment or care), contact the Canadian Cancer Society 's ***Cancer Information Service* at 1 888 939-3333**. Contact information for the Canadian Cancer Society, National, and the divisions is provided on page 66. Your local Canadian Cancer Society office is listed in the white pages of the telephone directory.

For information about cancer research funded by the **Canadian Cancer Society Research Institute**, contact the Canadian Cancer Society, National, at the address provided on page 66.

Information from the Public Health Agency of Canada
More detailed information on methodology is available from the Chronic Disease Surveillance and Monitoring Division, CCDPC, Public Health Agency of Canada, 785 Carling Avenue, Ottawa, Ontario, K1A 0K9. Tel: (613) 952-5176, Fax: (613) 941-2057.

Chronic Disease Infobase Cubes (www.infobase.phac-aspc.gc.ca) is an interactive online tool for easy access to cancer surveillance data. It allows you to generate tables, chart and maps according to a choice of parameters, such as cancer type, geographic area and period of time.

Information from Statistics Canada
Detailed standard tables are available on the Statistics Canada website (www.statcan.gc.ca). Custom tabulations are available on a cost recovery basis upon request from the Health Statistics Division, Statistics Canada, National Contact Centre: (613) 951-8116 or toll-free 1 800 263-1136; infostats@statcan.gc.ca. Analytical articles appear regularly in *Health Reports,* Statistics Canada, Catalogue no. 82-003 (www.statcan.gc.ca/bsolc/olc-cel/olc-cel?catno=82-003-x&lang=eng).

Information from the provincial or territorial cancer registries
Cancer incidence data are supplied to Statistics Canada by provincial and territorial cancer registries. Detailed information regarding the statistics for each province or territory is available from the relevant registry (see pages 64-65 for contact information).

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Tim Catterall
In November 2004, Tim Catterall, a firefighter for the Burlington, Ontario Fire Department, was diagnosed with chronic lymphocytic leukemia. He took a stand and created Firefighters Against Cancer's Existence.
Photography: Caitlin den Boer

Deanne
After being diagnosed with Hodgkin's disease at age 26, Deanne was determined to survive. She would joke, "I have to keep living: I haven't found the perfect shade of purple nail polish yet!"
Photography: Sheilagh O'Leary

Eddie
Photographer Larry Frank was Eddie's peer support volunteer. They met through Cancer Connection, a division of the Canadian Cancer Society. The two spoke regularly during the two years following Eddie's cancer diagnosis, while he underwent surgery and radiation. Eddie is now well and looking forward to a healthy life with his wife Tara and young daughter.
Photography: Larry Frank

Dan Blackburn
The photographer took this image of her Uncle Dan, who has a passion for cooking, sitting peacefully in his kitchen in December 2007. He was receiving chemotherapy, having been diagnosed with colon cancer four months earlier. Sadly, he passed away in March 2008.
Photography: Kendra Vamplew

Evan Pickard
Throughout his battle with cancer, Evan Pickard's heart was continuously open to others, making everyone around him laugh. He died in April 2007, leaving behind endless hearts touched by his sincere generosity.
Photography: Jennifer Globush

Francilla Charles
Francilla Charles has been diagnosed twice with pancreatic cancer and survived for 10 years and counting. She now lives with diabetes and continues to inspire and amaze her daughter, photographer Michele Clarke.
Photography: Michele Clarke

APPENDIX F
Mobile phone use and glioma risk: comparison of epidemiological study results with incidence trends in the United States, MP Little et al., March 2012

See attached.

Research

Mobile phone use and glioma risk: comparison of epidemiological study results with incidence trends in the United States

BMJ 2012; 344 doi: 10.1136/bmj.e1147 (Published 8 March 2012)

Cite this as: BMJ 2012;344:e1147

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Accepted 3 January 2012

Abstract

Objective In view of mobile phone exposure being classified as a possible human carcinogen by the International Agency for Research on Cancer (IARC), we determined the compatibility of two recent reports of glioma risk (forming the basis of the IARC's classification) with observed incidence trends in the United States.

Design Comparison of observed rates with projected rates of glioma incidence for 1997-2008. We estimated projected rates by combining relative risks reported in the 2010 Interphone study and a 2011 Swedish study by Hardell and colleagues with rates adjusted for age, registry, and sex; data for mobile phone use; and various latency periods.

Setting US population based data for glioma incidence in 1992-2008, from 12 registries in the Surveillance, Epidemiology, and End Results (SEER) programme (Atlanta, Detroit, Los Angeles, San Francisco, San Jose-Monterey, Seattle, rural Georgia, Connecticut, Hawaii, Iowa, New Mexico, and Utah).

Participants Data for 24 813 non-Hispanic white people diagnosed with glioma at age 18 years or older.

Results Age specific incidence rates of glioma remained generally constant in 1992-2008 (−0.02% change per year, 95% confidence interval −0.28% to 0.25%), a period coinciding with a substantial increase in mobile phone use from close to 0% to almost 100% of the US population. If phone use was associated with glioma risk, we expected glioma incidence rates to be higher than those observed, even with a latency period of 10 years and low relative risks (1.5). Based on relative risks of glioma by tumour latency and cumulative hours of phone use in the Swedish study, predicted rates should have been at least 40% higher than observed rates in 2008. However, predicted glioma rates based on the small proportion of highly exposed people in the Interphone study could be consistent with the observed data. Results remained valid if we used either non-regular users or low users of mobile phones as the baseline category, and if we constrained relative risks to be more than 1.

Conclusions Raised risks of glioma with mobile phone use, as reported by one (Swedish) study forming the basis of the IARC's re-evaluation of mobile phone exposure, are not consistent with observed incidence trends in US population data, although the US data could be consistent with the modest excess risks in the Interphone study.

Introduction

The association between microwave radiation exposure from mobile phone use and tumour development in the brain and central nervous system has been much investigated, yet remains controversial. Although many large and well conducted studies have found little evidence to support such a link,1 2 3 4 5 a few studies have observed modest to large increases in relative risk,6 7 8 9 10 11 generally of glioma but with some reports of acoustic neuroma.9 11 Results have been generally negative for an association between phone use and risk of meningioma.12 The International Agency for Research on Cancer (IARC) has recently re-evaluated the risk of tumour development in the brain and central nervous system from mobile phone use, and rated this type of exposure as a possible human carcinogen (grade 2B).12 This declaration was based mainly on the results of two epidemiological studies: the Interphone study4 and a recent Swedish study by Hardell and colleagues.10

Temporal trends in brain tumour incidence could add valuable data to the results of analytical epidemiological studies assessing exposures that have changed over time, such as the use of mobile phones. A large study in the United States13 assessed trends in brain cancer incidence in 1973-2006, and observed general reductions in incidence rates in 1992-2006. Compared with the marked increase in ownership and use of mobile phones in the US over this same period, the reductions did not support the notion that phone use causes brain cancer. In a study of brain cancer incidence in Scandinavia in 1974-2004, researchers observed gradually rising rates that did not correspond with the substantial increase in mobile phone use in the late 1990s,14 again implying no strong association.

A study in the United Kingdom observed no changes over the period 1998-2007 in the total incidence of brain cancer overall, nor for any sex or age group.15 Although researchers saw an increasing trend in cancer of the temporal lobe, this trend had begun in the late 1970s, with no change in rate in recent years; therefore, these results were unlikely to support the carcinogenic effect of mobile phone exposure.16 A similar survey of glioma incidence rates in Swedish adults in 1970-2009 yielded no evidence of changing rates over time for various age groups.17 However, none of these studies13 14 15 17 assessed the potential effect of latency or possible variation in excess relative risk with the cumulative duration of phone use on trends in brain cancer incidence.

In this study, we compared the observed patterns for glioma incidence trends in the US in 1992-2008 with projected incidence rates for the same period based on relative risks reported by the two epidemiological studies forming the basis of the IARC Working Group classification.4 10 Our comparisons considered hypothesised latency periods, anatomical sites, and glioma grades, and we also took account of changes in mobile phone use during this period.

Methods

Data collection

We used incidence data from the National Cancer Institute's Surveillance, Epidemiology, and End Results (SEER) programme that compiles information from a series of population based cancer registries throughout the US.18 Because incidence rates vary by race and origin, and the population composition has changed over time, we focused our analysis on non-Hispanic white people (although subsidiary analysis was conducted of other ethnic groups). Hispanicity as well as race has been recorded since 1992 among residents of the areas in the 12 SEER registries used in this analysis (Atlanta, Detroit, Los Angeles, San Francisco, San Jose-Monterey, Seattle, rural Georgia, Connecticut, Hawaii, Iowa, New Mexico, and Utah).19

Primary site and histological type of the cancers were coded according to the International Classification of Diseases, 3rd edition (ICD-3), from 1992 onwards.20 We selected all 28 850 diagnoses of brain cancer (ICD-3 topography codes C71.0-C71.9, behaviour 3, excluding brain lymphomas) in non-Hispanic white people in 1992-2008. We focused on glioma (ICD-3 morphology codes 9380-9480), but also looked at astrocytoma (9400-9421, 9424, 9440-9442),21 a subgroup of gliomas that was assessed in detail in the Swedish study, although the study did not specify their exact codes.10 Most studies of brain cancer have focused on glioma in relation to mobile phone use2 3 4 6 9 10 (web appendix, table A1). Clinically, glioma is the most common category of brain cancer, and among those with the worst prognosis. Survival at five years is less than 50% for adults, and only 2.9% for glioblastoma, the most common histological subtype.22 These survival rates fall substantially with increasing age,18 although some patients with low grade glioma have had rates approaching 60%.23

We analysed data for 27 457 cases of glioma. Since most studies of mobile phone use and glioma have concentrated on adults,2 3 4 7 10 we concentrated on the 24 813 people diagnosed with glioma at age

18 years or older (table 1⇓). We further categorised gliomas by primary anatomical site and grade,

based on the World Health Organization's brain tumour classification.24 We considered astrocytoma separately. We also did summary cross tabulations of the numbers of glioma and the underlying population by age, sex, and SEER registry (web appendix, tables A2 and A3).

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Table 1

Numbers of malignant glioma cases and person-years at risk in study population

We downloaded data for mobile phone subscriptions per year in the US in 1985-2010 from the Cellular Telecommunications International Association's website.25 Minimum latency periods of up to 10 years are thought to apply for mobile phone exposure4 10; therefore, we assessed subscriptions from 1982 onwards, for evaluation of glioma incidence from 1992 up to 2008. We estimated data for 1982-4 by log linear regression, with the assumption that the number of subscriptions per year was approximately C exp[α year] (where C and α are parameters determined by the regression). More specifically, we fitted a model via ordinary least squares to log[number of subscriptions per year], using subscriptions data for

1985-90. We estimated the number of subscriptions per capita for each year by dividing the number of subscriptions by the total US population in that year (fig 1⇓).26

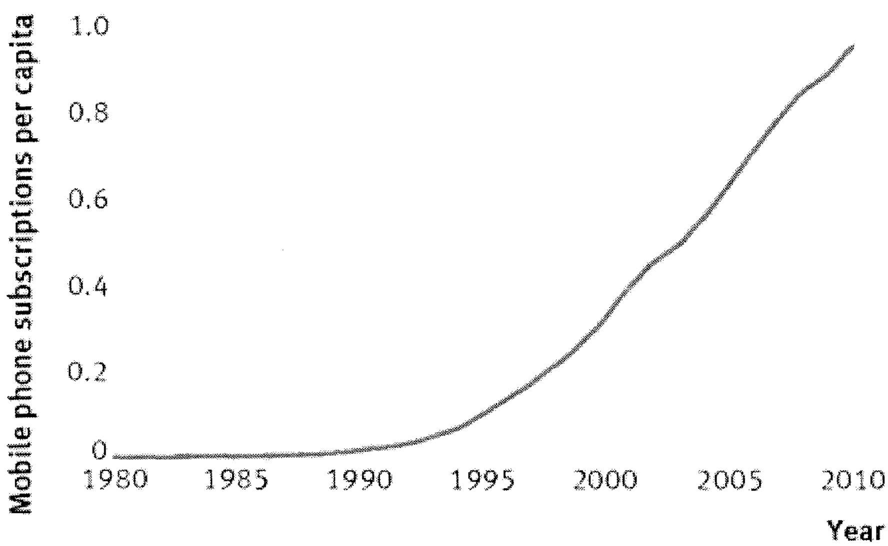

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Fig 1 Mobile phone subscriptions per capita in the US, by year25

Statistical methods

Substantial mobile phone use only began in the mid-1990s (fig 1), and preliminary Poisson model fitting did not suggest that glioma rates in the 1990s varied greatly. Therefore, we fitted a model that estimated glioma rates in 1992-6 (assumed to be constant and largely independent of mobile phone use) and then in separate years from 1997 to 2008, adjusted for age group, specific SEER registry, and sex. We used model fitted rates to estimate observed rates, rather than crude rates, to avoid the introduction of errors from changes in the underlying population distribution (by age, sex, and registry). Model observed rates of glioma were estimated using men aged 60-64 years from the Los Angeles SEER registry as the baseline categories (web appendix, model A1), but the entire dataset (all ages ≥18 years, sexes, registries) was used to estimate these rates using this model. The reason for using these baseline categories is given in the web appendix. We fitted the model by Poisson maximum likelihood27 using Epicure (web appendix).28

We calculated predicted risks of glioma with (ever versus never) mobile phone use in 1997-2008 by combining the estimated rates of glioma in 1992-6, the number of phone subscriptions per capita, and various assumed relative risks associated with ever using a phone and latency periods (fig 2⇓). In figure

2, we also included a line corresponding to a relative risk of 0.8 (approximately corresponding to what was observed in the Interphone study).4

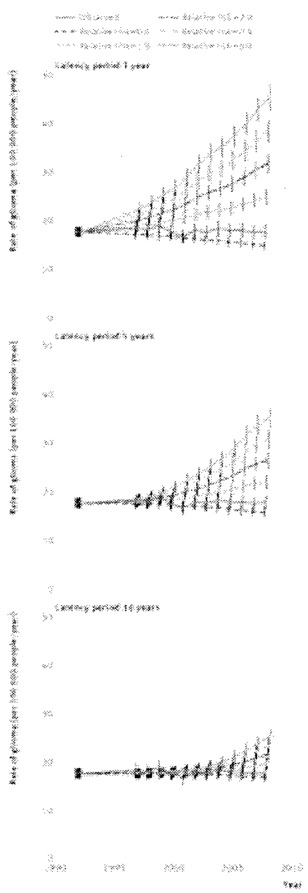

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Fig 2 Observed and projected rates (95% CI) of malignant glioma in non-Hispanic white people, by latency period and various assumed levels of relative risk associated with ever using a phone

We further estimated the predicted rates by combining the number of mobile phone subscriptions with the relative risks by latency period and cumulative hours of phone use estimated in the Swedish study10 and Interphone study4 (web appendix, model A2). We assumed that the cumulative hours of phone use in the US population had the same distribution as that in the control groups in each study, as shown in tables 2-4⇓ ⇓ ⇓.

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Table 2

Relative risk of glioma (and astrocytoma) from the Swedish study10

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Table 3

Relative risk of glioma from the Interphone study4

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Table 4

Relative risk* of glioma from appendix 2 of the Interphone study4

We compared these projected rates of glioma for each year from 1997 onwards, with the corresponding "observed" rates predicted by the model (that had adjusted for age, registry, and sex) (figs 3⇓ and 4⇓,

tables 5⇓). We also used predicted data from appendix 2 of the Interphone study4 (tables 4 and 6⇓), which calculated risks relative to low use categories of mobile phone users (rather than the non-regular users used in the main analysis). We did this additional analysis to minimise potential bias that had been indicated by the J shaped dose-response curve in the Interphone study.4 However, when predicting the risk of US glioma incidence in table 6, we assumed that these relative risks were relative to the group of non-users of mobile phones. Because many relative risks of exposed people, compared with non-exposed people, were less than 1 in the Interphone study4 (implying an unexpected protective effect of phone use), we also estimated rates assuming that Interphone study risks were 1 or more (thus setting all relative risks less than 1 to 1), which assumes no protective effects in any category. The reporting of our study conforms to the STROBE statement29 (web appendix, table A4).

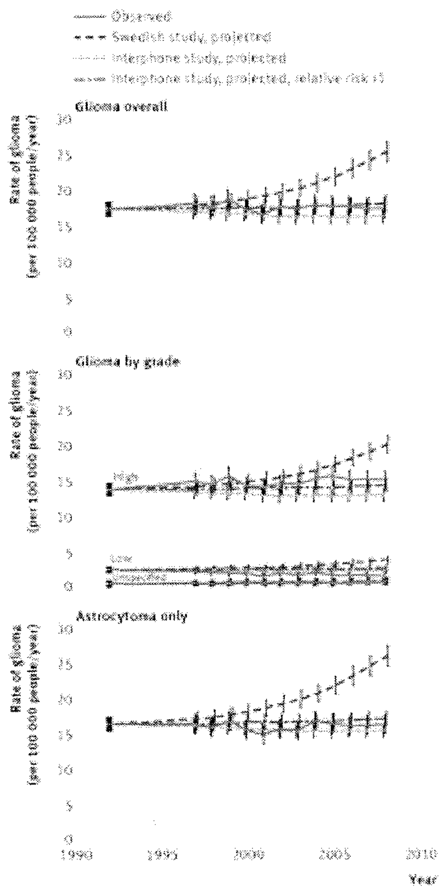

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Fig 3 Observed and projected rates (95% CI) of malignant glioma in non-Hispanic white people, by histological type and WHO grade of glioma, using the relative risks, periods of latency, and cumulative hours of phone use from the Swedish study10 and Interphone study4

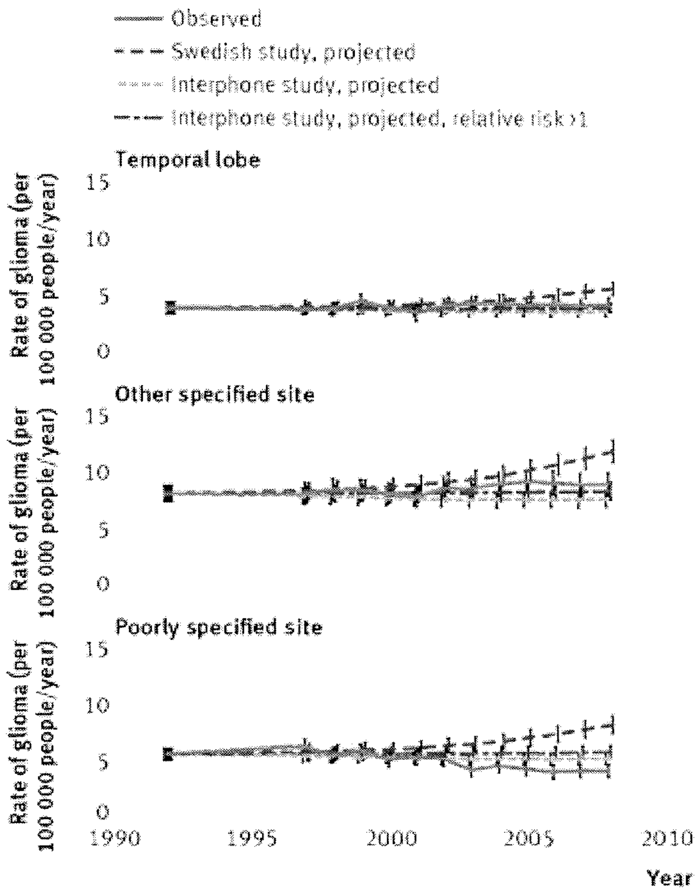

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Fig 4 Observed and projected rates (95% CI) of malignant glioma in non-Hispanic white people, by tumour location, using the relative risks, periods of latency, and cumulative hours of phone use from the Swedish study10 and Interphone study4

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Table 5

Comparison of observed rates of glioma in non-Hispanic white people in 2008 with projected rates for 2008 based on relative risks, periods of latency, and cumulative hours of phone use from the Swedish study (table 2)10 and Interphone study (table 3)4

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Table 6

Projected rates of glioma for 2008, based on relative risks from appendix 2 of the Interphone study (table 4)4

Results

Glioma rates were generally stable from 1992 to 2008 (figs 2-4, table 5), changing by about −0.02% per year (95% confidence interval −0.28% to 0.25%) over this period (table 7⇓). The only marked exceptions were gliomas of low grade and those with a poorly specified anatomical location, which showed decreased rates (−3.02% per year (−3.49 to −2.54) and −2.35% per year (−2.81 to −1.89), respectively), and gliomas of the temporal lobe and other specified sites, which showed modest increases in rates (0.73% per year (0.23 to 1.23) and 0.79% per year (0.40 to 1.19), respectively) (figs 3 and 4, tables 5 and 7). However, we saw no acceleration in the rate of gliomas at the temporal lobe (P=0.279) or at other specified sites (P=0.090) before 1996 compared with after 1996 (results not shown). Equally, we saw no evidence to indicate a decrease in glioma risk by about 20% (that is, a relative risk of 0.8), which had been indicated by the Interphone study for regular users of mobile phones.

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Table 7

Trends in SEER glioma rates for non-Hispanic white people over the period 1992-2008

The result of assuming a true association of mobile phone use greatly increased the expected glioma rates. Even with a lag of 10 years and the smallest assumed relative risk more than 1 that was associated with ever using a phone (that is, a relative risk of 1.5), the underlying glioma rate estimated by age, registry, and sex was predicted to increase from 17.7 per 100 000 people per year (95% confidence interval 16.7 to 18.7) in 1992-6 to 19.5 per 100 000 people per year (18.5 to 20.7) in 2008, an increase of 10.7% (fig 2). With greater relative risks or shorter lag periods, this increase became much larger. In general, glioma rates were predicted to increase by at least 20% with a short latency period (≤5 years) or large relative risks (≥2.0) (fig 2).

Predicted rates were substantially more than observed rates if we applied the relative risks of the Swedish study10 to the 1992-6 baseline rates (and took account of the distribution by latency periods and cumulative phone use reported), and if we accounted for the increasing per capita prevalence of mobile phone use (figs 3-4, table 5). For example, the observed rate for glioma in 2008 was 17.7 per 100 000 people per year (95% confidence interval 16.5 to 19.0), whereas the projected rate in that year, assuming that the Swedish study's relative risks associated with mobile phone use apply, was 44.5% higher than the observed rate (25.5 per 100 000 people per year (24.2 to 27.0)), and clearly inconsistent with it. In general, the model predicted the same or greater effects for astrocytoma only (fig 3, table 5), various grades of glioma (fig 3, table 4), and different anatomical sites (fig 4, table 5). Results were similar if we used the Swedish study's "ever versus never use" data10 rather than the data taking account of cumulative hours of phone use (results not shown).

However, if we used the relative risks from the Interphone study,4 the expected incidence rate of glioma in 2008 changed to 16.5 per 100 000 people per year (95% confidence interval 15.6 to 17.5), compared with the observed rate of 17.7 per 100 000 people per year, or 18.2 per 100 000 people per year (95% confidence interval 17.3 to 19.3) if we restricted excess risks to be positive (that is, relative risk ≥1) (fig 3, table 5). The confidence intervals around the glioma rates implied that the observed trends were consistent with those predicted by the Interphone study; we observed the same effect if we used the relative risks taken from appendix 2 of the Interphone study4 (table 6). We saw similar results for specific groups aged 40 to 69 years (web appendix, table A5 and fig A1). Results were also similar for different categories of sex, or race (web appendix, tables A6-A10) and differing baseline periods (1992-5 or 1992-7; results not shown).

Discussion

The results of this study suggest that, if the effects of mobile phones on malignant glioma risk are substantial, then the incidence rates in the US population would be far higher than those observed over most of the study period in 1992-2008 (fig 2). Although we cannot rule out modest increases in glioma incidence since 1992, increases of 20% or more that might occur if the latency period was short (≤5 years) or relative risk was large (≥2.0) were inconsistent with the observed SEER data. Using the relative risks from the Swedish study10 and accounting for the substantial increase in phone use in 1992-2008, our alternative analysis predicted that glioma rates should be about 44% higher than the observed incidence rates for 2008.

However, if we used the relative risks from the Interphone study,4 the increase in mobile phone use in 1992-2008 predicted a modest reduction in glioma incidence of about 7% (or an increase of about 3% if assuming relative risks ≥1); these results were consistent with the observed rate. However, we did not find evidence supporting the overall reduction of about 19% when comparing ever use and never use groups, as implied by the Interphone study (fig 2). The J shaped dose-response curve in the Interphone study, of which this 19% reduction is one indicator, has been used to argue for possible participation bias, implying that risks ought to be estimated relative to the lowest use group, rather than to non-users (that is, using the results from appendix 2 of the study).4 The findings based on appendix 2 of the Interphone study were consistent with observed glioma trends (tables 5 and 6).

Without data indicating substantial effects of mobile phone exposure on incidence rates of brain cancer,1 2 3 4 5 it is not possible to accurately estimate the minimum latency period. Ionising radiation is generally assumed to have a minimum latency period of 2-5 years.30 31 The induction of cancer is thought to occur largely by the initiation of DNA lesions.32 In particular, clinical evidence has shown clonal DNA mutations in brain tumours,33 34 35 36 implying that DNA damage could be the initiating event. Ionising radiation, which is known to induce brain cancer,30 is thought to do so by initiating large scale chromosomal damage resulting from DNA breakage and rearrangement.32

Since microwave radiation produced by mobile phones is non-ionising and therefore not strong enough to cause DNA lesions directly, it probably acts later in the carcinogenic process. This effect implies that the minimum latency period for radiation produced by mobile phones is probably shorter than that for ionising radiation (that is, <5 years). However, since the cause of brain cancer is still unclear, we could not definitively state a minimum latency period, and therefore considered several periods between 1 and 10 years, similar to other studies.4 10 The Swedish study10 suggested a minimum latency period of at least 10 years (table 2; web appendix, table A1). This result is puzzling, because the study used data for people diagnosed in 1997-2003, and mobile phone use in Sweden only began to be appreciable only in the mid to late 1990s.14 17

Several scientific groups have reviewed the experimental in vivo and in vitro data available for microwave exposure from mobile phone use.12 37 No compelling data have suggested that microwave exposure can increase the risk of any type of cancer, or raise rates of somatic or germ cell mutation.37 In particular, a study of 480 Fischer rats did not find any excess risk of glioma or astrocytoma in those exposed to 835.62 MHz or 847.74 MHz of microwave radiation.38 However, the study's statistical power for astrocytoma was probably low, because the 160 controls had a 1% prevalence.

Strengths and limitations of the study

This study used population based incidence data from the well regarded SEER programme. The SEER data's high quality was evidenced by the completeness of case ascertainment and the accurate classification of cancer sites and histological types. However, the appropriate exposure measure for brain cancer is still unclear in relation to mobile phone use. A widely used method is to use an "ever versus never use" comparison.1 2 3 4 5 6 7 8 9 Metrics based on the duration of mobile phone use have also been used—that is, the number of minutes per day of operation, duration of use (in years), or cumulative period of use (in hours).1 2 4 7 8 10 We used a model based on an "ever versus never use" comparison (fig 2) and another based on the cumulative hours of mobile phone use (figs 3 and 4, table 4). (Our definition of "ever use" was based on the ownership of a phone, whereas the Interphone study defined "ever use" as an average of at least one phone call per week for six months or more, based on interview data from individuals.4) We used both models in conjunction with data for phone subscriptions gathered for the US as a whole,25 to assess the effect of mobile phone use on glioma incidence.

Subscription data may have slightly underestimated the proportion of people who were mobile phone users, because people might have used a phone without being a subscriber. More likely, the data could have overestimated the proportion, because some individuals might have had multiple subscriptions. The number of subscribers in 2011 exceeded the US population by about 2%,25 implying that the estimate was unlikely to be substantially in error downwards, and we suspect also upwards. The area covered by the SEER registries might not have represented the US as a whole in its ownership and use of mobile phones. Furthermore, the age distribution of users might not have matched that of the underlying SEER population, although the two cannot be very different towards the end of the period considered when ownership approached 100% of the population.

The second model used was slightly more sophisticated, and used estimates of relative risk for specific classes of latency periods and cumulative hours of phone use reported by the Swedish study10 and Interphone study.4 We used both models to predict cancer rates (particularly for the period 1997-2008), with data for mobile phone ownership. A critical assumption of both models was that the underlying cancer rates (in the absence of phone use) remained constant at the levels determined for the period 1992-6, when use was relatively modest. However, for low grade tumours and those of poorly specified anatomical location, incidence seemed to decrease in 1992-2008 (figs 3 and 4), so this assumption might not have been valid for these endpoints. The reduction in tumours with poorly specified sites might have indicated improvements in diagnosis during this period, which would therefore lead to increased rates of gliomas at the temporal lobe and at other specified sites. The fact that the rate of increase did not change substantially after 1996 for gliomas at the temporal lobe and at other specified sites suggests that phone use was not a contributing factor.

The generally flat trend in incidence could have masked an increasing glioma risk associated with mobile phone use that had been counterbalanced by a fall in incidence due to reductions in other hypothetical exposures associated with excess risk of glioma. However, the increase in phone use during the study period would probably not have cancelled out the overall reduction in glioma rates due to speculative other contributing factors. Finally, risks of glioma in small susceptible subgroups might not have been detectable in aggregate population risks.

We focused on non-Hispanic white people, because black and Hispanic white people are known to have lower rates of brain tumours13 and also make up variable proportions of the underlying SEER population, as seen with the rapidly increasing proportion of Hispanic white people in the largest SEER registry (Los Angeles). However, analyses in additional ethnic groups have produced similar results (web appendix, tables A6-A8).

Excess risks of glioma associated with mobile phone use might not become apparent for at least 10 years. However, the latency periods used in our models were based on observations in the Interphone study4 and Swedish study.10 The Swedish study suggested an appreciable risk of glioma within 10 years of exposure.

Delays in cancer registration of glioma cases could have caused recent incidence rates to underestimate the true rates. Calculations based on SEER data have suggested that 2008 rates of brain cancer in white people, after adjustment for delay, might be about 4% higher than those initially reported.18

The choice of 1992-6 as the baseline period was arbitrary, and the interval was used because of the low level of mobile phone subscriptions (<15% of the US population) during this period. Results obtained using alternative baseline periods (1992-5 and 1992-7) were very similar.

We assumed that the patterns of mobile phone use (numbers of hours used by years of latency) were similar to the Swedish10 and the Interphone studies.4 To the best of our knowledge, analogous data for phone use do not exist for the US population. However, in view of the similar distribution of hours of use by latency period in the Swedish10 and Interphone studies4 (tables 2 and 3), we would not expect any patterns of use in the US population to be substantially different from those considered in these two studies.

Another weakness was that the estimated cumulative hours of use was for the period 1997-2003 for the Swedish study10 or 2000-4 for the Interphone study,4 while incidence trends in our analysis were predicted from 1997 to 2008. Owing to the additional four or five years of incidence included in our study, a substantially larger proportion of the mobile phone users would have reached the numbers of hours of phone use in the highest exposure categories of the Swedish10 and the Interphone studies,4 as well as longer latency periods. The cumulative hours of use among participants in the Interphone study were recorded mostly in 1980-2004, when mobile phone use was less common, more expensive, and less a part of daily life than it is in the more recent years of the present study. Use of the estimated cumulative hours of use from the Swedish10 and Interphone4 studies would have resulted in our underestimating the predicted change in the incidence trends. However, this would only appreciably affect our results if we assumed a minimum latency period shorter than 5 years.

In the Interphone study,4 participation bias had been postulated as an explanation for the overall reduced risk for glioma and meningioma. Assuming that the bias was uniform across all exposure groups, this could be eliminated by using the renormalising strategy as proposed in appendix 2 of the Interphone study.4 The relative risks used in our study were always assumed to be relative to non-users. But we also used groups with the lowest phone use as a baseline category (as in appendix 2 of the Interphone study), with the assumption that glioma rates in these groups were identical to those in non-users.

What is already known on this topic

The IARC recently re-evaluated brain tumour risks associated with mobile phone exposure and classified microwave radiation produced by mobiles phones as a possible human carcinogen, largely based on relative risks reported by two epidemiological studies, the 2010 Interphone study and a 2011 Swedish study by Hardell and colleagues

However, trends in brain cancer incidence have not mirrored the substantial increase in mobile phone use since the mid-1990s, and have generally remained constant

What this study adds

We compared projected rates with observed rates of glioma incidence by also considering the effect of detailed latency distribution and patterns of mobile phone use

Based on relative risks from the Swedish study, predicted rates of glioma were much higher than (and therefore statistically inconsistent with) observed rates. However, based on relative risks from the Interphone study, projected rates could be consistent with the observed data

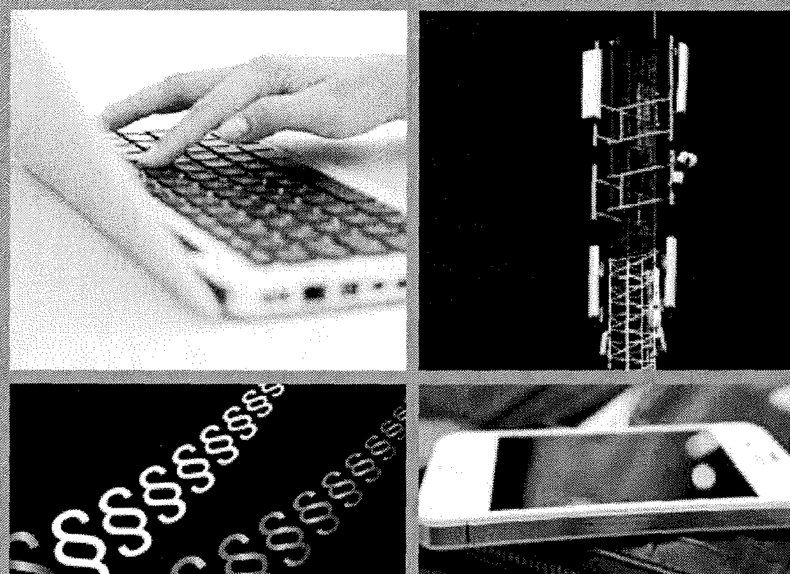
APPENDIX G

Norwegian Institute of Public Health, Low-level Radio Frequency Electromagnetic Fields: An Assessment of Health Risk and Evaluation of Regulatory Practice, Summary 2012

See attached.

report 2012:3

Low-level radiofrequency electromagnetic fields – an assessment of health risks and evaluation of regulatory practice



Report from the Expert Committee appointed by the Norwegian Institute of Health, commissioned by the Ministry of Health and Care Services and the Ministry of Transport and Communications

English summary

Norwegian Institute of Public Health

Summary

This is the English summary extracted from the Norwegian report about low-level radiofrequency electromagnetic fields (2012:3). The summary is translated by the Norwegian Institute of Public Health.

The use of equipment that emits radio waves has increased in recent years. Wireless communication technologies such as mobile phones are widespread. In recent years, the demands for better coverage, enhanced technology and extended features for mobile phone services have resulted in a significant increase in the number and density of radio transmitters. Exposure to electromagnetic fields and its potential health effects is a prominent topic in the media. This has led to public concern and uncertainty, not only about electromagnetic fields emitted from mobile phones, but also about electromagnetic fields emitted from base stations used by mobile phones and other wireless networks. The Norwegian Radiation Protection Authority receives daily enquiries about the possible adverse health effects from such exposure. The Norwegian health authorities decided that there was a need for a wider review and assessment of the potential health effects to be carried out by scientists from various disciplines, in order to clarify any risks to human health and to assess the need for changes in the regulation of electromagnetic fields.

On the basis of the public concerns, the Ministry of Health and Care Services and the Ministry of Transport and Communications requested, in a letter dated 16.11.2009, that the Norwegian Institute of Public Health should assemble a cross-disciplinary Expert Committee. The mandate requested that the group should: "... summarise the knowledge regarding exposure to weak high-frequency fields. It shall provide a summary of the current management practices in Norway and in comparable countries. The purpose is to investigate the management and regulations concerning electromagnetic radiation, including the placement of mobile masts, base stations and wireless networks. The analysis should also include an assessment of the suitability of the threshold limit values, as well as an assessment of how the potential risks related to exposure from electromagnetic fields should be managed in Norway."

The Expert Committee was established in spring 2010 and was composed of individuals with expertise in environmental and occupational medicine, biology, physics, metrology, biophysics, biochemistry, epidemiology and philosophy, as well as expertise in administration and risk management:

Jan Alexander, MD PhD, Prof., Deputy Director-General, Norwegian Institute of Public Health (Chair of Committee)
Gunnar Brunborg, PhD, Department Director, Norwegian Institute of Public Health
Maria Feychting, PhD, Prof., Karolinska Institutet
Ellen Marie Forsberg, PhD, Senior Scientist, Work Research Institute/ Oslo and Akershus University College of Applied Sciences
Svein Gismervik, Civil Engineer, Technical Team Leader, Trondheim Municipality
Jan Vilis Haanes, MD, Chief Medical Officer, University Hospital of North Norway
Yngve Hamnerius, Prof., Chalmers University of Technology
Merete Hannevik, MSc, Head of Section, Norwegian Radiation Protection Authority
Per Eirik Heimdal, MSc, Head of Section, Norwegian Post and Telecommunications Authority
Lena Hillert, MD PhD, Associate Prof., Senior Medical Officer, Karolinska Institutet
Lars Klæboe, PhD, Senior Scientist, Norwegian Radiation Protection Authority
Petter Kristensen, MD PhD, Prof., Research Director, National Institute of Occupational Health
Bente Moen, MD PhD, Prof., University of Bergen
Gunnhild Oftedal, PhD, Associate Prof., Sør-Trøndelag University College
Tore Tynes, MD PhD, Senior Medical Officer, National Institute of Occupational Health
Bjørn Tore Langeland, PhD, Norwegian Institute of Public Health (Secretary until 31.1.2012)
Observer: Solveig Glomsrød, Foreningen for el-overfølsomme (FELO) (Association of electromagnetic-hypersensitive citizens)

The Expert Committee has reviewed and evaluated recent research in the relevant fields. They have reviewed recent research reports and expert review reports by international and national expert groups. Based on this review and on available data about exposure to electromagnetic fields, the Committee has conducted a risk assessment and also evaluated the current regulatory practice.

The Committee's experts on health and exposure to electromagnetic fields share the main responsibility for part I and part II of this report. The Committee's experts on health effects and biophysics have primarily contributed to the recommendations regarding the regulatory practices, and ensured that these are consistent with the professional evaluations.

A reference group was established in response to requests from the Ministry of Health and Care Services and the Ministry of Transport and Communications. A number of institutions were invited. The reference group consisted of: Per Morten Hoff (ICT Norway), Bjørn Erikson and Ali Reza Tirna (The Norwegian Confederation of Trade Unions (LO)), and Solveig Glomsrød (FELO). The reference group has held meetings with the Chair and the Committee's Secretariat and has provided valuable input on an ongoing basis.

1.1 Process

An overall assessment of the health risks of exposure to electromagnetic fields – the part of the frequency spectrum called radiofrequency fields (RF fields; frequency range 100 kHz-300 GHz) – has been implemented in the same way as is common for other types of environmental exposure. Health risks have been evaluated on the basis of internationally published research literature, which is very extensive for RF fields. Exposure to RF fields in the Norwegian population has been considered primarily using measurements taken by the Norwegian authorities in the course of 2010. The Expert Committee has assessed the overall health risk based on these measurements.

Part I of the report describes the current exposure to RF fields, sums up the knowledge of potential health hazards and contains a risk assessment. *Part II* of the report addresses the general health problems that are attributed to electromagnetic fields (electromagnetic hypersensitivity). *Part III* describes the risk management, risk perception and concern for harmful effects of RF fields. *Part IV* reviews the present regulation of RF fields in other countries as well as in Norway. *Part V* assesses the current regulations in Norway and provides advice on how to regulate RF fields.

1.2 Exposure to low-level RF electromagnetic fields (Chapter 3)

Levels of natural (i.e. not man-made) RF fields are very low. RF fields in the environment are therefore generated by human activity.

The sources of RF fields are primarily equipment used in communications, industry and medicine. In communication systems (e.g., mobile phones), the antenna functions most often as both the transmitter and receiver of the electromagnetic field. The main factors that affect exposure are distance from the antenna, the effect from the transmitter, frequency, the antenna's transmission direction, the antenna location (e.g. height above ground), and the number of antennas. The source that most often provides the strongest exposure is the mobile phone.

In 2010, the Norwegian Post and Telecommunications Authority and the Norwegian Radiation Protection Authority conducted a study of exposure to RF fields in the environment. Prior to this, systematic studies had only been conducted in Norway to a limited extent, although individual measurements had been conducted on many occasions. The 2010 study included exposure from broadcasting, wireless internet (WLAN) and base stations for services like mobile broadband, mobile telephony and the public safety radio network (TETRA) in a selection of buildings and outdoors. Total exposure from all sources in the environment was less than 0.01 W/m^2 for 99 per cent of the measurement points and below 0.001 W/m^2 for 70 per cent of the measurement points. In most places, the level was well below 1/1000 of the reference values for maximum exposure as recommended by the International Commission on Non-ionising Radiation Protection (ICNIRP). These reference values apply as the threshold limit values in the Norwegian radiation protection regulations. Wireless networks were generally the weakest of the RF field sources. Base stations for mobile telephony (GSM900 and GSM1800) were, on average, the source type that contributed the most in relative terms, although the levels from these sources were still low. In office environments, wireless networks were the dominant source, but the overall exposure to RF fields was low. Similar measurements carried out in some other European countries show that the levels in Norway are comparable, with the same technology.

Due to the short distance, local exposure to the head from hand-held mobile phones is significantly higher than that from the other RF sources in the environment, and mobile phones provide the highest contribution to the total exposure for individuals. The use of hands-free mobile phones reduces exposure significantly. When a GSM mobile phone transmits at maximum power, the exposure from some models approaches the ICNIRP's reference values for maximum exposure. A greater density of base stations leads to better coverage so that mobile phones can transmit with lower power, leading to lower exposure. In recent years, technological developments have contributed further to lower exposure to RF fields. Even if usage time of mobile telephony were to continue to increase, it is assumed that the total exposure from mobile phone use may decrease because of better transmission networks and because the emitted power from newer UMTS phones is much lower than from GSM phones.

1.3 Health effects from exposure to electromagnetic fields (Chapter 4)

Chapter 4 provides a summary of possible health hazards following exposure to weak RF fields, and at which exposure levels these may occur when fields are stronger. In addition, the Expert Committee has reviewed scientific evidence about the significance of electromagnetic field exposure for individuals who experience health problems from electromagnetic fields (electromagnetic hypersensitivity).

1.3.1 Known health effects from strong RF fields

Thermal effects, i.e., heating of cells and tissues, can occur from exposure to RF fields that exceed certain intensities in the frequency range 100 kHz - 10 GHz. The degree of heating may depend on the field intensity and frequency and also on the balance between the amount of absorbed energy per unit time and the body or tissue's ability to dissipate the heat. There are exposure thresholds above which heating becomes harmful following exposure to RF fields. It is known that whole body exposure with SAR = 4 W / kg (for a mean of 30 minutes) can cause a temperature increase of about 1 °C which is considered to be a threshold for adverse health effects, implying that a temperature increase of up to 1 °C has no negative consequences. So-called basic restriction values are derived from the exposure threshold values, with additional safety factors. For workers and the general public, the basic restriction values are, respectively, 1/10 and 1/50 of the exposure threshold value of 4 W / kg for SAR, i.e. 0.4 and 0.08 W/kg. From the basic restriction values, the so-called reference values are derived for external fields, i.e., these are values which can be measured in the air outside the body.

Excitation of nerve tissue, i.e. the initiation of nerve signals, can occur from exposure to RF fields in the frequency range up to 10 MHz when electric fields are induced above certain intensities in the body. The exposure levels required to cause excitation of nerve tissue vary with frequency. As for heating, the ICNIRP basic restriction values of electric field intensities are derived from the exposure levels, with additional safety factors. From the basic restriction values, reference values are derived for the external field.

There is a broad international consensus among experts that the ICNIRP reference values (recommended values for maximum exposure) provide good protection against both the excitation of nerve tissue and harmful heating of body tissues. For exposure at levels below the ICNIRP reference values, the ICNIRP has found no documented adverse effects, despite extensive research. No mechanisms have been identified which could account for any such effect.

The Expert Committee has used the ICNIRP's basic restriction and reference values as the foundation for its review and assessment of possible adverse effects that may occur as a result of exposure to weak RF fields. The questions discussed by the Expert Committee mainly concern whether there may be adverse effects at exposures lower than the ICNIRP basic and reference values, i.e., weak RF fields. Is there evidence of harmful effects from the scientific study of cells, animals or people? If the answer to that question is no - how good is the evidence that exposure is safe at levels below the ICNIRP levels?

1.3.2 Health effects of weak RF fields[1]

There are a large number of older and newer studies of possible health effects caused by RF fields. Compared with many other types of environmental exposure where there is a proven health risk, the research literature for weak RF fields is extensive.

The Expert Committee has reviewed previous scientific reports from independent expert panels worldwide, as well as recently published studies on the possible effects on health following exposure to weak RF fields. Emphasis has been placed on whether there is consensus among the conclusions of the various expert groups. The health effects that are most studied are : the risk of cancer development and effects associated with cancer development (e.g., DNA damage); the effects on reproduction; the nervous system; the cardiovascular system; the immune system; hormone regulation; gene expression in cells; and the significance of electromagnetic fields for individuals who experience health problems following exposure to electromagnetic fields (electromagnetic hypersensitivity). The conclusions below are based on an overall assessment of both older and newer studies, performed in either cells and tissues, in animals, or in humans - i.e., experimental clinical trials and population studies.

[1]Weak RF fields are defined by the Expert Committee as being below ICNIRP's Reference Values

Most recent studies have investigated the possible health effects from exposure to weak RF fields at levels that are lower than those known to cause dielectric heating or excitation of nerve tissue.

Some studies observed that exposure to weak RF fields may have measurable biological effects. In several studies, it is difficult to rule out that exposure might have led to local heating. It is important to note that cells and tissues that are exposed to very low heat will respond with measurable biological responses in the same way that the body responds to other physical influences, such as heat and cold from other sources. In such cases, the body will seek to maintain normal body temperature. Thus, such biological responses do not imply that an adverse health effect has been induced.

1.3.2.1 Cancer

A number of population studies have studied possible cancer risks as a result of RF exposure. Most studies have been on head tumours in connection with the use of mobile phones, since this is the area with the highest RF exposure. Methodological problems in these studies include the risk of erroneous registration of RF exposure by mobile phone use. In cohort studies (where populations are followed and exposure data is collected before any disease diagnosis), inaccurate exposure data can mean that possible associations are not detected. In case-control studies, mobile phone use among patients who developed brain cancer is compared with mobile phone use among healthy control subjects. Exposure data is collected after diagnosis. In such studies, exposure reports can be affected by disease status, leading to false or apparent associations, where in reality there are none (recall bias). It is reasonable to assume that the gradually increasing and widespread use of mobile phones would have led to an increased cancer incidence over time, if use was carcinogenic. Using several cancer registries, incidence studies have examined changes in the incidence of suspected cancers since mobile telephony was introduced. An overall assessment must take into account the results from all types of studies, i.e., cohort studies, case control studies and incidence studies. With the exception of some case-control studies, the majority of the case-control studies and cohort studies have reported no increased risk of cancer. The results of the incidence studies show no evidence of increasing incidence of these cancers over time.

The Expert Committee considers the increased risk reported in some case-control studies to be inconsistent with the results from studies of time trends based on cancer registry data in either the Nordic or other countries.

Overall, the available data show no association between exposure to RF fields from a mobile phone and fast-growing tumours, including gliomas in the brain which have a short induction period (time from exposure to disease).

For slow-growing tumours, including meningiomas and acoustic neuromas, the data available so far do not indicate an increased risk. However, it is too early to completely exclude the possibility that there may be an association with exposure to RF fields from mobile phones, because the period of use of mobile phones is still too short. Available epidemiological cohort and case-control studies provide no information about a possible effect after a long induction period. The longest induction period studied is 13 years, and no participants had used mobile phones for more than 20 years old when the studies were conducted.

For leukaemia, lymphoma, salivary gland tumours and other tumours, there are insufficient data to draw conclusions, but the available studies do not suggest an increased risk. The only study that looked at exposure to RF fields from mobile phones and the possible risk of brain tumours among children and adolescents does not support an association, but a minor increase in risk cannot be excluded as a result of limited statistical power in the study.

There are several registry-based studies that have examined the development of the incidence of brain tumours over time among children and adolescents. They show no indication of increased disease incidence in these groups after the introduction of mobile phones.

Exposure from base stations and radio and television transmitters is significantly lower than from using a mobile phone and the available data do not suggest that such low exposure could increase the risk of cancer.

A number of studies of cancer in animals have been performed, and relevant mechanisms have also been studied using micro-organisms and cells. Overall, these studies provide further evidence that exposure to weak RF fields does not lead to cancer.

As a result of the specific methodological problems, new case-control studies would probably only provide limited new information. In new studies, it will be more important to monitor the incidence of brain tumours in population-based cancer registries with high quality records. This should identify whether the incidence of these tumours in children, adolescents and adults remains unchanged.

1.3.2.2 Reproductive health

It is well known that exposure to RF fields at levels that provide thermal effects (dielectric heating), can damage sperm. Several studies of sperm samples from humans and animals have been carried out to investigate possible non-thermal effects of RF exposure on sperm. Since sperm cells are particularly sensitive to heating from RF fields, it is important that there is good control of exposure during the experiments. Most of the earlier studies were of too poor quality, particularly with regard to control of this aspect of exposure, for any conclusion to be drawn from them. Some recent experimental studies have high methodological quality and good control of exposure. The results of these studies are ambiguous. Several new animal studies of high quality showed no effect on sperm quality after RF exposure. There are three new studies of reasonable quality where the exposure is performed on human sperm samples. Two showed effects from weak RF fields, while one study showed no effect. The effects are observed on mature sperm, and the changes are likely to revert when new sperm are produced. The results must be reproduced and confirmed by several research groups before conclusions can be made. It is uncertain what the relevance of exposure of sperm outside the body is compared to exposure of sperm in the testicles. Furthermore, there is a lack of knowledge about the significance of moderate changes in sperm quality on male fertility. There are few population studies of a possible change in fertility caused by RF exposure, and they have significant weaknesses, so conclusions cannot be drawn from these.

Very few of the older studies show evidence of harmful effects on the foetus after exposure to weak RF fields. Recent animal studies with good exposure control have shown no signs of injury. A few population studies of possible effects on the foetus after exposure to weak RF fields have been carried out, and those that exist have significant weaknesses.

Behaviour and development in children of mothers who used mobile phones during pregnancy have been studied in a few, relatively large population studies. These studies provide little evidence that there is a link between pregnant mothers' use of mobile phones and the risk of changes in the behaviour and development of the child.

Overall, there is little indication that exposure to weak RF fields adversely affects fertility. The few studies that do exist do not provide evidence that exposure to weak RF fields during pregnancy has adverse effects on the foetus.

1.3.2.3 Heart, blood pressure and circulation

There are several earlier studies of the cardiovascular system in animals and humans exposed to weak RF fields, but relatively few studies have been reported in recent years. Overall, the studies of high quality present no evidence that weak RF fields have adverse effects on the cardiovascular system.

1.3.2.4 The immune system

There are several earlier studies of the possible effects of RF exposure on the immune system; in some of these, transient effects due to heat and stress have been observed. In recent years, there have only been a few studies on the immune system of animals and humans and on immune cells outside the body (*in vitro*). Older studies, as well as recent high quality studies, provide no clear evidence of negative effects of exposure to weak RF fields on the immune system.

1.3.2.5 Hormonal effects

There are relatively few earlier or recent studies where the effect of exposure to weak RF fields on hormonal regulation has been investigated. Several studies have examined whether there are changes in melatonin production, a hormone that regulates circadian rhythm. There is less information on other hormone systems. Several studies have methodological weaknesses, and therefore emphasis should not be placed on them; however there are also some high quality studies. Previous and recent studies do not provide evidence that exposure to weak RF fields adversely affects the hormone system in humans.

1.3.2.6 Effects on the nervous system

The possible effects of weak RF fields on the nervous system have been investigated in many studies, and are divided into three main groups. These include biological effects and functional changes, effects on performance and behaviour, and possible adverse health effects. As previously mentioned, any observed biological effects and functional changes do not necessarily have an impact on performance or health or disease, even in the nervous system. In many cases, the responses can represent a physical adaptation to external stimuli, as with other physical stimuli such as heat or cold

Animal studies provide no basis for assuming that exposure to weak RF fields causes biological effects in the nervous system. Most human studies monitor electrical brain activity using EEG. Many of these are of high quality, and they provide some evidence that exposure to RF fields from GSM phones can cause small and transient changes measured at rest and during sleep. The changes in brain activity are not accompanied by symptoms or poor sleep quality. 3G (UMTS) phones do not seem to have such an effect, but there are few studies of this type of phone. Some human studies have examined blood flow in the brain, or effects on brain metabolism following RF exposure, but there are few studies and the results are inconsistent.

Performance and behaviour in adults after exposure to weak RF fields have been studied in several large studies of high quality. There are few studies of adolescents and these are of variable quality. Overall, there is no evidence that exposure to weak RF fields affects performance or behaviour.

Based on a large number of studies, many of which are of high quality, there is no evidence that weak RF fields cause symptoms such as headache, fatigue or concentration problems, either after short or long-term exposure. From animal studies there is no evidence of damage to vision, hearing or the balance organ. Human studies support this conclusion with regard to short-term effects on hearing and balance. Long-term effects on hearing have only been investigated in a few studies, which have methodological limitations. Few animal studies and epidemiological studies have examined severe effects on the central nervous system. So far there is no evidence that severe disorders can occur as a result of exposure to weak RF fields.

Although certain changes in electrical brain activity from some forms of exposure to weak RF fields have been observed, there is no evidence that such exposure can have negative effects on performance or behaviour, or have health-related consequences for the nervous system. There is no evidence that exposure to weak RF fields leads to an increased risk of disease of the nervous system. A limited number of studies have been conducted with children and adolescents, but the results so far provide no evidence that children differ from adults in terms of possible effects on the nervous system.

1.3.2.7 Changes in gene expression

In recent years, there have been a large number of cell and animal studies on the effect of RF fields on gene expression. Gene expression in cells is normally in constant change, e.g., when cells are exposed to internal or external stimuli. Changes in gene expression have been observed after RF exposure, but studies show inconsistent results, especially with regard to which groups of genes show altered regulation. At present, there is little to suggest that exposure to weak RF fields causes changes in gene expression that can be linked to adverse effects in humans.

1.3.2.8 Health problems attributed to electromagnetic fields (electromagnetic hypersensitivity)

A large number of controlled experiments have been carried out on groups of individuals with adverse health effects that they attribute to electromagnetic fields (see also 1.5). Most studies are performed in the laboratory, in the workplace or in the home. Although the quality varies, there are many trials that are methodologically sound. One study of good quality was a follow-up study of groups of individuals (defining themselves as electromagnetic hypersensitive or not; the former group had more health problems but they did not seem to be related to electromagnetic field exposure); this is the only prospective study that is available. A few experiments have been designed to examine individuals with repeated exposure. The relatively extensive literature provides no evidence that exposure to electromagnetic fields is the real cause of the health problems that individuals attribute to electromagnetic fields, whether exposure occurs alone or in combination with other factors that may affect the induction of symptoms. There is also no evidence that individuals with health problems that they attribute to electromagnetic fields are able to detect such exposure. Blind trials show that symptoms also occur when subjects are not exposed. This means that electromagnetic fields do not need to be present for health problems attributed to electromagnetic fields to occur. Health problems can thus be due to other factors; see further discussion in Section 1.5. The Expert Committee concludes that scientific studies indicate that electromagnetic fields are not the direct or contributing cause of the condition of health problems attributed to electromagnetic fields (electromagnetic hypersensitivity).

1.3.3 Overall conclusion on the possible health hazards from exposure to weak RF fields

A large number of studies have examined the possible effects of exposure to weak RF fields (i.e., exposure within the ICNIRP's reference values). The studies have been performed on cells and tissues, and in animals and humans. The effects that have been studied apply to changes in organ systems, functions and other effects. There are also a large number of population studies with an emphasis on studies of cancer risk. The large total number of studies provides no evidence that exposure to weak RF fields causes adverse health effects. Some measurable biological / physiological effects cannot be ruled out.

1.4 Characterisation of risk and assessment of uncertainty (Chapter 5)

Characterisation of risk following exposure to weak RF fields in the Norwegian population is accomplished by comparing the actual exposure, as described in Chapter 3, with the health problems that can be caused by different degrees of RF exposure, described in Chapter 4.

As typical exposure lies far below the ICNIRP's recommended reference values, and since it is not scientifically proven that adverse health effects may occur after exposure under the ICNIRP reference levels, there is no reason to assume that the low typical exposure in Norway is associated with health risks. On this basis the Expert Committee considers that the general public is well protected against adverse health effects from RF exposure.

In the mandate, the Committee was also asked to assess any *uncertainties in the risk assessment,* and how they should be taken into account in the risk management.

The Committee believes that our knowledge of typical public exposure is based on realistic measurements. With regards to potential health hazards from exposure to weak RF fields, many studies have been carried out with different methodologies. In general, the documentation is very comprehensive. The scope and quality vary with respect to the various health effects that have been studied. In particular, for health effects of a more severe nature, such as cancer and effects on the nervous system, many studies have been carried out using both animal and human data. Many of the experimental studies have used exposure with weak RF fields, although the levels are relatively high compared to typical exposure. The remaining uncertainties in the risk assessment mainly relate to health effects arising after a very long time, and to situations that produce the highest exposure (i.e., personal use of a mobile phone). This uncertainty in the risk assessment is considered to be low. There is negligible uncertainty in the risk assessment associated with other sources, such as base stations, wireless networks, television transmitters and the use of mobile phones by other individuals.

Overall, the uncertainty in risk assessment is therefore small.

1.5 Health problems attributed to electromagnetic fields (electromagnetic hypersensitivity) (Chapter 6)

Health problems attributed to electromagnetic fields, often referred to as electromagnetic hypersensitivity, denotes a condition where individuals believe that their health problems are caused by electromagnetic fields. A large number of scientific studies provide evidence that electromagnetic fields do not cause the symptoms (see 1.3.2.8). However, their health problems as such are genuine and must be taken seriously. There are large differences between individuals with health problems attributed to electromagnetic fields, such as the symptoms they experience, their severity, and which forms of electromagnetic fields trigger them. The proportion of the population with such health problems is unknown. Figures from other countries are uncertain and vary significantly, from 1.5 per cent up to 10 per cent of the population.

There are several possible circumstances that may contribute to health problems attributed to electromagnetic fields. There is probably no single explanatory model that will apply to all of these problems. The primary cause of symptoms may be other influences: physical, psychological and social; and different circumstances can play a role. Cultural conditions, stress reactions, adaptation and other psychological mechanisms can explain why electromagnetic fields in particular are perceived to be the cause of health problems, even if there is no physical link.

An overall assessment of health and of possible adverse physical, psychological and social burdens, as well as the patient's own motivation, is needed as a basis for medical treatment and other interventions. The goal of treatment and intervention is to reduce symptoms and their negative impact on life. It is important to develop a relationship of trust between doctor and patient, and that the patient's own experience of problems is taken seriously while scientific information is provided in a supportive way. In some cases, it has emerged that a diagnosable disease is causing the symptoms. It is therefore important that the first consultation with the doctor should always result in an adequate medical examination of patients reporting such problems. Scientific knowledge gives no basis to recommend measures to reduce or avoid exposure to electromagnetic fields.

Patients with health problems attributed to electromagnetic fields can be characterised as a sub-group of patients with health problems attributed to environmental factors (e.g., multiple chemical hypersensitivity and hypersensitivity to their own amalgam fillings). A common feature for the group of patients who attribute their health problems to electromagnetic fields, and patients who attribute their health problems to other environmental factors is that they often have a strong belief in a causal relationship, but scientific studies are unable to demonstrate or to confirm this.

1.6 Risk management and risk perception (chapters 7 and 8)

The result of the risk assessment, i.e., the degree of risk of adverse health effects and severity of health problems, is essential for the authorities' risk management. Risk management may cover legal regulation, including the establishment of threshold limit values, information, and other measures. In addition, any uncertainties in risk assessment will have significance, among other things, in selecting a precautionary strategy.

1.6.1 Precautionary measures

Risk management also involves assessing whether there is a need to introduce precautionary measures (if applicable) and if so at what level. The Committee has outlined three levels of precaution that can be exercised when handling a risk, depending on the nature of the risk, the severity, uncertainty in the assessment, and any consequences. These levels can be described as follows:

Level 1: "Any exposure should not be higher than needed to achieve the intended purpose." For example, in order to achieve the intended purpose of a technology, in many cases only a fraction of the acceptable exposure from a health risk perspective is required. This is particularly true for exposures where adverse health effects are unknown.

Level 2: "Prudent avoidance" is an internationally used principle that implies a stricter level of caution than the "general caution" specified in level 1.

Level 3: The "precautionary principle" is a regulatory principle that is used when there are substantial scientific uncertainties and injury scenarios that are based on plausible scientific knowledge. The potential damage is severe or potentially irreversible. The use of the precautionary principle may have significant societal implications, such as economic and other disadvantages. There is consensus that there should be requirements for grounds on which the principle should be applied.

1.6.2 Perception of risk

A number of factors associated with how the risk is interpreted could help to modify individual risk perception of possible adverse health effects from environmental exposure. This also applies to electromagnetic fields. The majority of the population seems to have low or moderate concern about adverse health effects resulting from exposure to RF/electromagnetic fields. However, a significant minority is concerned to varying degrees and/or believes that they experience health problems due to exposure. This concern does not correspond with the result of the risk assessment described in part I of this report.

Whether a precautionary strategy should be introduced depends on the nature and severity of the uncertainty in the basis of the risk assessment. Measures to further reduce public exposure to RF fields should not be implemented unless there is a scientific basis for assuming that the exposure could be harmful. It is relatively well supported that the use of certain types of precautionary measures not justified by a risk assessment does not reduce public concern about the adverse health effects. In some cases, such measures may increase concern. Good risk communication is considered to be a useful tool in the dialogue between the authorities and the public. This should be transparent and should form the basis for good understanding of the risks and for the implementation of measures.

1.7 International regulation practices and strategies (Chapter 9)

Chapter 9 gives a brief overview of international organisations' findings and recommendations. There is also a brief review of regulatory practices and strategies in various parts of the world with emphasis on comparable countries. In most industrial countries in recent years, organisations and expert committees have been established with a mission to evaluate research in this area and/or make recommendations to the authorities. This applies to both threshold limit values and other regulatory measures. In recent years, several other national and international institutions have compiled and published reports in this area, either on their own initiative or commissioned by governments or international organisations. These include the World Health Organization (WHO) and the ICNIRP. The ICNIRP recommends guidelines for maximum exposure to non-ionising radiation, based on extensive and ongoing research into the health effects of exposure to such radiation. ICNIRP guidelines are used in more than 80 countries. ICNIRP collaborates with WHO. WHO decides on its advice on an independent basis.

1.7.1 Regulations in Europe

The European Commission has funded research into electromagnetic fields and potential health effects since 1999. The Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), an independent scientific European Committee under the Directorate General for Health and Consumers (DG SANCO), has summarised and reviewed research into electromagnetic fields, the last time in 2009. The European Union's Ministerial Council Recommendation, dated 12.7.1999, concerning the restriction of exposure of the public to electromagnetic fields (0 Hz to 300 GHz), follows the ICNIRP's recommended levels for maximum exposure. In some countries, the recommendations have been incorporated into binding national legislation, meaning that the ICNIRP's recommended reference levels must be followed. This applies to: Cyprus, the Czech Republic, Estonia, Finland, France, Hungary, Ireland, Malta, Portugal, Romania, Spain, Germany and Slovakia. Other EU member countries encourage adherence to the ICNIRP recommendations, although this is not compulsory, or they have less stringent threshold limit values or no regulation. These include: Austria, Denmark, Latvia, the Netherlands, Sweden and the United Kingdom. A third group of Member States has introduced more stringent limits than the ICNIRP's recommendations, including Belgium and Luxembourg. This is a result of political decisions to use the precautionary principle, and/or public pressure. There are different practices about the choice of the exposure levels and which sources of exposure should be regulated.

1.8 Regulations in Norway (Chapter 10)

Several government agencies are involved or have responsibility in the themes addressed in this report. The Norwegian Radiation Protection Authority is the regulatory and supervisory authority for electromagnetic fields and must be scientifically up-to-date on the health effects of electromagnetic fields. The Norwegian Post and Telecommunications Authority regulates and monitors the postal and telecommunications sector. The health service is responsible for providing treatment and follow up to patients, while the Norwegian Directorate of Health is responsible for providing professional recommendations and regulations for the health service. The Norwegian Institute of Public Health provides research-based advice in public health issues. In addition, other governmental agencies, such as the Directorate for Civil Protection and Emergency Planning, the Directorate for Emergency Communication, the County Governor and the Parliamentary Ombudsman are all potential stakeholders with regards to electromagnetic fields.

Municipalities often encounter various issues related to electromagnetic fields, both in the role of local community planning and as the local health authority with responsibility for the new public health act that covers health education, preventive health measures and monitoring of factors that affect health. Municipalities have some direct governmental and administrative tasks relating to exposure to RF fields. With regards to establishing electromagnetic field-based communication, larger antenna systems require planning permission according to building regulations. For smaller antenna systems with heights up to 2 metres, there is no obligation to apply for planning permission. Consideration of applications does not normally include assessment of emission power; the only condition is that section 34 of the Regulations on Radiation Protection and Use of Radiation (Forskrift om strålevern og bruk av stråling), in effect from 01.01.2011, should be met. The regulations are practised according to the regulation's definitions of threshold limit values (see 1.2) and the requirement that "any exposure should be kept as low as reasonably practicable".

As building owners, some municipalities have followed a more stringent practice when it comes to positioning base stations than that imposed by the radiation protection regulations. Some municipalities may not allow installation of base stations for mobile phones on, or in the immediate vicinity of, the municipality's own schools and kindergartens. The municipalities' motive in such cases is to reduce the risk of exposure from base stations for mobile telephony. However, the result of such a practice might be that users of mobile phones near these buildings actually experience increased exposure from their own mobile phone usage due to the lower coverage.

The Norwegian Radiation Protection Authority provides advice and information according to the current regulations about how exposure can be "as low as reasonably practicable". For the base stations for mobile telephony/emergency network, the Norwegian Radiation Protection Authority recommends that transmitter direction, transmitter power and proximity to areas where individuals stay for long periods should be considered before mounting. The Norwegian Radiation Protection Authority provides information to those who want to reduce exposure from wireless networks by mounting routers at some distance from where people will spend time. There is also information about how exposure from personal mobile phone use can be reduced. The Norwegian Radiation Protection Authority does not recommend that wireless networks should be replaced by wired networks.

1.9 Expert Committee's recommendations for regulations (Chapter 11)

The Committee's recommendations for regulations are based on the conditions stated in part I-IV of the report. The assessment contained in part V is primarily based on the results of risk assessment in Chapter 5, the medical discussion of health problems attributed to electromagnetic fields (electromagnetic hypersensitivity) in Chapter 6, the discussion of risk management in Chapter 7, the discussion of public concern and risk communication in Chapter 8, and the discussion of international and national policy in chapters 9 and 10. Recommendations for regulations are discussed based on three different issues:

1. Health risks arising from the physical exposure to electromagnetic fields/RF
2. Health problems attributed to electromagnetic fields (electromagnetic hypersensitivity)
3. Concern about the hazardous effects of electromagnetic fields

In line with the mandate and the Committee's interpretation of it, the discussion of section 1 is limited to the RF field, whereas points 2 and 3 to a lesser extent differentiate between frequencies within the electromagnetic field spectrum.

The Committee's recommendations for risk management do not include occupational exposure to RF fields beyond that of occupational exposure in conjunction with mobile telephony, wireless networks, etc, and applies as for the general public. Hence, the Expert Committee considers it unnecessary to introduce specific recommendations on the use of wireless communication in a professional context.

Moreover, the report does not include exposure to RF fields in connection with medical diagnostics (MRI-scans), treatment (surgical use of diathermy), or medical implants that may be sensitive to RF fields.

1.9.1 General recommendations

The current regulations are based on the ICNIRP reference values for maximum exposure. The Expert Committee does not recommend special measures to reduce exposure, e.g., by changing the threshold limit values. The knowledge base in this health risk assessment provides no reason to assert that adverse health effects will occur from the typical public exposure. This also applies to the use of wireless communications in the office environment.

The mandate also asks the Committee to consider whether uncertainties are revealed that require the application of the precautionary principle when managing the risk and, if so, how the precautionary principle should be applied.

The Committee has therefore thoroughly discussed whether there are grounds to apply the precautionary principle for weak RF fields. The Committee considers that the conditions for applying the principle have not been met. Furthermore, the Committee considers that the administrative authorities can select a precautionary strategy according to the lowest level, i.e. "any exposure should not be higher than needed for the intended purpose to be achieved".

1.9.2 Recommendations for health problems attributed to electromagnetic fields (electromagnetic hypersensitivity)

A large number of scientific studies agree that it is probable that the physical characteristics of electromagnetic fields are not the direct or contributory cause of health problems attributed to electromagnetic fields (electromagnetic hypersensitivity). The Committee believes that there is no need to revise radiation protection legislation for individuals who attribute their health problems to electromagnetic field exposure.

It is scientifically improbable that the reduction of exposure to electromagnetic fields is significant for health problems attributed to electromagnetic fields. The Committee therefore believes that there is no basis to recommend measures aiming to reduce exposure to electromagnetic fields for individuals with health problems attributed to electromagnetic fields. The health service and other parties should instead encourage the reduction of avoidance behaviour and discourage implementation of measures for which there is no scientific basis. However, it is always important to respect individuals and their choices.

The Committee does not recommend the building of "electronic-free" treatment rooms in hospitals, but that affected patients should be given appropriate medical assistance with support and practical measures.

The Expert Committee believes that patients with these types of health problems can mainly be taken care of within the primary and specialist health services. The health problems that these individuals experience are genuine and must be taken seriously. However, the competence of the health service and health administration regarding patients with health problems attributed to electromagnetic fields and other environmental factors is low. There is a need for expertise in environmental health (e.g., in the regional occupational- and environmental health hospital departments) that are responsible for providing knowledge and guidelines to the health service. The Norwegian Directorate of Health should ensure that there is information specifically prepared for the health service and those who are affected. The Committee further proposes the establishment of a new expert committee to review the literature and to provide advice on management practices and the health service's treatment for patients with health problems attributed to electromagnetic fields and other environmental factors.

Employers should ensure that there is information about the risk to employees who are concerned about electromagnetic field exposure in their working environment. If the information does not help reduce concerns, in special cases the employer should consider implementing simple facilitation measures. It is important to clarify that these measures are implemented to alleviate concerns and to find practical solutions in a difficult situation, and not because the exposure itself is deemed to pose a health risk.

1.9.3 Recommendations for information requirements and concerns

There is no reason to recommend reduced exposure to RF fields as a tool to reduce general concerns about the hazardous effects of electromagnetic fields.

There is a need for good information and communication about the weak RF fields and possible health risks, through a deliberate strategy that includes information, communication and use of the media. Information should be provided by, amongst others, the Norwegian Radiation Protection Authority and the Norwegian Post and Telecommunications Authority. These authorities are responsible for ensuring that relevant information is tailored to different target groups, including local authorities, employers and the general public.

1.9.3.1 Recommendations for establishing networks for mobile telephony and mobile broadband

The establishment of new network operator antennas should point to locations that meet the general principle that "any exposure should not be higher than needed for the intended purpose to be achieved". This means that good coverage for mobile phones should be established as it will give the lowest possible exposure to the mobile phone user. Also, if it does not cause significant inconvenience and cost, an antenna location should be selected that provides the lowest exposure levels in areas where individuals spend long periods.

The Norwegian Post and Telecommunications Authority should evaluate procedures to include planned new installations in the current list of base stations which can be found on the website www.finnsenderen.no. This will make information available to stakeholders in a development and give the opportunity to provide input on the planned location. There should be no implementation of new threshold limit values for exposure, or of regulations that require application handling at a municipality level.

The Norwegian Post and Telecommunications Authority should take the initiative for a working group to establish common guidelines for safe distances to base stations for mobile telephony. Safe distances would ensure that nobody is exposed to levels above the ICNIRP reference values; essentially, this would apply when working close to antennas (e.g., clearing snow from a roof).

1.9.4 Recommendations for measurement of exposure

Individuals sometimes request measurements of exposure from RF fields for health-related purposes. Before such measurements are taken, it should be considered how the results will be interpreted and communicated. Based on the type of exposure situation, in many cases it is possible to use prior experiences about exposure levels. If the current situation is extraordinary in that previous measurements and theoretical calculations cannot be applied, or when other circumstances give reason to believe that the exposure is high, it may be appropriate to take measurements. Concern by itself is rarely a reason to take measurements. Instead, it is important to provide good information about exposure and communicate with the concerned individuals. Measurements should always be performed by qualified personnel.

Relevant government agencies, such as the Norwegian Radiation Protection Authority and the Norwegian Post and Telecommunications Authority should monitor typical RF exposure levels and more specific exposure situations where relevant. In accordance with the intention of the radiation protection regulations, it may also be appropriate for the authorities to take measurements to assess whether exposure sources meet the general principle that "any exposure should not be higher than needed for the intended purpose to be achieved".

1.9.5 Recommendations for the industry's obligations

Personal mobile phone use accounts for the relatively highest exposure to the general public. Individuals can choose to easily reduce exposure. Mobile providers could equip all phones with hands-free kits and provide information about the SAR value for exposure and the importance of using hands-free. Dealers should have information about the SAR value for all new mobile phones available to the customer.

Consumer goods with low emission power (< 100 mW) represent such a low exposure that measures are unnecessary. The industry should supply information about exposure, and that increased distance gives lower exposure.

It is important that suitable information is made available to retailers and subcontractors who are responsible for sales of supplies and installation of base stations and antennas so that information can be used in contact with the public.

1.9.6 Recommendations for research and professional follow-up

The Norwegian research environments should contribute to and monitor international research about possible health effects of exposure to electromagnetic fields. The authorities should take into account the need for research funding in this area. The development of cancer incidence over time should be followed in cancer registries. WHO has presented recommendations on priority research areas in the field.

Published by the Norwegian Institute of Public Health
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Order:
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ISSN: 1503-1403
ISBN: 978-82-8082-509-4 printed version
ISBN: 978-82-8082-510-0 electronic version

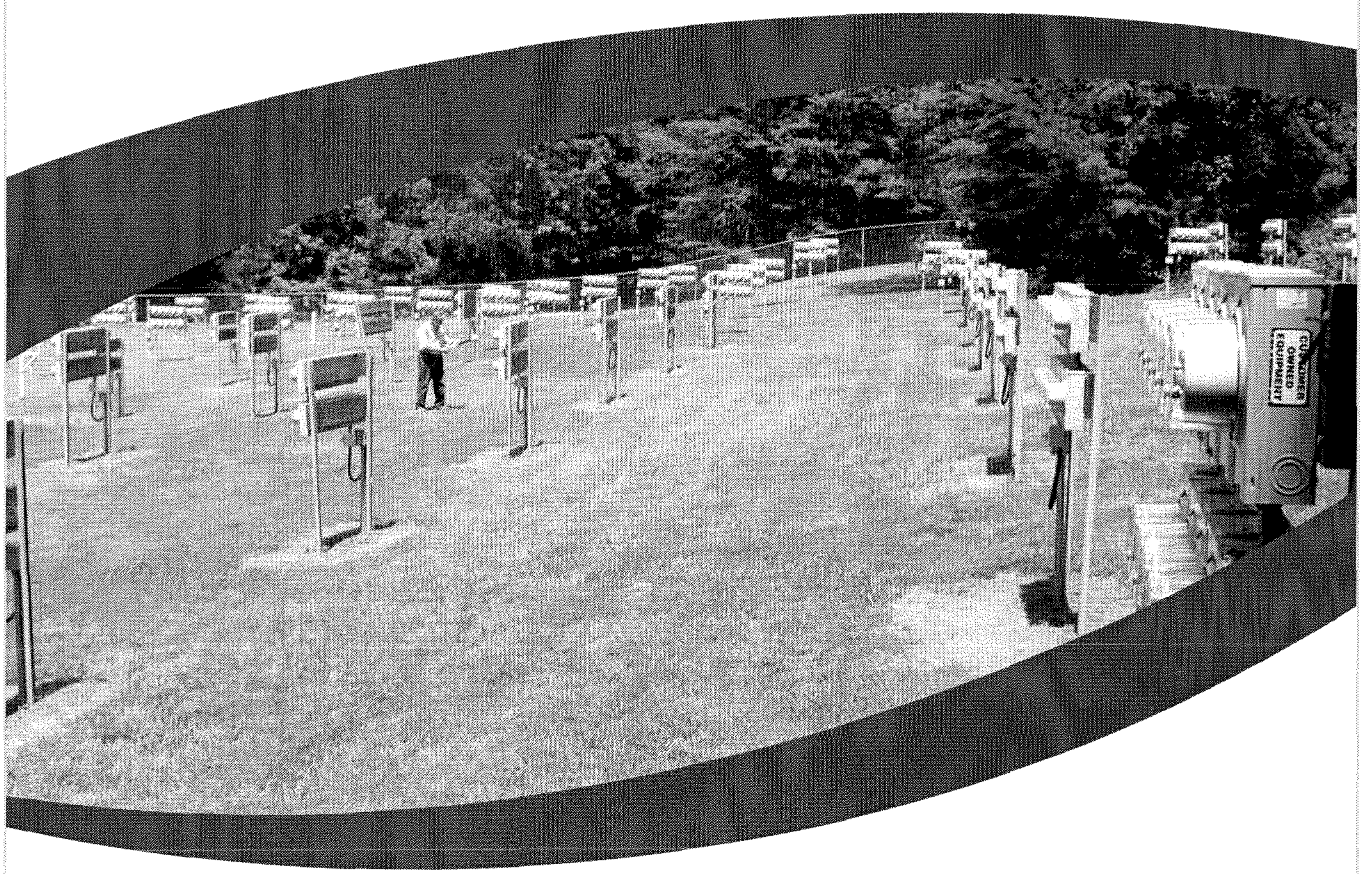
APPENDIX H
Electrical Power Research Institute, An Investigation of Radio Frequency Fields Associated with the Itron Smart Meter, Technical Report 2010

See attached.

ELECTRIC POWER RESEARCH INSTITUTE

2010 TECHNICAL REPORT

An Investigation of Radiofrequency Fields Associated with the Itron Smart Meter



An Investigation of Radiofrequency Fields Associated with the Itron Smart Meter

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1021126
Final Report, December 2010

The following organization, under contract to EPRI, prepared this report:

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Acknowledgments

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This report describes research sponsored by EPRI and overseen by Gabor Mezei, MD, Ph.D, EPRI's Program Manager for the EMF and RF Health Assessment and Safety Program. Expertise, review and comment were provided by a cross-functional team at EPRI including Rob Kavet, D.Sc., Senior Technical Executive; Chris Melhorn, Program Manager; Kermit Phipps, Project Engineer/Scientist and Brian Seal, Senior Project Manager, EPRI.

Numerous individuals from Southern California Edison (SCE) Electric Company conducted and supported the measurement work reported here in both South Carolina and California: Glenn Sias, Manager, SCE EMF and Energy Group; Al Vazquez, Enterprise Network Architect, SmartGrid Engineering; Kevin Nesby, Project Manager in the Edison SmartConnect™ Deployment Program; Brian Thorson, EMF Specialist in the Operations Support Business Unit; Jack Sahl, Director of Operations Support in the SCE Operations Support Business Unit; and John Bubb, Manager of Product Management for SCE SmartConnect.

Background information on operational characteristics of smart meters was provided by Vijay Lakkasetty, System Engineering & Operations - Smart Meter Project, Jay Xu, Principal Engineer, and Jim Turman, Program Manager, Department & Employee Readiness, Safety and Emergency Services, all of San Diego Gas and Electric Company.

As further described within the report, testing support, facility access and cooperation was provided by Itron, which facilitated this work, particularly by Dan Lakich, Design & Development Manager, Electricity Metering; Mike Belanger, Product Line Manager, Itron OpenWay Network Communications; Sudhir Thumaty, R&D Manager; Suresh Kumar Yada, Design Engineer; Ben Smith, Engineer; Ken Prevatte, Project Director; and Matthew DeCubellis, Application Engineer.

This publication is a corporate document that should be cited in the literature in the following manner:

An Investigation of Radiofrequency Fields Associated with the Itron Smart Meter
EPRI, Palo Alto, CA: 2010. 1021126

Product Description

Smart meters represent one component of the advanced metering infrastructure (AMI). Although data to and from smart meters may be transmitted through wired connections, many smart meters make use of miniature, low power radio transceivers to wirelessly communicate with the electric utility and with the Home Area Network (HAN) that provides home owners with the ability to interact with electrical appliances and systems within the home. Deployment of smart meters has raised concerns by members of the public about possible adverse health effects that could be related to exposure to the radiofrequency (RF) emissions of the meters. As part of on-going efforts to address public concerns on this issue, this report documents the collection of information on RF exposure related to the operation of two particular models of Smart Meter produced by Itron Inc.

Results & Findings

The smart meters studied in this report are currently being deployed by two electric utilities in California. The meters are part of wireless mesh networks in which one meter is configured as a collector point, referred to as a "cell relay" by Itron, for each of approximately 500 to 750 "end point meters." The cell relay collects data from the various end point meters and conveys these data onto the cellular wireless wide area network (WWAN) for communication back to the electric utility company's data management system. Mesh network communication among the many meters is provided by the 900 MHz band transceiver RF LAN (local area network). A HAN feature is supported by a 2.4 GHz transceiver.

Data collection was carried out in a laboratory setting and at residences and in neighborhoods in southern California and Colville, Washington, supplemented with theoretical modeling studies. The results indicate that RF field from the investigated smart meter are well below the maximum permitted exposure (MPE) established by the Federal Communications Commission (FCC). For instance, at one foot, the RF field from an end point meter would be expected to not exceed 0.8% of the MPE) established by the Federal Communications Commission (FCC). For the cell relay, the RF field would not exceed 0.2% of the MPE. Even at very close distances, such as one foot directly in front of the meter, with an unrealistic assumption that the transmitters operate at 100% duty cycle, the resulting exposure is less than the FCC MPE. When viewed in the context of a typical, realistic exposure distance of 10 feet, the RF fields are much smaller, about 0.008% for the end point meter and about 0.002% of MPE for the cell relay. For occupants of a home equipped with a Smart Meter, interior RF fields would be expected to be at least ten times less intense simply due to the directional properties of the meter. When the attenuation afforded by a stucco home's construction is included, a realistic

value of the interior RF field would be about 0.023% of the MPE for an end point meter and about 0.065% for a cell relay. Regardless of duty cycle values for end point and cell relay meters, typical exposures that result from the operation of smart meters are very low and comply with scientifically based human exposure limits by a wide margin.

Challenges & Objective(s)

This report is focused on the RF aspects of smart meters and in particular, the strength of the transmitted RF fields that may be produced by the meters from a human exposure perspective. The greatest difficulty in arriving in determining realistic time-averaged exposure from smart meters is associated with determining transmitter duty cycles since the meters only emit RF radiation at intervals

Applications, Values & Use

This report documents an investigation of the characteristics of RF fields associated with Itron Smart Meter. The project was undertaken to improve understanding of public exposure to the RF emissions produced by smart meters and to respond to public concerns about potential health effects.

EPRI Perspective

Measuring electric energy consumption with so-called smart meters in residential and commercial environments is becoming more commonplace as part of the development of Advanced Metering Infrastructure (AMI) in the electric utility industry. With the deployment of smart meters public concern was raised about potential health effects associated with RF emissions from smart meters EPRI is responding to these concerns with research efforts to provide objective information on RF emissions related to smart meters.

Approach

The project team conducted laboratory and field measurements of the RF emissions of Itron smart meters. A key objective was to determine realistic estimates of the operational duty cycle of meter transmitters. The team also investigated the effectiveness of metal meshes and stucco walls in shielding smart meters.

Keywords

Smart meters
Radiofrequency emissions
EMF health assessment
Environmental issues

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Section 1: Summary

Measuring electric energy consumption with so-called Smart Meters in residential and commercial environments is becoming more commonplace. Smart Meters represent one component of what is referred to as Advanced Metering Infrastructure (AMI) in the electric utility industry. AMI systems comprise both wired and wireless technologies with each exhibiting their own advantages. Electric utility companies, thus, have options to implementing AMI systems. Even within the wireless category of AMI system, equipment can operate over a wide range of frequencies and powers and levels of activity. The Smart Meters, based on wireless technology, make use of miniature, low power radio transceivers, typically inside the meter, to wirelessly communicate with the electric utility. Two-way radio communication provided by Smart Meters allows for transmission of energy consumption data from a residence or business to the utility company and reception of data pertaining to time-of-day pricing of electric energy.

As wireless AMI technology is projected to become widely distributed, it becomes prudent to quantitatively assess the levels of RF emissions fro meters to which the public may be exposed. Nearly two dozen communities have placed moratoria on further deployment of Smart Meters in northern California and more than 2000 health-related complaints have been received by the California Public Utilities Commission[1]. This report documents the collection of information related to the operation of two particular models of Smart Meters[2] produced by Itron Inc. for purposes of supporting exposure assessment exercises that can address public concerns about exposure. The Itron products are currently being deployed by Southern California Edison Electric Company (SCE) and San Diego Gas and Electric Company (SDG&E) and both companies provided support to EPRI (the Electric Power Research Institute) for this activity. A number of companies currently manufacture different forms of Smart Meters and, most commonly, these meters employ radio transmitters that operate in Federal Communications Commission (FCC) designated license free bands[3]. The Itron meters in this study use transmitters that operate in the license free bands of 902 MHz to 928 MHz (the "900 MHz band") and 2400 MHz to 2500 MHz (the "2.4 GHz band").

The Smart Meters studied here act as nodes in wireless mesh networks consisting of approximately 500 residences (for SCE) or 750 residences (for SDG&E); these are referred to as "end point meters." Within each mesh network, one residence, designated as a "collection point," is equipped with a Smart Meter having an additional internal transmitter (referred to as a "cell relay" for communicating data to the utility over a wireless wide area network (WWAN). The cell relay collects data from the various end point meters and conveys these data onto the cellular wireless wide area network (WWAN) for communication back to the electric utility company's data management system. Mesh network communications among the many meters is provided by the 900 MHz band transceiver RF LAN (local area network). A HAN feature is supported by the 2.4 GHz transceiver. A data protocol used by the HAN called Zigbee is used to refer to the 2.4 GHz transceiver as in "the 2.4 GHz Zigbee radio".

The data collection effort included gathering of information and working with the manufacturer at their facility in West Union, South Carolina, measurements at residences and in neighborhoods in southern California and some more limited measurements in Colville, Washington. Itron graciously provided technical support and access to its facilities and personnel to assist in this effort. Data included transmitter power levels, radiation patterns, RF field strengths or power densities of individual meters and groups of meters, spatial variations of RF fields in a vertical plane near Smart Meters, attenuation of Smart

[1]See, for example, "Smart Meters - They're Smart, But Are They Safe?". http://www.publicnewsservice.org/index.php?/content/article/16846-1 (November 8, 2010).

[2] Itron model CL200 (end point meter) and model C2SORD (cell relay).

[3] Some Smart Meters are designed to operate in FCC licensed bands and may operate with higher powers.

Meter RF fields by building materials, and information potentially useful for assessing transmitter duty cycles. To characterize the systems currently operating, parallel efforts included modeling of RF fields based on measured values of maximum equivalent isotropic radiated power (EIRP) of both end point and cell relay meters and analysis of end point meter transmission statistics for estimating duty cycles. Antenna patterns were determined for the 900 MHz RF LAN and 2.4 GHz Zigbee transmitter in both end point and cell relay meter configurations. Patterns were also measured for both the 850 MHz and 1900 MHz cellular bands from a cell relay.

Antenna pattern measurements revealed that RF fields are emitted preferentially toward the frontal region of the meters; the direction of maximum EIPR, however, might not be directly normal to the front of the meter. Apparent antenna gain values were modest, ranging between 0.88 dBi and 5.08 dBi, depending on the frequency band and the configuration (end point vs. cell relay). Patterns typically exhibited a reduced RF field behind the meter of approximately 10 dB down from the maximum frontal value of field with relatively narrow notches in the pattern directly behind the meter of as much as 20-30 dB less than in front.

Transmitter power data were obtained on 200,000 RF LAN 900 MHz transmitters with a most likely value of approximately 24.5 dBm (282 mW) with a 99th percentile power of 26.0 dBm (298 mW). Based on a sample size of 200,000 2.4 GHz radios, the most likely power was found to be 18.5 dBm (70.8 mW) with a 99th percentile power of 20.8 dBm (114.8 mW). Cellular transmitters were specified as 31.8 dBm in the 850 MHz band and 28.7 dBm in the 1900 MHz band.

Because of the very intermittent nature of transmissions from Smart Meters and their frequency hopping spread spectrum transmitters, accurate measurement of RF fields can be challenging. To facilitate the measurements, Smart Meters were programmed to transmit continuously on a single frequency. RF field measurements were performed on a single meter inside the Itron anechoic chamber and on ten individual meters installed in the Itron meter farm. These measurements were obtained with two different instruments including an isotropic, broadband, frequency conformal electric field probe (Narda Model B8742D) and a spectrum analyzer based selective radiation meter (Narda Model SRM-3006). Measurement data for the 900 MHz RF LAN transmitters showed RF fields in the range of a few percent of the FCC MPE for the general public at 30 cm (approximately 1 foot) in front of the meters (0.7 to 5.5%) with the broadband probe depending on frequency. Similar measurements for the 2.4 GHz Zigbee radios at a distance of 20 cm showed 0.75% to 1.7% of the MPE, again depending on the frequency of the transmitter.

Using the SRM-3006 instrument, RF fields were measured as a function of distance from the rack of ten meters in both the 900 MHz and 2.4 GHz bands. These measurements produced readings ranging between approximately 8% at 1 foot to less than 0.1% at 75 feet from the meters in the 900 MHz band and approximately 4.5% at 1 foot to less than 0.01% at 75 feet in the 2.4 GHz band. 900 MHz field measurements showed that the emissions associated with the ten meters dropped into the background produced by other meters in the meter farm at a distance of approximately 50 feet.

By using the maximum hold and average measurement feature of the SRM-3006, a measurement in the meter farm obtained by walking along two rows of meter racks resulted in an integrated peak RF field equivalent to 0.114% of MPE and an average value of 0.00023% of MPE. The ratio of average to peak readings corresponds to an apparent duty cycle of about 0.2%. In measurements taken at two apartment houses in Downey, California, ratios of average to peak values of RF field obtained over five-minute monitoring periods resulted in estimated duty cycles of approximately 0.001%. Using a tiny USB spectrum analyzer designed specifically for just the 900 MHz band in the Itron meter farm, spectral measurements were captured for approximately one hour. This measurement resulted in an apparent duty cycle of approximately 0.02%.

Interior residential measurements were performed in two homes in Downey, California after temporarily replacing the existing Smart Meter with specially programmed units that would transmit continuously in the 900 MHz and 2.4 GHz bands. Inside measurements ranged from approximately 0.006% to 22% of MPE, the highest value associated with operation of a microwave oven in the kitchen at 2 feet from the oven. The greatest value immediately behind the Smart Meter, inside the home, was 0.009% of MPE. Wireless routers found in both homes resulted in RF fields in the range of 0.02 to 0.03% of MPE.

Residential neighborhood surveys were performed in areas with and without deployed Smart Meters while driving the streets of two communities, one in Downey, CA and one in Santa Monica, CA respectively. The exercise demonstrated that the emissions of randomly emitting Smart Meters could be detected in the Downey neighborhood but virtually no signals were detected in Santa Monica with the exception that when driving through a commercial district, the 900 MHz band came alive with noticeable activity, presumably caused by various 900 MHz sources, such as cordless telephones, etc. Spectrum measurements in several other band were also performed including the FM radio broadcast band, two cellular telephone bands and the 2.4 GHz Wi-Fi band.

The insertion loss of three different metal meshes was evaluated in California at one of the residences in which RF measurements were obtained. Three different sizes of mesh were used in the tests by inserting the mesh between a specially prepared, portable Smart Meter as a source, and the SRM-3006 meter. These measurements were performed at close range with the Smart Meter approximately six inches behind the mesh and the SRM-3006 probe approximately the same distance on the other side of the mesh. These measurements resulted in values for insertion loss ranging from 4.1 dB to 19.1 dB in the 900 MHz band and from 1.2 dB to 11.4 dB in the 2.4 GHz band, depending on mesh opening size. Additional insertion loss measurements were performed on a simulated stucco wall in Colville, WA resulting in values of 6.1 dB and 2.5 dB for the 900 MHz and 2.4 GHz bands respectively.

Since human RF exposure standards are based on spatial averages, spatially averaged values of RF fields were obtained along a vertical line at approximately one foot in front of a Smart Meter. It was found that over a six-foot vertical span, the spatially averaged RF field in the 900 MHz band corresponded to a value 23% of the measured peak value found near the height of the meter. In the 2.4 GHz band, the spatially averaged field was 18% of the spatial peak.

Using the detailed pattern measurement data described earlier, theoretical calculations of RF fields that could be associated with each of the transmitters in either end point meters or cell relays were made. A detailed analysis was developed to investigate the effect that ground reflected fields could have on the resultant field and what factors would be appropriate for including the effect of ground reflections in theoretical RF field calculations.

Human exposure to RF fields is judged by comparison to applicable exposure limits or standards. For the United States, and in regard to Smart Meters, the most applicable limits are those promulgated by the FCC, a spatially averaged and time averaged value of 610 microwatts per square centimeter ($\mu W/cm^2$) in the 900 MHz band and 1000 $\mu W/cm^2$ in the 2.4 GHz band. A proper comparison of Smart Meter produced RF fields to these limits should involve a determination of the time-averaged value where the averaging time is specified as any 30-minute period. To arrive at time-averaged values, the measurements or calculated fields reported above must be corrected for the operational duty cycle of the transmitters. This is the most complex issue connected with Smart Meter RF evaluations since transmitter activity is semi-random in nature, with only brief transmissions occurring throughout a day. The maximum value of duty cycle for end point meters has been estimated by Itron to be in the range of 5%. Actual measurements, however, tend to result in substantially smaller values, typically less than 1%. Because of the variable nature of transmitter activity, even accurate measurements of a specific meter or meters need to be repeated for some days and, possibly, weeks to obtain reliable estimates of typical duty cycles. Rather than measurements, Itron developed special software implemented by the two companies to collect transmit data gathered and reported on in this report. Such an approach represents a practical way for bracketing realistic values of meter duty cycles since it can be implemented in software and extended to a very large sample size, something that would be impractical to do via physical measurements of RF fields at the meters. Using this approach, SCE generated data were examined to identify what fraction of meters in the sample exhibited transmit durations over a range of times which are related directly to the transmitter duty cycle. This exercise, for example, supported 99th and 99.9th percentile duty cycles of 0.11% and 4.7% for the RF LAN component of end point meters. A complimentary analysis conducted by SDG&E but using a more accurate determination of transmitter activity revealed smaller duty cycles. Similarly small duty cycle values are associated with the HAN and cellular transmitters. Figure 1-1 illustrates the estimated maximum likely time-averaged RF fields that would be produced by both end point and cell relay meters.

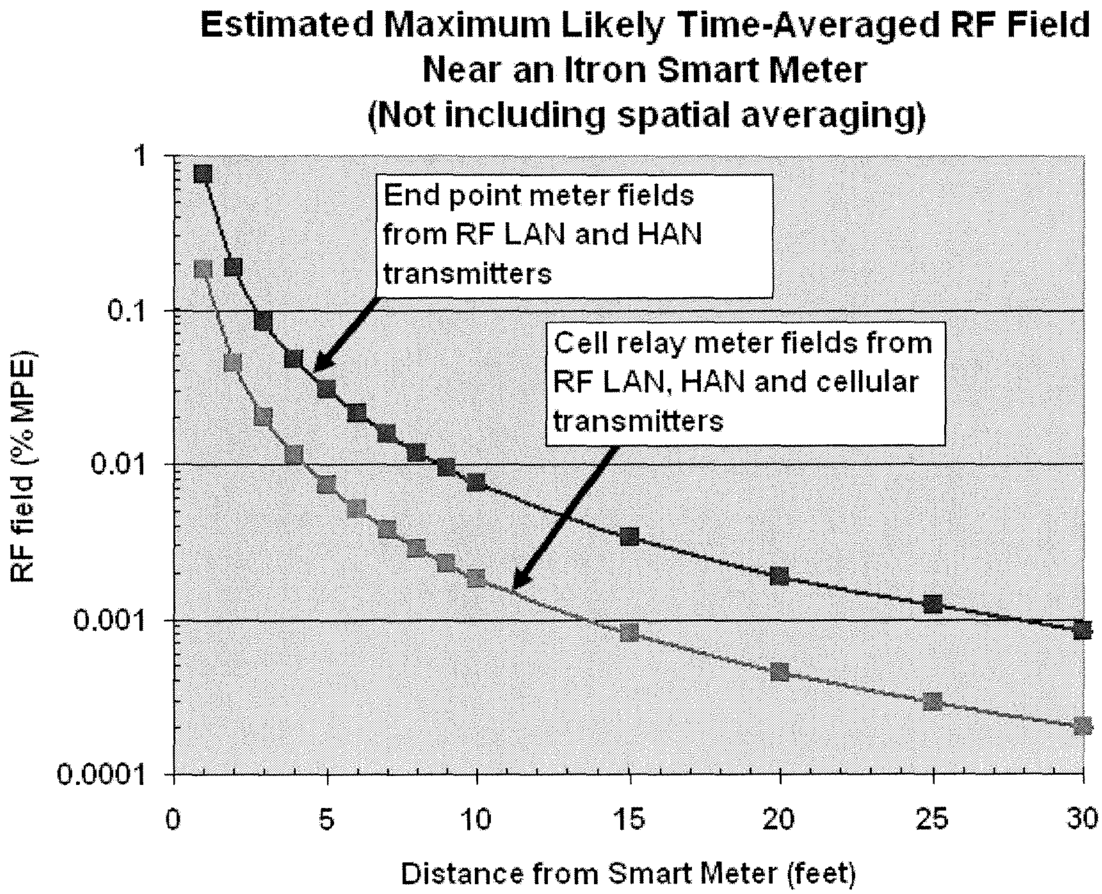

Figure 1-1
Calculated RF fields near Itron end point and cell relay meters based on 99th percentile transmitter power values, main beam exposure (point of maximum RF field), inclusion of the possibility of ground reflected fields and assumed 99th percentile duty cycles.

These data, when taken collectively, indicate that the RF emissions produced by the Itron Smart Meters evaluated in this study result in RF fields <0.06 mW/cm^2 (at least 10-fold below the FCC limit at 900 MHz). For instance, at one foot, the RF field from an end point meter would be expected to not exceed 0.8% of the MPE. For the cell relay, the RF field would not exceed 0.2% of the MPE. Even at very close distances, such as one foot directly in front of the meter, with an unrealistic assumption that the transmitters operate at 100% duty cycle (at which point the mesh network would not function) the resulting exposure is less than the FCC MPE. When viewed in the context of a typical, realistic exposure distance of 10 feet, the RF fields are much smaller, about 0.008% for the end point meter and about 0.002% of MPE for the cell relay. Spatial averaging of these "spatial maximum" fields brings the estimated values down to approximately one-fourth of these magnitudes.

For potential exposure of occupants of a home equipped with a Smart Meter, interior RF fields would be expected to be at least ten times less intense simply due to the directional properties of the meter. When the attenuation afforded by a stucco home's construction is included, a realistic value of the interior RF field would be about 0.023% of the MPE for an end point meter and about 0.065% for a cell relay meter. The WWAN operates at a far greater data throughput than the RF LAN within the mesh. Therefore, the duty cycle is correspondingly less for the cellular modem within the cell relay, despite the fact that it transmits all of the data collected from the relevant meters of its mesh network.

The most uncertainty in determining realistic time-averaged exposure from Smart Meters is associated with transmitter duty cycles. Hence, the most potentially useful avenue of future RF exposure assessment would include extensive statistical analyses of Smart Meter transmitter activity.

A detailed evaluation of possible RF fields produced by the Itron meters included in this study shows that regardless of duty cycle values for end point and cell relay meters, typical exposures that result from the operation of Smart Meters are very low and comply with scientifically based human exposure limits by a wide margin.

Section 2: Introduction and Background

As the electric utility industry in the United States moves toward implementing a "smart grid", one of the key components consists of so-called Smart Meters. These new technology electric power meters represent a part of the advanced metering infrastructure (AMI) that provides for automatic meter reading (AMR) and sophisticated control over the use of electric energy by consumers in their homes and businesses. When AMI technology is fully implemented, an enhanced balancing of power distribution throughout the various electrical grids of the country will exist and utility customers will be able to, among other things, determine when certain electrically operated appliances may operate, based on time-of-day pricing of electricity. Such advanced capability requires close to real-time data acquisition on electric energy usage and such data requirements mean that the existing, traditional electric power meters that employ manual energy consumption readings, for example, once a month, can't provide such timely data.

The modern technology of Smart Meters provides for an ability to almost instantly interrogate specific power meters as to electric energy usage. For the Smart Meters investigated in this study, this capability is accomplished via the use of data communications between the electric utility company and individual power meters through the medium of radio signals. This report is focused on the radiofrequency (RF) aspects of Smart Meters and in particular, the strength of the transmitted RF fields that may be produced by the meters from a human exposure perspective.

Smart Meters as RF Sources

A wireless Smart Meter makes use of miniature, low power (typically less than one watt) radio transceivers inside the meter to wirelessly communicate with the electric utility company. The transceivers (transmitter and receiver) allow both transmission of data as well as reception of data and instructions from the utility. These transmitters are contained within the housing of the electric meter but are not necessarily visually obvious to an observer. Antennas used for the transmitters are commonly created as slots on the various printed circuit boards that constitute the electronic makeup of the meter. A common transmitter configuration of Smart Meters includes two or three transmitters in the meter. Figure 2-1 shows a Smart Meter with its digital display that is used to indicate electric energy usage.

Figure 2-1
Photo of Itron Smart Meter.

How Smart Meters are Deployed

Radio communication by Smart Meters makes use of wireless networks whereby each Smart Meter can both transmit and receive data to and from the electric utility company. The wireless network is configured as a so-called mesh network. Mesh networks are characterized by providing a means for routing data and instructions between nodes. A mesh network allows for continuous connections and reconfiguration around broken or blocked data paths by "hopping" from node to node until the destination is reached. In the context of how Smart Meters are deployed, end-point meters are installed throughout neighborhoods, replacing existing electromechanical meters. The transceivers[4] within the Smart Meters act as wireless routers, identifying and, then, connecting with available transmission paths between themselves and a cell relay meter that collects data from the many, various meters in the region.[5] If communication between a given end-point meter and the associated cell relay cannot be achieved due to inadequate signal strength, an alternative end-point meter is used to establish communications onward toward the cell relay meter. In this sense, the mesh network is said to be self-healing in that should a particular transmission path becomes blocked, the network finds another way to get its data through the system. A simple example of this process could be that at some particular moment, a moving van travels down a street and temporarily blocks the previously preferred path from an end-point meter to the cell relay meter. In

[4] The RF devices inside the Smart Meter function as transceivers since they both transmit and receive radio signals. In this report, the term transmitter is often used in place of transceiver since the primary characteristic of the meters of interest in this study is the meter's ability to transmit radio signals.

this case, the data is rerouted via other end-point meters that act as alternative paths for the meter to initiate the data communications. This very powerful networking approach provides for good data communication reliability and can even allow communications for end-point meters that are outside the line-of-sight range to their cell relay meter. Additional end-point meters, therefore, have the ability to expand the geographical extent of a network. Figure 2-2 illustrates the concept behind a wireless mesh network implemented for a Smart Meter equipped neighborhood. Each meter communicates either directly with the cell relay meter or via multiple "hops" of the signals through other meters.

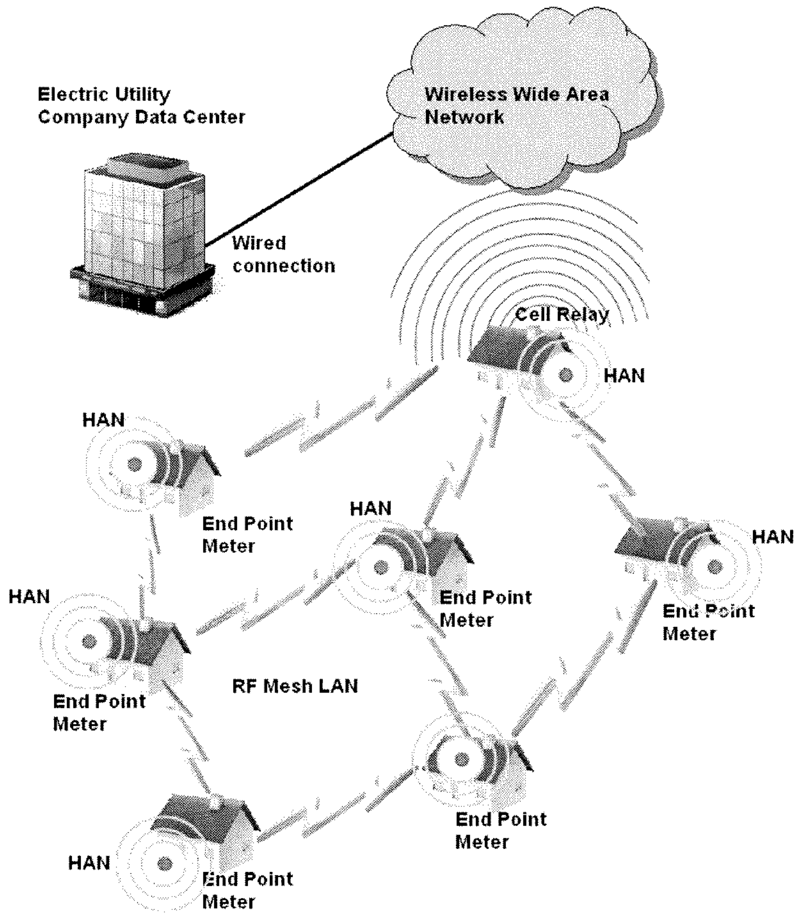

Figure 2-2
Simplistic illustrative diagram of an RF mesh network. Each end point also provides a Home Area Network (HAN) feature. The cell relay acts as a collector point for multiple meters distributed in a neighborhood and transmits received data onto a cellular wireless wide area network (WWAN).

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[5] Southern California Edison Electric Company is deploying Smart Meters as part of their SmartConnect™ program with one access point for approximately every 500 end-point meters on residences. In the case of San Diego Gas and Electric Company, each access point serves for data collection from approximately every 750 end-point meters.

For the Itron equipment that was the subject of this investigation, two separate transmitters are contained in the end-point meters. The wireless mesh network can be referred to as an RF LAN (radio frequency local area network). The Itron RF LAN operates in the 902-928 MHz license free band using spread spectrum transmitting technology. A second, separate transmitter that operates in the 2.4 GHz frequency range (2405 MHz to 2483 MHz) uses direct sequence spread spectrum technology that is referred to as a Zigbee radio[6]. This second transmitter is included for use with Home Area Networks (HANs) allowing customers, for example, to control certain electric appliances or systems within the home. When fully implemented, the customers will be able to connect wirelessly with the HAN radio and set times at which various appliances and/or electrical systems may operate, thereby taking advantage of those times during which electricity rates are lowest.

The RF LAN provides data communications among the various end-point meters and an associated cell relay meter. Cell relays are end-point meters that contain yet a third transceiver that is designed for wireless connection to the cellular WWAN, i.e., relaying of the data received from the various end-point meters over a private connection to the electric utility company. The transceivers use the same frequency bands used by cell phones. Two different frequency bands are used by these cell-relay transceivers, either the 850 MHz band or the 1900 MHz band.[7] Figure 2-3 shows a cell relay with the flexible dual band antenna located on the inside surface of the meter cover.

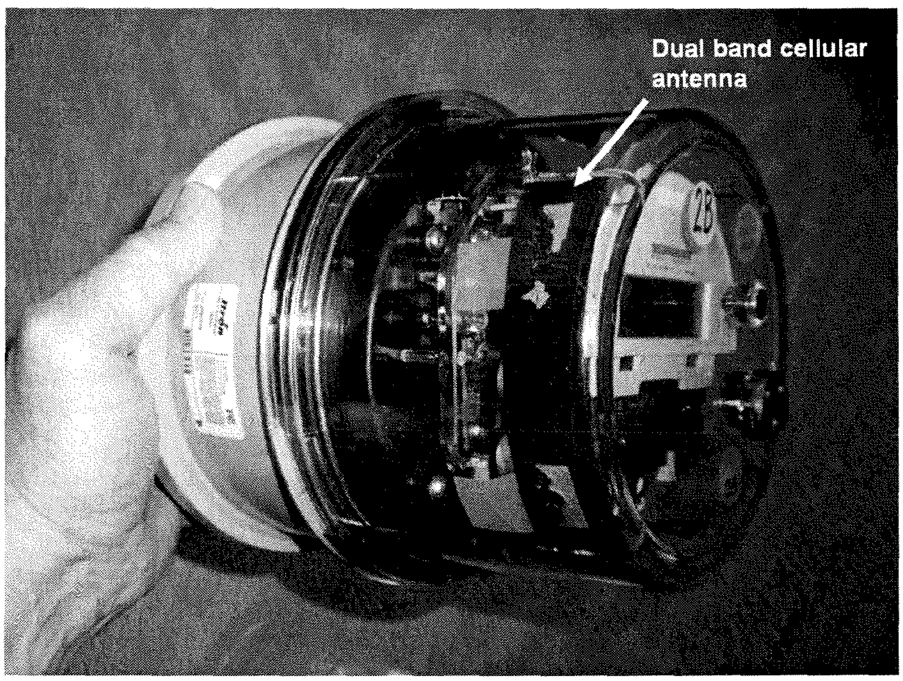


Figure 2-3
Cell relay meter with flexible, dual band (850 MHz and 1900 MHz) antenna affixed to interior surface of the meter cover.

[6]Zigbee is a name for a particular data communications protocol used in the HAN system.

[7]These frequency designations indicate the nominal frequencies used for the wireless WAN for Internet connectivity.

An important characteristic of this wireless mesh network technology is the fact that the RF emissions produced by Smart Meters, i.e., the signals that represent the data being transmitted, are not continuous but very intermittent in nature. For example, an electric utility company may interrogate the Smart Meters multiple number of times a day to acquire electric energy usage by the customer. While the Smart Meter may remain in stand-by in terms of transmissions at other times of the day, when an instruction is received to transmit energy consumption data, the meter transmits and proceeds to deliver the requested data to the cell relay meter. Hence, for the most part, Smart Meter transmissions are relatively infrequent during the day and may only consist of emissions for a few milliseconds during each of the interrogations throughout the day. This means that while the transceivers stand ready to transmit, there may be very little or no activity during most of the time. In addition to those periods during which data on electricity usage has been requested, however, Smart Meters must insure that they have a mesh network connection with at least one other Smart Meter so that, when necessary, it can deliver the data requested. Maintaining this connectivity within the mesh network requires periodic transmissions to alert the cell relay meter and other meters to its availability to be interrogated for data. So, Smart Meters spend part of their time in a so-called stand-by mode in which they issue beacon signals[8] to signify their identity to other nodes of the network with the objective of establishing a connection with the network. These beacon signals last for very brief periods of, nominally, 7.5 milliseconds and occur at various intervals. Finally, there are other instances during which certain network maintenance activities are accomplished and during which, again, various, very short duration and intermittent emissions exist. The cumulative effect of these transmissions is that while the total time spent transmitting signals from a Smart Meter is generally very modest within a day, the signals are very intermittent. They are not continuous in the same sense as the signal received from an FM radio broadcast station but, rather, exist as very short duration signals scattered throughout the day. This intermittency contributes to the difficulty in accurately measuring the strength of the emissions.

In practice, homes in a Smart Meter equipped neighborhood will have end-point Smart Meters installed that communicate with a cell relay meter either directly or though the medium of multiple end-point meter radio signal hops. Approximately every 500th (in the case of SCE) or 750th (in the case of SDG&E) residence may be equipped with a cell relay that not only handles the normal RF LAN communications but, also, relays these data onward, wirelessly, to the electric utility. All of these data communications proceed intermittently throughout each day.

The fact that the Itron Smart Meters studied here contain RF transmitters, albeit low power transmitters, means that relatively weak ambient RF fields exist in the vicinity of the meters. At the surface of the meter, the RF field strengths will be greatest with rapidly decreasing field strengths with increasing distance from the meter. While these low power transmitters cannot produce extremely intense RF fields, nonetheless, the issue of potential human exposure to these RF fields has, in some areas, become a question by the public.[9] A concern expressed by some has been the potential for adverse health effects that might be caused by exposure to the weak RF fields produced by Smart Meters. This report documents an investigation of the characteristics of RF fields associated with the Itron wireless Smart Meter that can assist in a better understanding of possible public exposure to the RF emissions produced by Smart Meters. Throughout this report, the term Smart Meter is intended to refer to the wireless type represented by the Itron meters discussed in this report.

[8] During the initial installation of an Itron Smart Meter, the meter enters a "discovery phase" in which it seeks to establish a link with the mesh network. During this discovery phase, beacon signals are emitted during approximately 3.5 second intervals until the meter becomes synchronized with the network or until a total time of about 6 minutes is reached after which beacons are emitted once about every 34 seconds until linked with the network or for up to 1½ hours. After this period, if a meter does not establish a link, it issues beacons once every hour during which it attempts to connect with the network. After 104 attempts, if still not linked with the network, the meter resets itself and begins the discovery sequence again. Once the meter becomes synchronized with the network, a beacon signal is emitted once every 94 seconds to 30 minutes depending on the level of other data traffic.

[9] Newspaper accounts of public reaction to Smart Meters

Section 3: Objective of Investigation

The work described in this report was focused on understanding the physical characteristics of the RF fields that are produced by Smart Meters such that an informed conclusion can be made as to the magnitude of possible human RF exposure caused by the meters. In this context, the objective of the work was to develop insight to the magnitude and spatial characteristics of Smart Meter RF fields including temporal aspects of the emissions that would allow a meaningful evaluation of possible exposures by reference to applicable RF human exposure limits.

Section 4: Technical Approach to Investigation

Characterizing RF fields produced by Smart Meters can be difficult. The intermittent nature of the emissions, addressed above, means that it is not a simple matter to simply bring instrumentation to an installed meter and be able to instantly detect the presence of the various emissions. The meter may or may not be in a transmit mode at the time when measurements are sought. Further, the spread spectrum characteristic of the emissions of the RF LAN and HAN transmitters leads to a further complication. For example, with the 900 MHz RF LAN transmitter, the emitted signal, at any particular instant in time, may be on any specific frequency within the 902 to 928 MHz band. When using narrow-band instrumentation, such as a frequency swept spectrum analyzer, the challenge is to have the analyzer on the specific frequency at the very instant in time that the emission is occurring to be able to measure its strength. Since the emissions are highly intermittent, this may take considerable time to insure that any such emissions have been captured by the instrumentation.

After careful consideration of the complexities associated with these kinds of measurements, it was decided that direct support of the testing by Itron, the manufacturer of the Smart Meter, could prove to be the most expedient approach to collecting the data useful to a complete exposure assessment study. As the manufacturer, Itron would have the knowledge and ability to control the Smart Meter to allow for meaningful measurements, avoiding the complications and uncertainties associated with working with already deployed meters.

Measurements at Itron

During the week of July 27, 2010, an extensive series of measurements was accomplished by the Principal Investigator at the Itron facility.

While at the Itron facility, detailed antenna pattern measurements were performed by the Principal Investigator on end point (Model CL200) and cell relay (Model C2SORD) meters. This included pattern measurements for the 900 MHz RF LAN transmitters in both the end point meter and as installed in a cell relay meter, pattern measurements of the 2.4 GHz Zigbee transmitter in both an end point meter and a cell relay meter and pattern measurements of the cell relay cellular transceiver operating in both the 850 MHz and 1900 MHz bands.

In addition to pattern measurements, Itron provided access to their Smart Meter farm, an area of some 20 acres in which approximately 7000 Smart Meters are installed. The ability to access this field provided insight to the cumulative RF field environment of multiple Smart Meters in close proximity with one another, and whether aggregate exposure produced by a multiplicity of Smart Meters concentrated in one area raises exposure risks.

Measurements in residential locations

Beyond the on-site measurements performed at the Itron facility, additional Smart Meter measurements were performed in a variety of residential environments. Using two Smart Meters that had been specifically programmed by Itron to operate continuously, to facilitate the measurements of field strength, measurements were performed at two residences in Downey, CA. These specially programmed meters were temporarily installed in the electrical service panel at each home and RF measurements were accomplished in the near vicinity of the meter and throughout the interior of each home. This procedure allowed for characterizing the RF fields that might exist inside of residences equipped with a Smart Meter. As a part of the residential measurements, a brief evaluation of the insertion loss afforded by three different metallic meshes, similar to what might be used in the construction of residential stucco walls, was conducted.

In addition to residence specific measurements with pre-programmed meters, RF fields were also measured adjacent to two separate apartment buildings wherein groups of 9 and 11 Smart Meters were grouped tightly together. Finally, a general area survey was conducted by driving throughout an established route within Downey, CA representative of a Smart Meter deployed neighborhood to form general observations of the ability to detect the presence of Smart Meter emissions. The residential measurements aspect of the work reported

here was concluded with a driving survey through Santa Monica, CA within which, at the time, there had been no deployment of Smart Meters.

Measurements in Colville, WA

Separate from the measurements at the Itron facility and the residential measurements in Downey, California, some limited measurements were conducted at the author's location in Colville, WA. These measurements included an evaluation of the comparative readings of RF field obtained by both the broadband field probe and the spectrum analyzer (selective radiation meter) used in the project measurements as well as an evaluation of the attenuation effect on Smart Meter signal propagation through a simulated, residential stucco wall.

Section 5: Transmitter Powers

A crucial aspect of any RF source, relative to its ability to produce RF fields, is the power of the transmitter. At the beginning of interactions with Itron, measurement data were sought on transmitter power levels. Historically, Itron has determined the power level of every transmitter used for the 900 MHz RF LAN and the 2.4 GHz Zigbee radios. These are transmitter devices on Itron manufactured printed circuit boards. All of the transmitters used in the Itron Smart Meters operate with low power, regardless of the frequency band used, nominally one watt or less. The 900 MHz RF LAN transmitter operates at a nominal power of 24 dBm (251 mW). Using Itron test data obtained from power measurements on a sample of 200,000 RF LAN transmitters, Figure 5-1 illustrates the accumulative fraction of transmitters having output powers across a range of power.

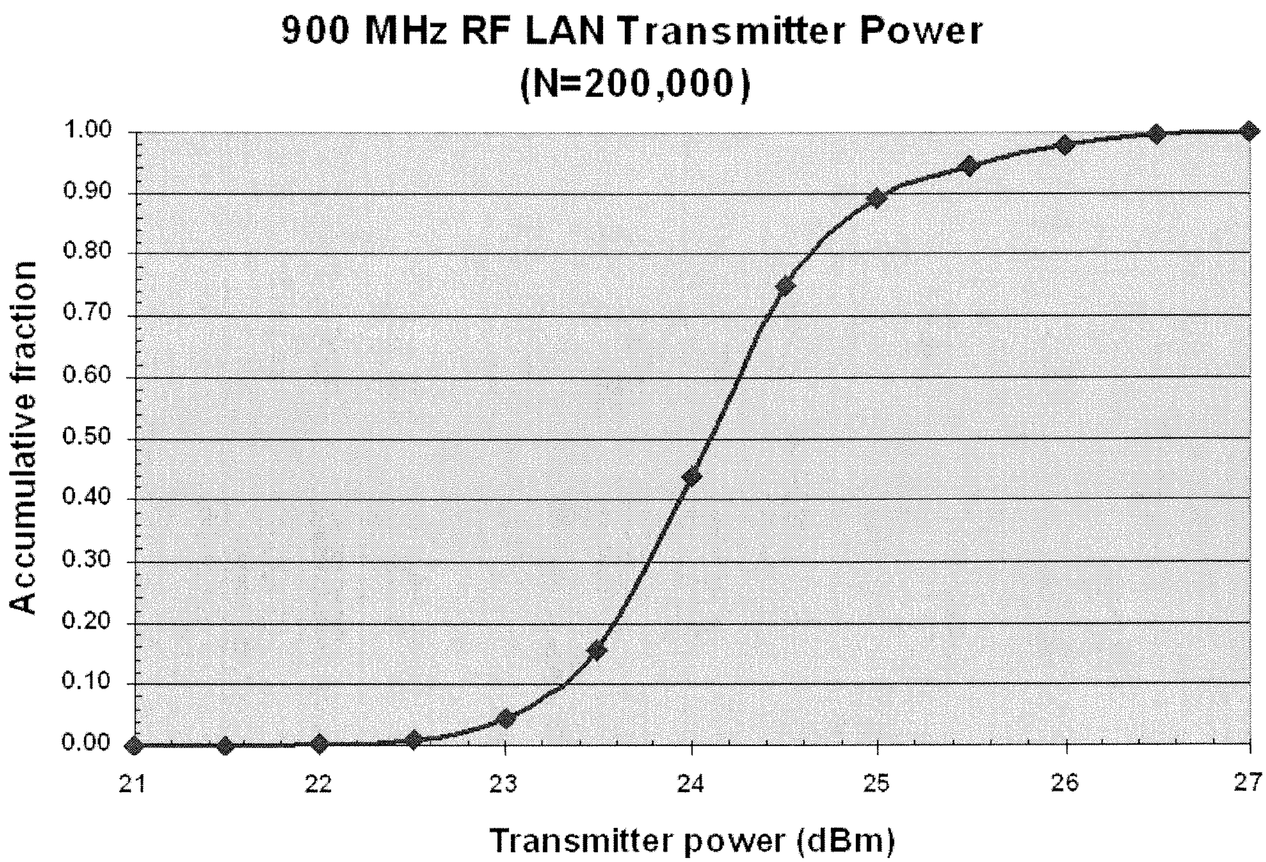


Figure 5-1
Accumulative fraction of 900 MHz RF LAN transmitter output power vs. transmitter power for a sample of 200,000 units. The median transmitter power is approximately 24.1 dBm (257 mW).

Based on a separate sample of 65,536 transmitters, used in end point meters, an average power output of 23.95 dBm (248 mW) was obtained with a standard deviation of 0.695 dBm.. Using these data, the 95% confidence interval would correspond to a range of transmitter power from 22.6 dBm (182 mW) to 25.3 dBm (339 mW) and the 99% confidence interval would correspond to a power range from 22.2 dBm (166 mW) to 25.7 dBm (372 mW).

Using the 200,000 transmitter sample, the median power level corresponds to approximately 24.1 dBm (257). The number of transmitters with power values in selected ranges is shown in Figure 5-2. The mode of transmitter power is approximately 24.5 dBm (282 mW).

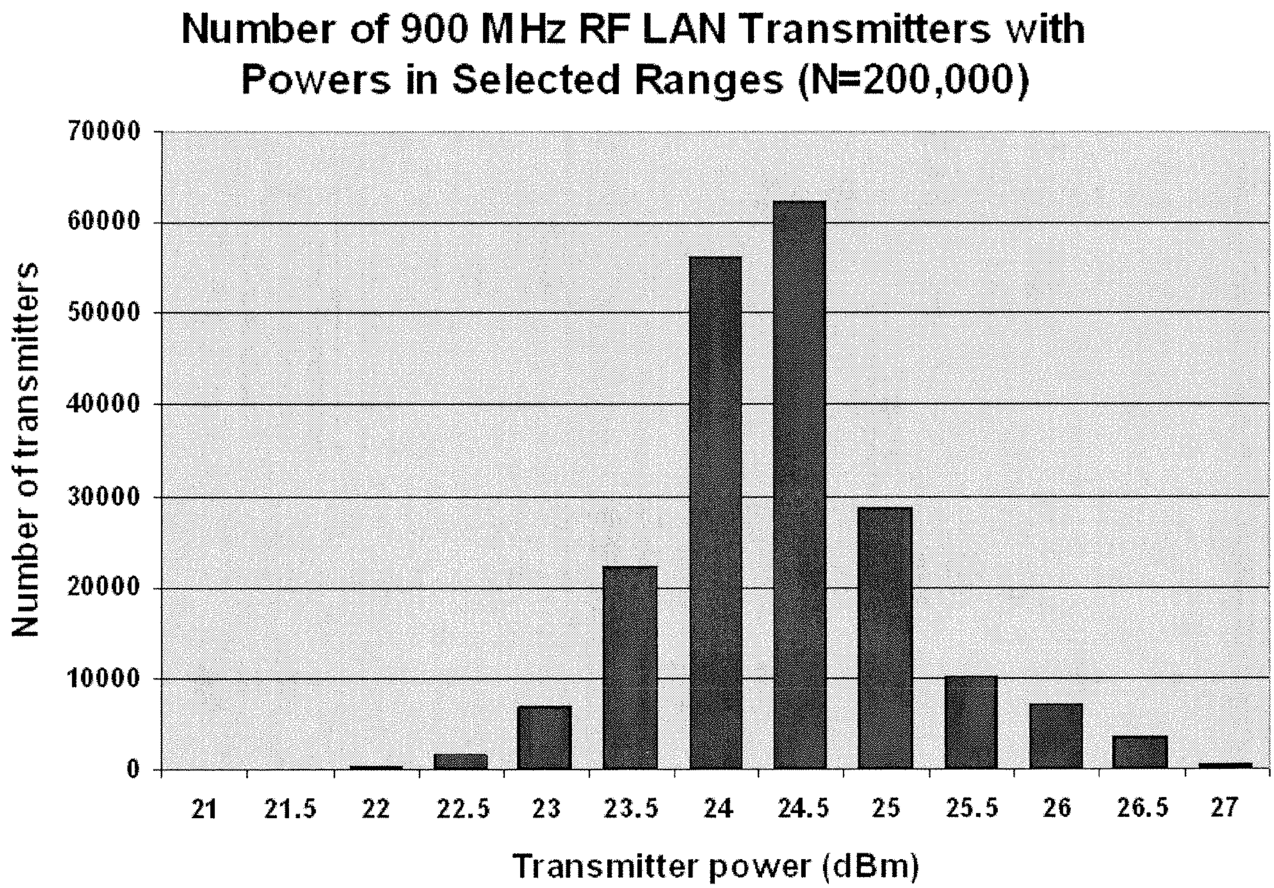


Figure 5-2
Number of 900 MHz RF LAN transmitters with powers within selected ranges. The transmitter power mode is approximately 24.5 dBm (282 mW).

These statistical data on the 900 MHz RF LAN transmitter powers indicate that the most likely power is 24.5 dBm (282 mW); an upper value of 26.0 dBm (398 mW), a value 41% greater than the most likely power, would include 99% of all transmitters.

In the case of the 2.4 GHz Zigbee transmitters, in a sample of 65,535 units used in end point meters, the mean value was found to be 18.31 dBm (67.6 mW) with a standard deviation of 0.76 dBm. This distribution would represent a 95% confidence interval of transmitter power from 16.8 dBm (47.9 mW) to 19.8 dBm (95.5 mW) and the 99% confidence interval would correspond to a power range from 16.4 dBm (43.7 mW) to 20.3 dBm (107.2 mW).

Figure 5-3 shows the accumulative fraction of transmitters having output powers across a range of power. Figure 8 illustrates the number of 2.4 GHz transmitters with powers within selected ranges. The transmitter power mode is approximately 18.5 dBm (70.8 mW).

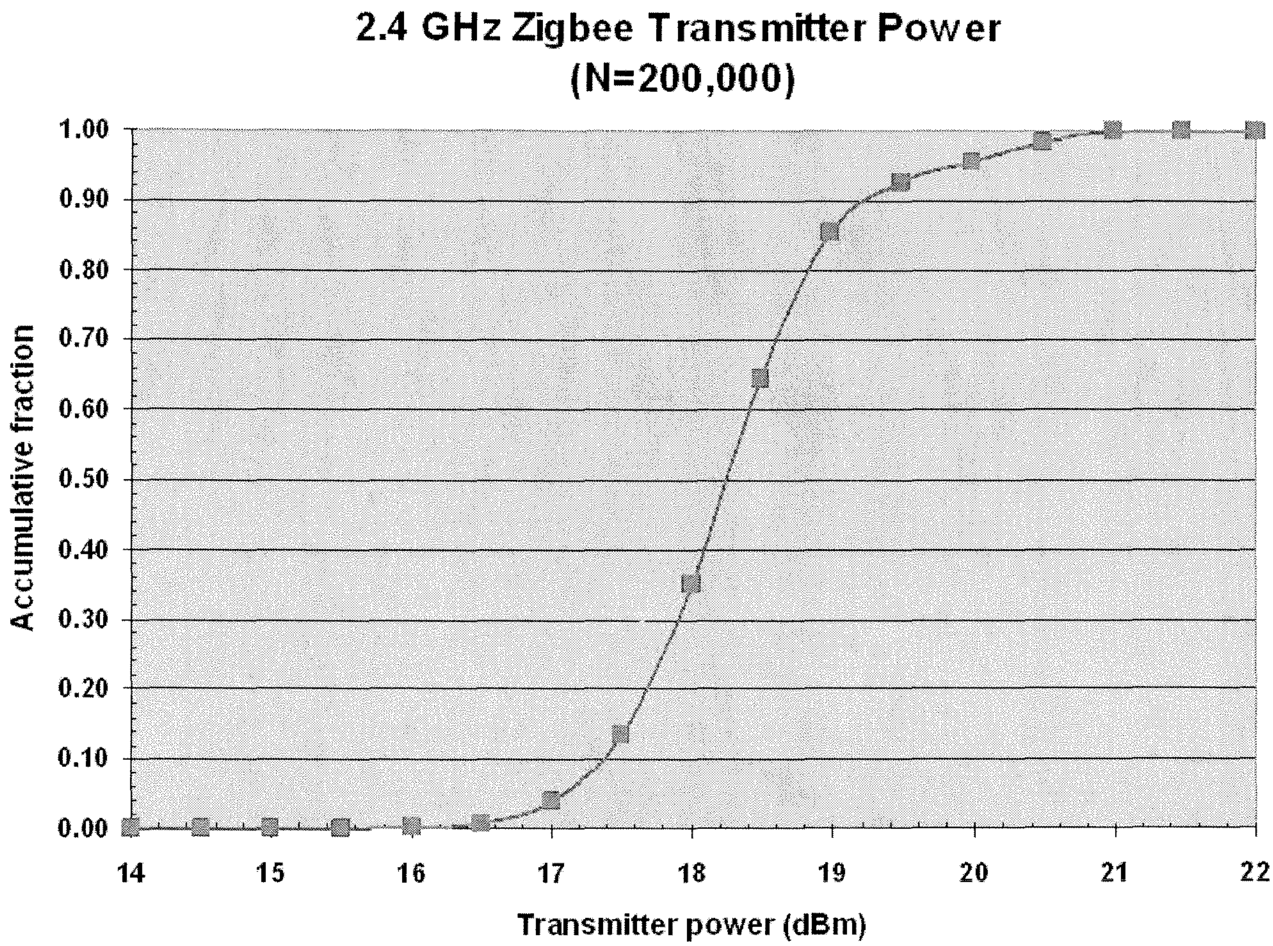


Figure 5-3
Accumulative fraction of 2.4 GHz Zigbee transmitter output power vs. transmitter power for a sample of 200,000 units. The median transmitter power is approximately 18.2 dBm (66.1 mW).

These statistical data on the 2.4 GHz Zigbee transmitter powers indicate that the most likely power is 18.5 dBm (70.8 mW); an upper value of 20.6 dBm (114.8 mW), a value 62% greater than the most likely power, would include 99% of all transmitters.

Cell relay meters contain the additional transceiver used for cellular WWAN connectivity in either the 850 MHz cellular band or 1900 MHz PCS band (personal communications service). Because these transceiver boards are produced by a different company and the units are specified to operate with specific powers and the fact that these units are separately certified by independent test labs for compliance with those specifications, Itron does not carry out additional power measurements. The transceivers, produced by Sierra Wireless operate with the following maximum powers:

Table 5-1
Sierra Wireless Transceivers Operation Maximum Powers

	GSM Modem Model MC8790 FCC ID: N7NMC8790	CDMA Modem Model MC5725 FCC ID: N7N-MC5725
Frequency Band (MHz)	Maximum power output (dBm) (mW)	
850	31.8 (1,514)	25.13 (326)
1900	28.7 (741)	24.84 (305)

Cell relays operate at the highest power of any of the meters due to their cellular/PCS modems but, similar to cellular telephones, the output power of the cellular modem is dynamically controlled by the applicable WWAN base station. This means that the actual operating power of the cellular radio in a cell relay will, generally, be less than the maximum power but will be determined by the signal strength it produces at whatever base station it is communicating with. Only one of the two modems would be active in a given deployment of Smart Meters in a neighborhood; the modem of choice is determined by the cellular wireless network service available and selected by the electric utility company.

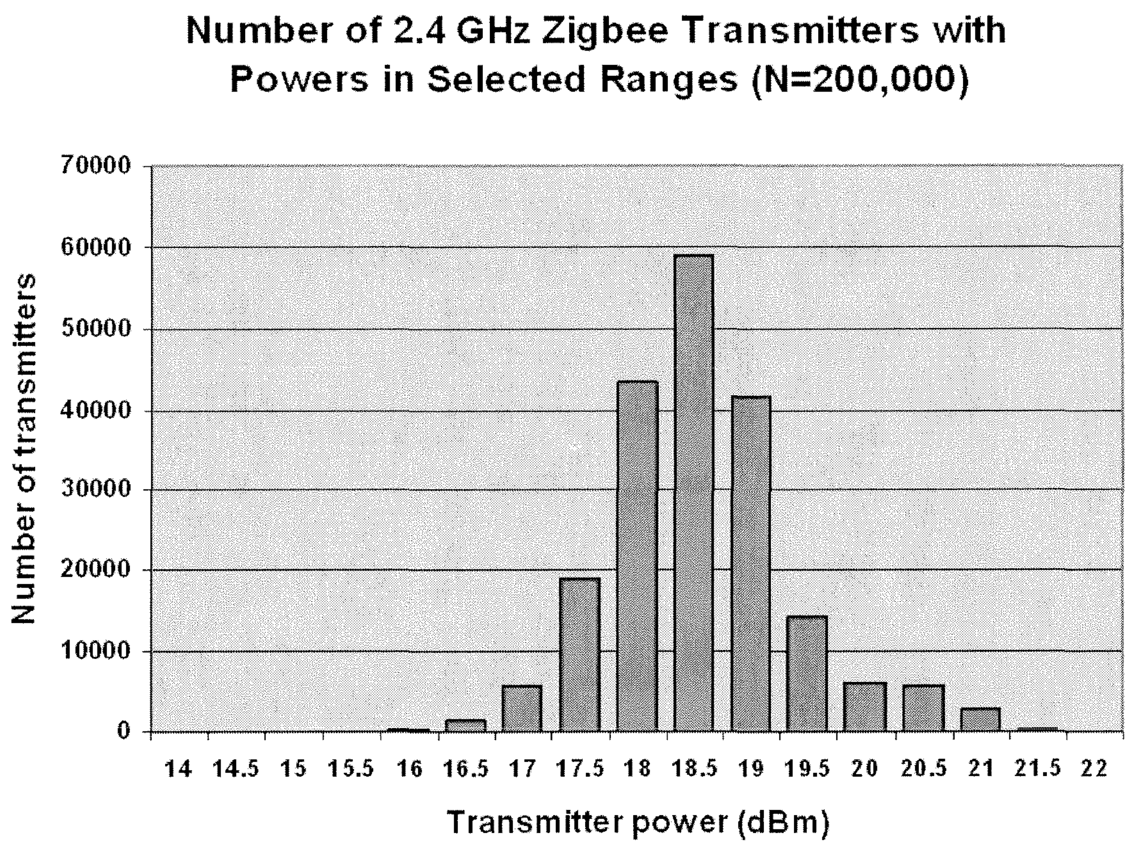


Figure 5-4
Number of 2.4 GHz Zigbee transmitters with powers within selected ranges. The transmitter power mode is approximately 18.5 dBm (70.8 mW).

Section 6: The Measurement Challenge Presented by Smart Meters

The difficulty of accurate RF field measurements near Smart Meters was discussed earlier. Low transmitted power levels in conjunction with intermittent emissions place considerable constraints on the measurement process. While a broadband measurement probe can eliminate the problem of the RF emissions occurring randomly on many different frequencies within the band, the relatively low sensitivity of broadband instruments places considerable restrictions on performing field strength measurements except within extremely close proximity of the meter. Intermittent emissions with very short duration, even if detectable, mean that it is difficult to observe when a transmission occurred. Generally, the desired measure of RF fields, from a human exposure perspective, is a measure of the average (root mean square - rms) value of the field strength or incident power density. The ratio of the average power density to the peak power density, for most Smart Meters is such that trying to measure the average field magnitude for a normally operating meter is very challenging. This can change if there exists a large aggregation of Smart Meters such that with their random on-off transmissions, much greater opportunity to "see" the emissions is possible.

Because of the rapid changes of frequency associated with the spread spectrum nature of the RF LAN and Zigbee radios in the Itron Smart Meters, an alternative approach is used to facilitate any antenna pattern and field measurements. This approach involves programming the relevant radios to transmit continuously, rather than their normal intermittent operation, and to transmit on a specific frequency within the relevant band as opposed to hopping across more than 50 channels within the 900 MHz band. Through this programming of the radios, the average signal level is now at its maximum, making it much easier to detect the RF field, and the fact that the emitted signal is now fixed on a specific and known frequency allows for ready confirmation that the measurement is of the intended signal. Since measurements under this scenario will indicate the peak value of RF field, other information is required to translate the peak field into what the equivalent average field would be. This requires a knowledge of the duty cycle of the emissions from the Smart Meter. The duty cycle can be thought of as the ratio of the amount of time that the transmitter is transmitting its signal to the total observation period. For example, if the Smart Meter were to typically transmit as much as 10 seconds during an hour (3600 seconds), the duty cycle would be 0.28%. In other words, the time-averaged power density of the RF field would be just 0.28% of the peak power density measured. The issue of Smart Meter duty cycles will be addressed later in this report.

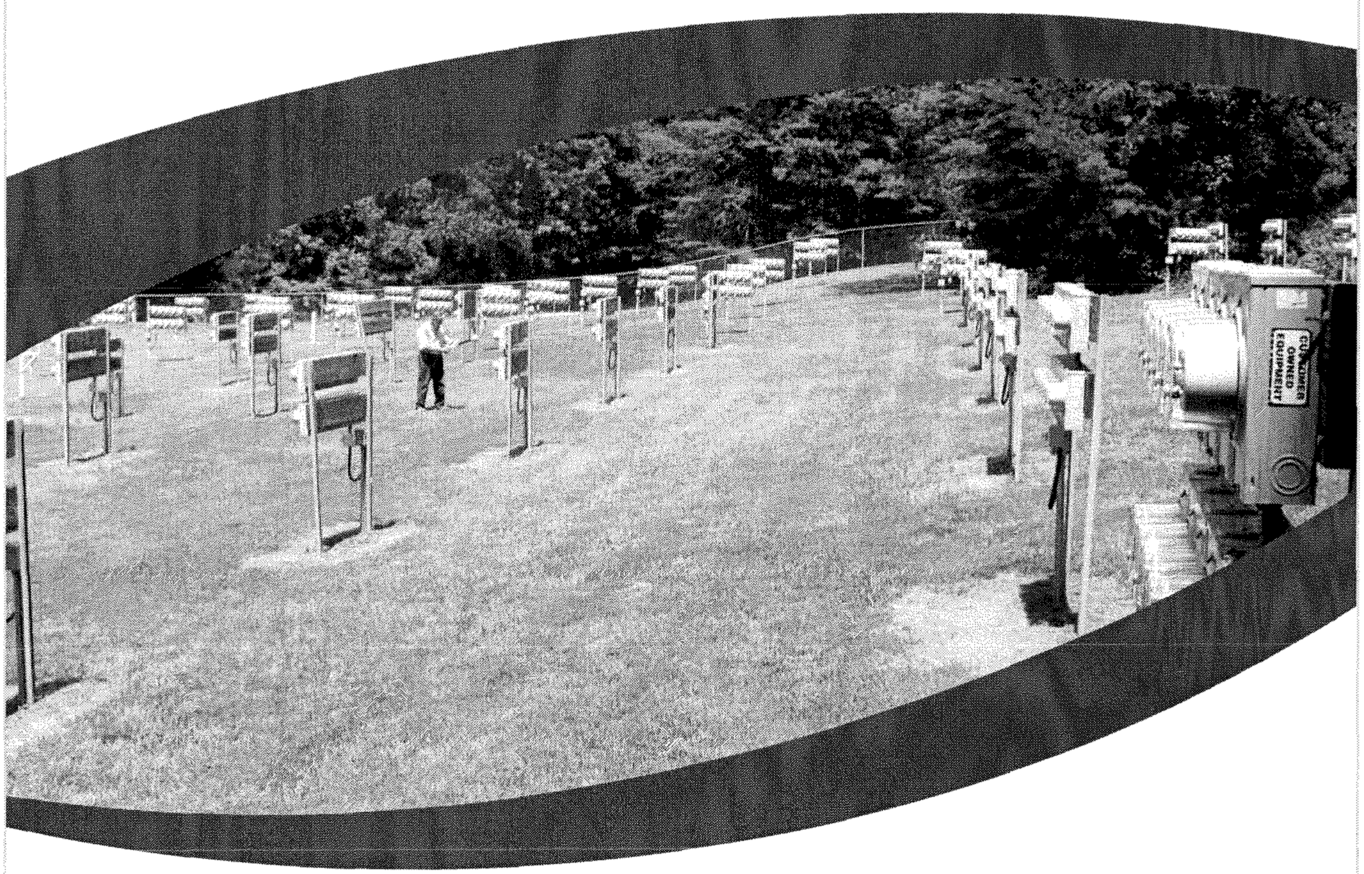
APPENDIX H
Electrical Power Research Institute, An Investigation of Radio Frequency Fields Associated with the Itron Smart Meter, Technical Report 2010

See attached.

ELECTRIC POWER RESEARCH INSTITUTE

2010 TECHNICAL REPORT

An Investigation of Radiofrequency Fields Associated with the Itron Smart Meter



An Investigation of Radiofrequency Fields Associated with the Itron Smart Meter

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1021126
Final Report, December 2010

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Acknowledgments

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This report describes research sponsored by EPRI and overseen by Gabor Mezei, MD, Ph.D, EPRI's Program Manager for the EMF and RF Health Assessment and Safety Program. Expertise, review and comment were provided by a cross-functional team at EPRI including Rob Kavet, D.Sc., Senior Technical Executive; Chris Melhorn, Program Manager; Kermit Phipps, Project Engineer/Scientist and Brian Seal, Senior Project Manager, EPRI.

Numerous individuals from Southern California Edison (SCE) Electric Company conducted and supported the measurement work reported here in both South Carolina and California: Glenn Sias, Manager, SCE EMF and Energy Group; Al Vazquez, Enterprise Network Architect, SmartGrid Engineering; Kevin Nesby, Project Manager in the Edison SmartConnect™ Deployment Program; Brian Thorson, EMF Specialist in the Operations Support Business Unit; Jack Sahl, Director of Operations Support in the SCE Operations Support Business Unit; and John Bubb, Manager of Product Management for SCE SmartConnect.

Background information on operational characteristics of smart meters was provided by Vijay Lakkasetty, System Engineering & Operations - Smart Meter Project, Jay Xu, Principal Engineer, and Jim Turman, Program Manager, Department & Employee Readiness, Safety and Emergency Services, all of San Diego Gas and Electric Company.

As further described within the report, testing support, facility access and cooperation was provided by Itron, which facilitated this work, particularly by Dan Lakich, Design & Development Manager, Electricity Metering; Mike Belanger, Product Line Manager, Itron OpenWay Network Communications; Sudhir Thumaty, R&D Manager; Suresh Kumar Yada, Design Engineer; Ben Smith, Engineer; Ken Prevatte, Project Director; and Matthew DeCubellis, Application Engineer.

This publication is a corporate document that should be cited in the literature in the following manner:

An Investigation of Radiofrequency Fields Associated with the Itron Smart Meter
EPRI, Palo Alto, CA: 2010. 1021126

Product Description

Smart meters represent one component of the advanced metering infrastructure (AMI). Although data to and from smart meters may be transmitted through wired connections, many smart meters make use of miniature, low power radio transceivers to wirelessly communicate with the electric utility and with the Home Area Network (HAN) that provides home owners with the ability to interact with electrical appliances and systems within the home. Deployment of smart meters has raised concerns by members of the public about possible adverse health effects that could be related to exposure to the radiofrequency (RF) emissions of the meters. As part of on-going efforts to address public concerns on this issue, this report documents the collection of information on RF exposure related to the operation of two particular models of Smart Meter produced by Itron Inc.

Results & Findings

The smart meters studied in this report are currently being deployed by two electric utilities in California. The meters are part of wireless mesh networks in which one meter is configured as a collector point, referred to as a "cell relay" by Itron, for each of approximately 500 to 750 "end point meters." The cell relay collects data from the various end point meters and conveys these data onto the cellular wireless wide area network (WWAN) for communication back to the electric utility company's data management system. Mesh network communication among the many meters is provided by the 900 MHz band transceiver RF LAN (local area network). A HAN feature is supported by a 2.4 GHz transceiver.

Data collection was carried out in a laboratory setting and at residences and in neighborhoods in southern California and Colville, Washington, supplemented with theoretical modeling studies. The results indicate that RF field from the investigated smart meter are well below the maximum permitted exposure (MPE) established by the Federal Communications Commission (FCC). For instance, at one foot, the RF field from an end point meter would be expected to not exceed 0.8% of the MPE) established by the Federal Communications Commission (FCC). For the cell relay, the RF field would not exceed 0.2% of the MPE. Even at very close distances, such as one foot directly in front of the meter, with an unrealistic assumption that the transmitters operate at 100% duty cycle, the resulting exposure is less than the FCC MPE. When viewed in the context of a typical, realistic exposure distance of 10 feet, the RF fields are much smaller, about 0.008% for the end point meter and about 0.002% of MPE for the cell relay. For occupants of a home equipped with a Smart Meter, interior RF fields would be expected to be at least ten times less intense simply due to the directional properties of the meter. When the attenuation afforded by a stucco home's construction is included, a realistic

value of the interior RF field would be about 0.023% of the MPE for an end point meter and about 0.065% for a cell relay. Regardless of duty cycle values for end point and cell relay meters, typical exposures that result from the operation of smart meters are very low and comply with scientifically based human exposure limits by a wide margin.

Challenges & Objective(s)

This report is focused on the RF aspects of smart meters and in particular, the strength of the transmitted RF fields that may be produced by the meters from a human exposure perspective. The greatest difficulty in arriving in determining realistic time-averaged exposure from smart meters is associated with determining transmitter duty cycles since the meters only emit RF radiation at intervals

Applications, Values & Use

This report documents an investigation of the characteristics of RF fields associated with Itron Smart Meter. The project was undertaken to improve understanding of public exposure to the RF emissions produced by smart meters and to respond to public concerns about potential health effects.

EPRI Perspective

Measuring electric energy consumption with so-called smart meters in residential and commercial environments is becoming more commonplace as part of the development of Advanced Metering Infrastructure (AMI) in the electric utility industry. With the deployment of smart meters public concern was raised about potential health effects associated with RF emissions from smart meters EPRI is responding to these concerns with research efforts to provide objective information on RF emissions related to smart meters.

Approach

The project team conducted laboratory and field measurements of the RF emissions of Itron smart meters. A key objective was to determine realistic estimates of the operational duty cycle of meter transmitters. The team also investigated the effectiveness of metal meshes and stucco walls in shielding smart meters.

Keywords

Smart meters
Radiofrequency emissions
EMF health assessment
Environmental issues

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Section 1: Summary

Measuring electric energy consumption with so-called Smart Meters in residential and commercial environments is becoming more commonplace. Smart Meters represent one component of what is referred to as Advanced Metering Infrastructure (AMI) in the electric utility industry. AMI systems comprise both wired and wireless technologies with each exhibiting their own advantages. Electric utility companies, thus, have options to implementing AMI systems. Even within the wireless category of AMI system, equipment can operate over a wide range of frequencies and powers and levels of activity. The Smart Meters, based on wireless technology, make use of miniature, low power radio transceivers, typically inside the meter, to wirelessly communicate with the electric utility. Two-way radio communication provided by Smart Meters allows for transmission of energy consumption data from a residence or business to the utility company and reception of data pertaining to time-of-day pricing of electric energy.

As wireless AMI technology is projected to become widely distributed, it becomes prudent to quantitatively assess the levels of RF emissions fro meters to which the public may be exposed. Nearly two dozen communities have placed moratoria on further deployment of Smart Meters in northern California and more than 2000 health-related complaints have been received by the California Public Utilities Commission[1]. This report documents the collection of information related to the operation of two particular models of Smart Meters[2] produced by Itron Inc. for purposes of supporting exposure assessment exercises that can address public concerns about exposure. The Itron products are currently being deployed by Southern California Edison Electric Company (SCE) and San Diego Gas and Electric Company (SDG&E) and both companies provided support to EPRI (the Electric Power Research Institute) for this activity. A number of companies currently manufacture different forms of Smart Meters and, most commonly, these meters employ radio transmitters that operate in Federal Communications Commission (FCC) designated license free bands[3]. The Itron meters in this study use transmitters that operate in the license free bands of 902 MHz to 928 MHz (the "900 MHz band") and 2400 MHz to 2500 MHz (the "2.4 GHz band").

The Smart Meters studied here act as nodes in wireless mesh networks consisting of approximately 500 residences (for SCE) or 750 residences (for SDG&E); these are referred to as "end point meters." Within each mesh network, one residence, designated as a "collection point," is equipped with a Smart Meter having an additional internal transmitter (referred to as a "cell relay" for communicating data to the utility over a wireless wide area network (WWAN). The cell relay collects data from the various end point meters and conveys these data onto the cellular wireless wide area network (WWAN) for communication back to the electric utility company's data management system. Mesh network communications among the many meters is provided by the 900 MHz band transceiver RF LAN (local area network). A HAN feature is supported by the 2.4 GHz transceiver. A data protocol used by the HAN called Zigbee is used to refer to the 2.4 GHz transceiver as in "the 2.4 GHz Zigbee radio".

The data collection effort included gathering of information and working with the manufacturer at their facility in West Union, South Carolina, measurements at residences and in neighborhoods in southern California and some more limited measurements in Colville, Washington. Itron graciously provided technical support and access to its facilities and personnel to assist in this effort. Data included transmitter power levels, radiation patterns, RF field strengths or power densities of individual meters and groups of meters, spatial variations of RF fields in a vertical plane near Smart Meters, attenuation of Smart

[1]See, for example, "Smart Meters - They're Smart, But Are They Safe?". http://www.publicnewsservice.org/index.php?/content/article/16846-1 (November 8, 2010).

[2] Itron model CL200 (end point meter) and model C2SORD (cell relay).

[3] Some Smart Meters are designed to operate in FCC licensed bands and may operate with higher powers.

Meter RF fields by building materials, and information potentially useful for assessing transmitter duty cycles. To characterize the systems currently operating, parallel efforts included modeling of RF fields based on measured values of maximum equivalent isotropic radiated power (EIRP) of both end point and cell relay meters and analysis of end point meter transmission statistics for estimating duty cycles. Antenna patterns were determined for the 900 MHz RF LAN and 2.4 GHz Zigbee transmitter in both end point and cell relay meter configurations. Patterns were also measured for both the 850 MHz and 1900 MHz cellular bands from a cell relay.

Antenna pattern measurements revealed that RF fields are emitted preferentially toward the frontal region of the meters; the direction of maximum EIPR, however, might not be directly normal to the front of the meter. Apparent antenna gain values were modest, ranging between 0.88 dBi and 5.08 dBi, depending on the frequency band and the configuration (end point vs. cell relay). Patterns typically exhibited a reduced RF field behind the meter of approximately 10 dB down from the maximum frontal value of field with relatively narrow notches in the pattern directly behind the meter of as much as 20-30 dB less than in front.

Transmitter power data were obtained on 200,000 RF LAN 900 MHz transmitters with a most likely value of approximately 24.5 dBm (282 mW) with a 99th percentile power of 26.0 dBm (298 mW). Based on a sample size of 200,000 2.4 GHz radios, the most likely power was found to be 18.5 dBm (70.8 mW) with a 99th percentile power of 20.8 dBm (114.8 mW). Cellular transmitters were specified as 31.8 dBm in the 850 MHz band and 28.7 dBm in the 1900 MHz band.

Because of the very intermittent nature of transmissions from Smart Meters and their frequency hopping spread spectrum transmitters, accurate measurement of RF fields can be challenging. To facilitate the measurements, Smart Meters were programmed to transmit continuously on a single frequency. RF field measurements were performed on a single meter inside the Itron anechoic chamber and on ten individual meters installed in the Itron meter farm. These measurements were obtained with two different instruments including an isotropic, broadband, frequency conformal electric field probe (Narda Model B8742D) and a spectrum analyzer based selective radiation meter (Narda Model SRM-3006). Measurement data for the 900 MHz RF LAN transmitters showed RF fields in the range of a few percent of the FCC MPE for the general public at 30 cm (approximately 1 foot) in front of the meters (0.7 to 5.5%) with the broadband probe depending on frequency. Similar measurements for the 2.4 GHz Zigbee radios at a distance of 20 cm showed 0.75% to 1.7% of the MPE, again depending on the frequency of the transmitter.

Using the SRM-3006 instrument, RF fields were measured as a function of distance from the rack of ten meters in both the 900 MHz and 2.4 GHz bands. These measurements produced readings ranging between approximately 8% at 1 foot to less than 0.1% at 75 feet from the meters in the 900 MHz band and approximately 4.5% at 1 foot to less than 0.01% at 75 feet in the 2.4 GHz band. 900 MHz field measurements showed that the emissions associated with the ten meters dropped into the background produced by other meters in the meter farm at a distance of approximately 50 feet.

By using the maximum hold and average measurement feature of the SRM-3006, a measurement in the meter farm obtained by walking along two rows of meter racks resulted in an integrated peak RF field equivalent to 0.114% of MPE and an average value of 0.00023% of MPE. The ratio of average to peak readings corresponds to an apparent duty cycle of about 0.2%. In measurements taken at two apartment houses in Downey, California, ratios of average to peak values of RF field obtained over five-minute monitoring periods resulted in estimated duty cycles of approximately 0.001%. Using a tiny USB spectrum analyzer designed specifically for just the 900 MHz band in the Itron meter farm, spectral measurements were captured for approximately one hour. This measurement resulted in an apparent duty cycle of approximately 0.02%.

Interior residential measurements were performed in two homes in Downey, California after temporarily replacing the existing Smart Meter with specially programmed units that would transmit continuously in the 900 MHz and 2.4 GHz bands. Inside measurements ranged from approximately 0.006% to 22% of MPE, the highest value associated with operation of a microwave oven in the kitchen at 2 feet from the oven. The greatest value immediately behind the Smart Meter, inside the home, was 0.009% of MPE. Wireless routers found in both homes resulted in RF fields in the range of 0.02 to 0.03% of MPE.

Residential neighborhood surveys were performed in areas with and without deployed Smart Meters while driving the streets of two communities, one in Downey, CA and one in Santa Monica, CA respectively. The exercise demonstrated that the emissions of randomly emitting Smart Meters could be detected in the Downey neighborhood but virtually no signals were detected in Santa Monica with the exception that when driving through a commercial district, the 900 MHz band came alive with noticeable activity, presumably caused by various 900 MHz sources, such as cordless telephones, etc. Spectrum measurements in several other band were also performed including the FM radio broadcast band, two cellular telephone bands and the 2.4 GHz Wi-Fi band.

The insertion loss of three different metal meshes was evaluated in California at one of the residences in which RF measurements were obtained. Three different sizes of mesh were used in the tests by inserting the mesh between a specially prepared, portable Smart Meter as a source, and the SRM-3006 meter. These measurements were performed at close range with the Smart Meter approximately six inches behind the mesh and the SRM-3006 probe approximately the same distance on the other side of the mesh. These measurements resulted in values for insertion loss ranging from 4.1 dB to 19.1 dB in the 900 MHz band and from 1.2 dB to 11.4 dB in the 2.4 GHz band, depending on mesh opening size. Additional insertion loss measurements were performed on a simulated stucco wall in Colville, WA resulting in values of 6.1 dB and 2.5 dB for the 900 MHz and 2.4 GHz bands respectively.

Since human RF exposure standards are based on spatial averages, spatially averaged values of RF fields were obtained along a vertical line at approximately one foot in front of a Smart Meter. It was found that over a six-foot vertical span, the spatially averaged RF field in the 900 MHz band corresponded to a value 23% of the measured peak value found near the height of the meter. In the 2.4 GHz band, the spatially averaged field was 18% of the spatial peak.

Using the detailed pattern measurement data described earlier, theoretical calculations of RF fields that could be associated with each of the transmitters in either end point meters or cell relays were made. A detailed analysis was developed to investigate the effect that ground reflected fields could have on the resultant field and what factors would be appropriate for including the effect of ground reflections in theoretical RF field calculations.

Human exposure to RF fields is judged by comparison to applicable exposure limits or standards. For the United States, and in regard to Smart Meters, the most applicable limits are those promulgated by the FCC, a spatially averaged and time averaged value of 610 microwatts per square centimeter ($\mu W/cm^2$) in the 900 MHz band and 1000 $\mu W/cm^2$ in the 2.4 GHz band. A proper comparison of Smart Meter produced RF fields to these limits should involve a determination of the time-averaged value where the averaging time is specified as any 30-minute period. To arrive at time-averaged values, the measurements or calculated fields reported above must be corrected for the operational duty cycle of the transmitters. This is the most complex issue connected with Smart Meter RF evaluations since transmitter activity is semi-random in nature, with only brief transmissions occurring throughout a day. The maximum value of duty cycle for end point meters has been estimated by Itron to be in the range of 5%. Actual measurements, however, tend to result in substantially smaller values, typically less than 1%. Because of the variable nature of transmitter activity, even accurate measurements of a specific meter or meters need to be repeated for some days and, possibly, weeks to obtain reliable estimates of typical duty cycles. Rather than measurements, Itron developed special software implemented by the two companies to collect transmit data gathered and reported on in this report. Such an approach represents a practical way for bracketing realistic values of meter duty cycles since it can be implemented in software and extended to a very large sample size, something that would be impractical to do via physical measurements of RF fields at the meters. Using this approach, SCE generated data were examined to identify what fraction of meters in the sample exhibited transmit durations over a range of times which are related directly to the transmitter duty cycle. This exercise, for example, supported 99th and 99.9th percentile duty cycles of 0.11% and 4.7% for the RF LAN component of end point meters. A complimentary analysis conducted by SDG&E but using a more accurate determination of transmitter activity revealed smaller duty cycles. Similarly small duty cycle values are associated with the HAN and cellular transmitters. Figure 1-1 illustrates the estimated maximum likely time-averaged RF fields that would be produced by both end point and cell relay meters.

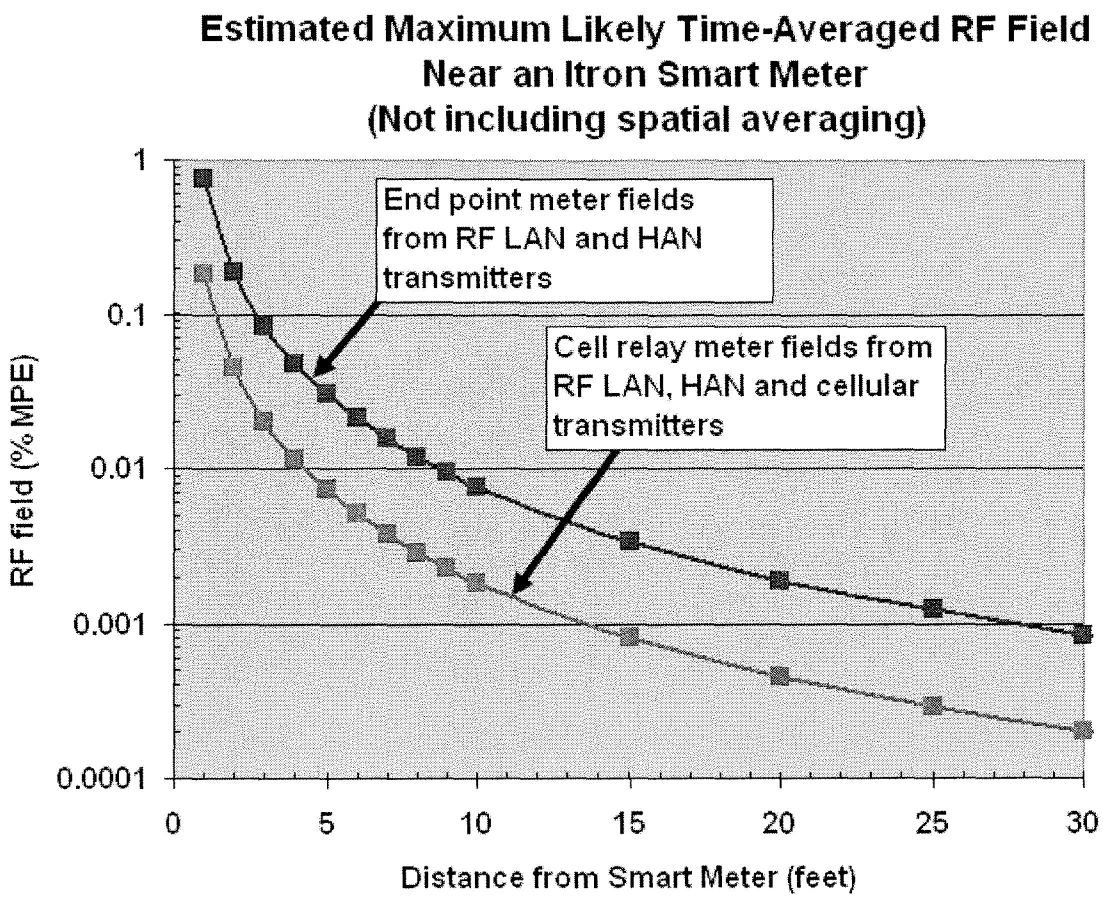


Figure 1-1
Calculated RF fields near Itron end point and cell relay meters based on 99th percentile transmitter power values, main beam exposure (point of maximum RF field), inclusion of the possibility of ground reflected fields and assumed 99th percentile duty cycles.

These data, when taken collectively, indicate that the RF emissions produced by the Itron Smart Meters evaluated in this study result in RF fields <0.06 mW/cm^2 (at least 10-fold below the FCC limit at 900 MHz). For instance, at one foot, the RF field from an end point meter would be expected to not exceed 0.8% of the MPE. For the cell relay, the RF field would not exceed 0.2% of the MPE. Even at very close distances, such as one foot directly in front of the meter, with an unrealistic assumption that the transmitters operate at 100% duty cycle (at which point the mesh network would not function) the resulting exposure is less than the FCC MPE. When viewed in the context of a typical, realistic exposure distance of 10 feet, the RF fields are much smaller, about 0.008% for the end point meter and about 0.002% of MPE for the cell relay. Spatial averaging of these "spatial maximum" fields brings the estimated values down to approximately one-fourth of these magnitudes.

For potential exposure of occupants of a home equipped with a Smart Meter, interior RF fields would be expected to be at least ten times less intense simply due to the directional properties of the meter. When the attenuation afforded by a stucco home's construction is included, a realistic value of the interior RF field would be about 0.023% of the MPE for an end point meter and about 0.065% for a cell relay meter. The WWAN operates at a far greater data throughput than the RF LAN within the mesh. Therefore, the duty cycle is correspondingly less for the cellular modem within the cell relay, despite the fact that it transmits all of the data collected from the relevant meters of its mesh network.

The most uncertainty in determining realistic time-averaged exposure from Smart Meters is associated with transmitter duty cycles. Hence, the most potentially useful avenue of future RF exposure assessment would include extensive statistical analyses of Smart Meter transmitter activity.

A detailed evaluation of possible RF fields produced by the Itron meters included in this study shows that regardless of duty cycle values for end point and cell relay meters, typical exposures that result from the operation of Smart Meters are very low and comply with scientifically based human exposure limits by a wide margin.

Section 2: Introduction and Background

As the electric utility industry in the United States moves toward implementing a "smart grid", one of the key components consists of so-called Smart Meters. These new technology electric power meters represent a part of the advanced metering infrastructure (AMI) that provides for automatic meter reading (AMR) and sophisticated control over the use of electric energy by consumers in their homes and businesses. When AMI technology is fully implemented, an enhanced balancing of power distribution throughout the various electrical grids of the country will exist and utility customers will be able to, among other things, determine when certain electrically operated appliances may operate, based on time-of-day pricing of electricity. Such advanced capability requires close to real-time data acquisition on electric energy usage and such data requirements mean that the existing, traditional electric power meters that employ manual energy consumption readings, for example, once a month, can't provide such timely data.

The modern technology of Smart Meters provides for an ability to almost instantly interrogate specific power meters as to electric energy usage. For the Smart Meters investigated in this study, this capability is accomplished via the use of data communications between the electric utility company and individual power meters through the medium of radio signals. This report is focused on the radiofrequency (RF) aspects of Smart Meters and in particular, the strength of the transmitted RF fields that may be produced by the meters from a human exposure perspective.

Smart Meters as RF Sources

A wireless Smart Meter makes use of miniature, low power (typically less than one watt) radio transceivers inside the meter to wirelessly communicate with the electric utility company. The transceivers (transmitter and receiver) allow both transmission of data as well as reception of data and instructions from the utility. These transmitters are contained within the housing of the electric meter but are not necessarily visually obvious to an observer. Antennas used for the transmitters are commonly created as slots on the various printed circuit boards that constitute the electronic makeup of the meter. A common transmitter configuration of Smart Meters includes two or three transmitters in the meter. Figure 2-1 shows a Smart Meter with its digital display that is used to indicate electric energy usage.

Figure 2-1
Photo of Itron Smart Meter.

How Smart Meters are Deployed

Radio communication by Smart Meters makes use of wireless networks whereby each Smart Meter can both transmit and receive data to and from the electric utility company. The wireless network is configured as a so-called mesh network. Mesh networks are characterized by providing a means for routing data and instructions between nodes. A mesh network allows for continuous connections and reconfiguration around broken or blocked data paths by "hopping" from node to node until the destination is reached. In the context of how Smart Meters are deployed, end-point meters are installed throughout neighborhoods, replacing existing electromechanical meters. The transceivers[4] within the Smart Meters act as wireless routers, identifying and, then, connecting with available transmission paths between themselves and a cell relay meter that collects data from the many, various meters in the region.[5] If communication between a given end-point meter and the associated cell relay cannot be achieved due to inadequate signal strength, an alternative end-point meter is used to establish communications onward toward the cell relay meter. In this sense, the mesh network is said to be self-healing in that should a particular transmission path becomes blocked, the network finds another way to get its data through the system. A simple example of this process could be that at some particular moment, a moving van travels down a street and temporarily blocks the previously preferred path from an end-point meter to the cell relay meter. In

[4] The RF devices inside the Smart Meter function as transceivers since they both transmit and receive radio signals. In this report, the term transmitter is often used in place of transceiver since the primary characteristic of the meters of interest in this study is the meter's ability to transmit radio signals.

this case, the data is rerouted via other end-point meters that act as alternative paths for the meter to initiate the data communications. This very powerful networking approach provides for good data communication reliability and can even allow communications for end-point meters that are outside the line-of-sight range to their cell relay meter. Additional end-point meters, therefore, have the ability to expand the geographical extent of a network. Figure 2-2 illustrates the concept behind a wireless mesh network implemented for a Smart Meter equipped neighborhood. Each meter communicates either directly with the cell relay meter or via multiple "hops" of the signals through other meters.

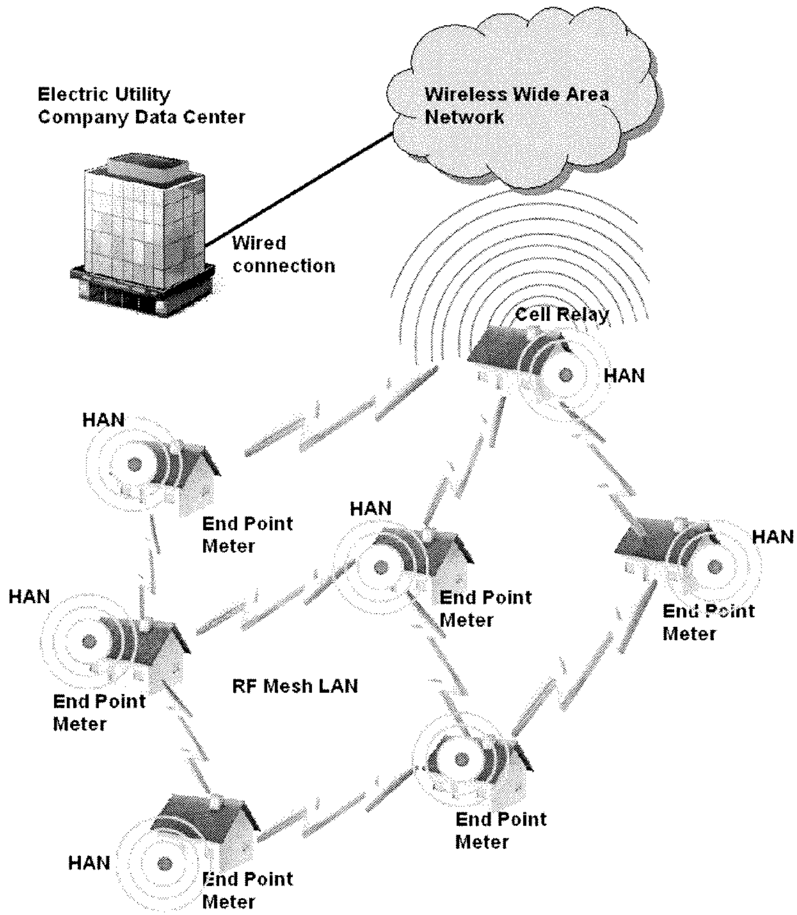


Figure 2-2
Simplistic illustrative diagram of an RF mesh network. Each end point also provides a Home Area Network (HAN) feature. The cell relay acts as a collector point for multiple meters distributed in a neighborhood and transmits received data onto a cellular wireless wide area network (WWAN).

[5] Southern California Edison Electric Company is deploying Smart Meters as part of their SmartConnect™ program with one access point for approximately every 500 end-point meters on residences. In the case of San Diego Gas and Electric Company, each access point serves for data collection from approximately every 750 end-point meters.

For the Itron equipment that was the subject of this investigation, two separate transmitters are contained in the end-point meters. The wireless mesh network can be referred to as an RF LAN (radio frequency local area network). The Itron RF LAN operates in the 902-928 MHz license free band using spread spectrum transmitting technology. A second, separate transmitter that operates in the 2.4 GHz frequency range (2405 MHz to 2483 MHz) uses direct sequence spread spectrum technology that is referred to as a Zigbee radio[6]. This second transmitter is included for use with Home Area Networks (HANs) allowing customers, for example, to control certain electric appliances or systems within the home. When fully implemented, the customers will be able to connect wirelessly with the HAN radio and set times at which various appliances and/or electrical systems may operate, thereby taking advantage of those times during which electricity rates are lowest.

The RF LAN provides data communications among the various end-point meters and an associated cell relay meter. Cell relays are end-point meters that contain yet a third transceiver that is designed for wireless connection to the cellular WWAN, i.e., relaying of the data received from the various end-point meters over a private connection to the electric utility company. The transceivers use the same frequency bands used by cell phones. Two different frequency bands are used by these cell-relay transceivers, either the 850 MHz band or the 1900 MHz band.[7] Figure 2-3 shows a cell relay with the flexible dual band antenna located on the inside surface of the meter cover.

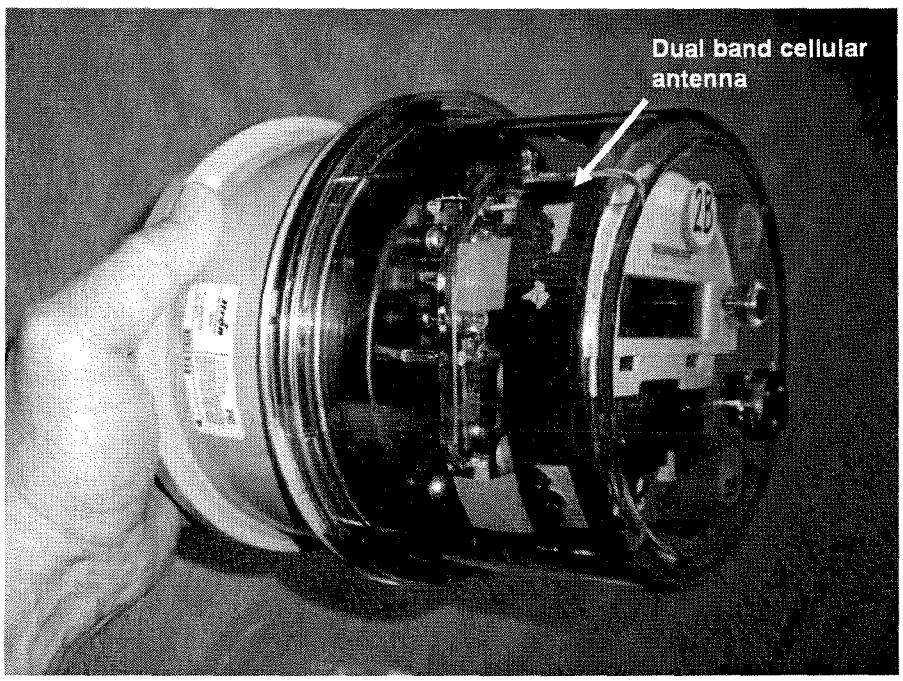


Figure 2-3
Cell relay meter with flexible, dual band (850 MHz and 1900 MHz) antenna affixed to interior surface of the meter cover.

[6]Zigbee is a name for a particular data communications protocol used in the HAN system.

[7]These frequency designations indicate the nominal frequencies used for the wireless WAN for Internet connectivity.

An important characteristic of this wireless mesh network technology is the fact that the RF emissions produced by Smart Meters, i.e., the signals that represent the data being transmitted, are not continuous but very intermittent in nature. For example, an electric utility company may interrogate the Smart Meters multiple number of times a day to acquire electric energy usage by the customer. While the Smart Meter may remain in stand-by in terms of transmissions at other times of the day, when an instruction is received to transmit energy consumption data, the meter transmits and proceeds to deliver the requested data to the cell relay meter. Hence, for the most part, Smart Meter transmissions are relatively infrequent during the day and may only consist of emissions for a few milliseconds during each of the interrogations throughout the day. This means that while the transceivers stand ready to transmit, there may be very little or no activity during most of the time. In addition to those periods during which data on electricity usage has been requested, however, Smart Meters must insure that they have a mesh network connection with at least one other Smart Meter so that, when necessary, it can deliver the data requested. Maintaining this connectivity within the mesh network requires periodic transmissions to alert the cell relay meter and other meters to its availability to be interrogated for data. So, Smart Meters spend part of their time in a so-called stand-by mode in which they issue beacon signals[8] to signify their identity to other nodes of the network with the objective of establishing a connection with the network. These beacon signals last for very brief periods of, nominally, 7.5 milliseconds and occur at various intervals. Finally, there are other instances during which certain network maintenance activities are accomplished and during which, again, various, very short duration and intermittent emissions exist. The cumulative effect of these transmissions is that while the total time spent transmitting signals from a Smart Meter is generally very modest within a day, the signals are very intermittent. They are not continuous in the same sense as the signal received from an FM radio broadcast station but, rather, exist as very short duration signals scattered throughout the day. This intermittency contributes to the difficulty in accurately measuring the strength of the emissions.

In practice, homes in a Smart Meter equipped neighborhood will have end-point Smart Meters installed that communicate with a cell relay meter either directly or though the medium of multiple end-point meter radio signal hops. Approximately every 500th (in the case of SCE) or 750th (in the case of SDG&E) residence may be equipped with a cell relay that not only handles the normal RF LAN communications but, also, relays these data onward, wirelessly, to the electric utility. All of these data communications proceed intermittently throughout each day.

The fact that the Itron Smart Meters studied here contain RF transmitters, albeit low power transmitters, means that relatively weak ambient RF fields exist in the vicinity of the meters. At the surface of the meter, the RF field strengths will be greatest with rapidly decreasing field strengths with increasing distance from the meter. While these low power transmitters cannot produce extremely intense RF fields, nonetheless, the issue of potential human exposure to these RF fields has, in some areas, become a question by the public.[9] A concern expressed by some has been the potential for adverse health effects that might be caused by exposure to the weak RF fields produced by Smart Meters. This report documents an investigation of the characteristics of RF fields associated with the Itron wireless Smart Meter that can assist in a better understanding of possible public exposure to the RF emissions produced by Smart Meters. Throughout this report, the term Smart Meter is intended to refer to the wireless type represented by the Itron meters discussed in this report.

[8] During the initial installation of an Itron Smart Meter, the meter enters a "discovery phase" in which it seeks to establish a link with the mesh network. During this discovery phase, beacon signals are emitted during approximately 3.5 second intervals until the meter becomes synchronized with the network or until a total time of about 6 minutes is reached after which beacons are emitted once about every 34 seconds until linked with the network or for up to 1½ hours. After this period, if a meter does not establish a link, it issues beacons once every hour during which it attempts to connect with the network. After 104 attempts, if still not linked with the network, the meter resets itself and begins the discovery sequence again. Once the meter becomes synchronized with the network, a beacon signal is emitted once every 94 seconds to 30 minutes depending on the level of other data traffic.

[9] Newspaper accounts of public reaction to Smart Meters

Section 3: Objective of Investigation

The work described in this report was focused on understanding the physical characteristics of the RF fields that are produced by Smart Meters such that an informed conclusion can be made as to the magnitude of possible human RF exposure caused by the meters. In this context, the objective of the work was to develop insight to the magnitude and spatial characteristics of Smart Meter RF fields including temporal aspects of the emissions that would allow a meaningful evaluation of possible exposures by reference to applicable RF human exposure limits.

Section 4: Technical Approach to Investigation

Characterizing RF fields produced by Smart Meters can be difficult. The intermittent nature of the emissions, addressed above, means that it is not a simple matter to simply bring instrumentation to an installed meter and be able to instantly detect the presence of the various emissions. The meter may or may not be in a transmit mode at the time when measurements are sought. Further, the spread spectrum characteristic of the emissions of the RF LAN and HAN transmitters leads to a further complication. For example, with the 900 MHz RF LAN transmitter, the emitted signal, at any particular instant in time, may be on any specific frequency within the 902 to 928 MHz band. When using narrow-band instrumentation, such as a frequency swept spectrum analyzer, the challenge is to have the analyzer on the specific frequency at the very instant in time that the emission is occurring to be able to measure its strength. Since the emissions are highly intermittent, this may take considerable time to insure that any such emissions have been captured by the instrumentation.

After careful consideration of the complexities associated with these kinds of measurements, it was decided that direct support of the testing by Itron, the manufacturer of the Smart Meter, could prove to be the most expedient approach to collecting the data useful to a complete exposure assessment study. As the manufacturer, Itron would have the knowledge and ability to control the Smart Meter to allow for meaningful measurements, avoiding the complications and uncertainties associated with working with already deployed meters.

Measurements at Itron

During the week of July 27, 2010, an extensive series of measurements was accomplished by the Principal Investigator at the Itron facility.

While at the Itron facility, detailed antenna pattern measurements were performed by the Principal Investigator on end point (Model CL200) and cell relay (Model C2SORD) meters. This included pattern measurements for the 900 MHz RF LAN transmitters in both the end point meter and as installed in a cell relay meter, pattern measurements of the 2.4 GHz Zigbee transmitter in both an end point meter and a cell relay meter and pattern measurements of the cell relay cellular transceiver operating in both the 850 MHz and 1900 MHz bands.

In addition to pattern measurements, Itron provided access to their Smart Meter farm, an area of some 20 acres in which approximately 7000 Smart Meters are installed. The ability to access this field provided insight to the cumulative RF field environment of multiple Smart Meters in close proximity with one another, and whether aggregate exposure produced by a multiplicity of Smart Meters concentrated in one area raises exposure risks.

Measurements in residential locations

Beyond the on-site measurements performed at the Itron facility, additional Smart Meter measurements were performed in a variety of residential environments. Using two Smart Meters that had been specifically programmed by Itron to operate continuously, to facilitate the measurements of field strength, measurements were performed at two residences in Downey, CA. These specially programmed meters were temporarily installed in the electrical service panel at each home and RF measurements were accomplished in the near vicinity of the meter and throughout the interior of each home. This procedure allowed for characterizing the RF fields that might exist inside of residences equipped with a Smart Meter. As a part of the residential measurements, a brief evaluation of the insertion loss afforded by three different metallic meshes, similar to what might be used in the construction of residential stucco walls, was conducted.

In addition to residence specific measurements with pre-programmed meters, RF fields were also measured adjacent to two separate apartment buildings wherein groups of 9 and 11 Smart Meters were grouped tightly together. Finally, a general area survey was conducted by driving throughout an established route within Downey, CA representative of a Smart Meter deployed neighborhood to form general observations of the ability to detect the presence of Smart Meter emissions. The residential measurements aspect of the work reported

here was concluded with a driving survey through Santa Monica, CA within which, at the time, there had been no deployment of Smart Meters.

Measurements in Colville, WA

Separate from the measurements at the Itron facility and the residential measurements in Downey, California, some limited measurements were conducted at the author's location in Colville, WA. These measurements included an evaluation of the comparative readings of RF field obtained by both the broadband field probe and the spectrum analyzer (selective radiation meter) used in the project measurements as well as an evaluation of the attenuation effect on Smart Meter signal propagation through a simulated, residential stucco wall.

Section 5: Transmitter Powers

A crucial aspect of any RF source, relative to its ability to produce RF fields, is the power of the transmitter. At the beginning of interactions with Itron, measurement data were sought on transmitter power levels. Historically, Itron has determined the power level of every transmitter used for the 900 MHz RF LAN and the 2.4 GHz Zigbee radios. These are transmitter devices on Itron manufactured printed circuit boards. All of the transmitters used in the Itron Smart Meters operate with low power, regardless of the frequency band used, nominally one watt or less. The 900 MHz RF LAN transmitter operates at a nominal power of 24 dBm (251 mW). Using Itron test data obtained from power measurements on a sample of 200,000 RF LAN transmitters, Figure 5-1 illustrates the accumulative fraction of transmitters having output powers across a range of power.

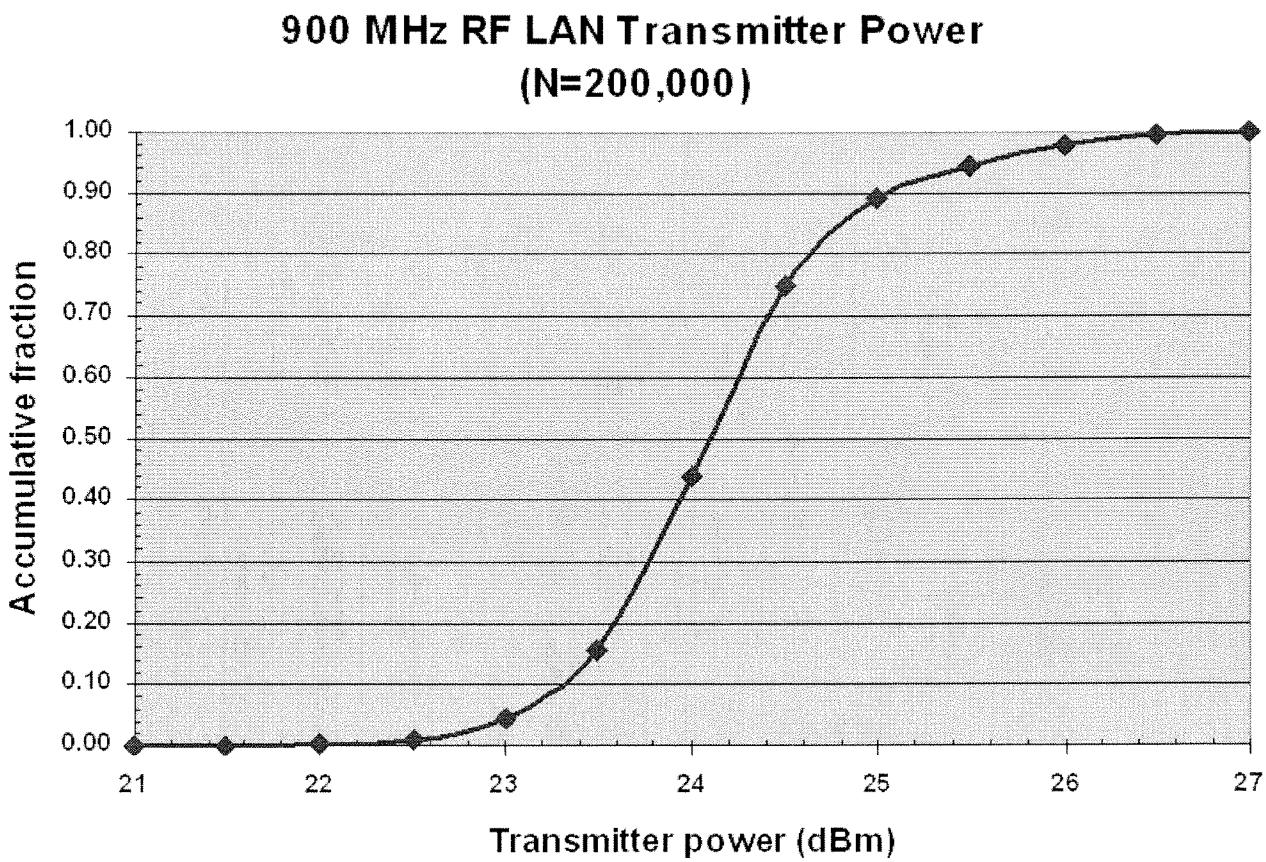


Figure 5-1
Accumulative fraction of 900 MHz RF LAN transmitter output power vs. transmitter power for a sample of 200,000 units. The median transmitter power is approximately 24.1 dBm (257 mW).

Based on a separate sample of 65,536 transmitters, used in end point meters, an average power output of 23.95 dBm (248 mW) was obtained with a standard deviation of 0.695 dBm.. Using these data, the 95% confidence interval would correspond to a range of transmitter power from 22.6 dBm (182 mW) to 25.3 dBm (339 mW) and the 99% confidence interval would correspond to a power range from 22.2 dBm (166 mW) to 25.7 dBm (372 mW).

Using the 200,000 transmitter sample, the median power level corresponds to approximately 24.1 dBm (257). The number of transmitters with power values in selected ranges is shown in Figure 5-2. The mode of transmitter power is approximately 24.5 dBm (282 mW).

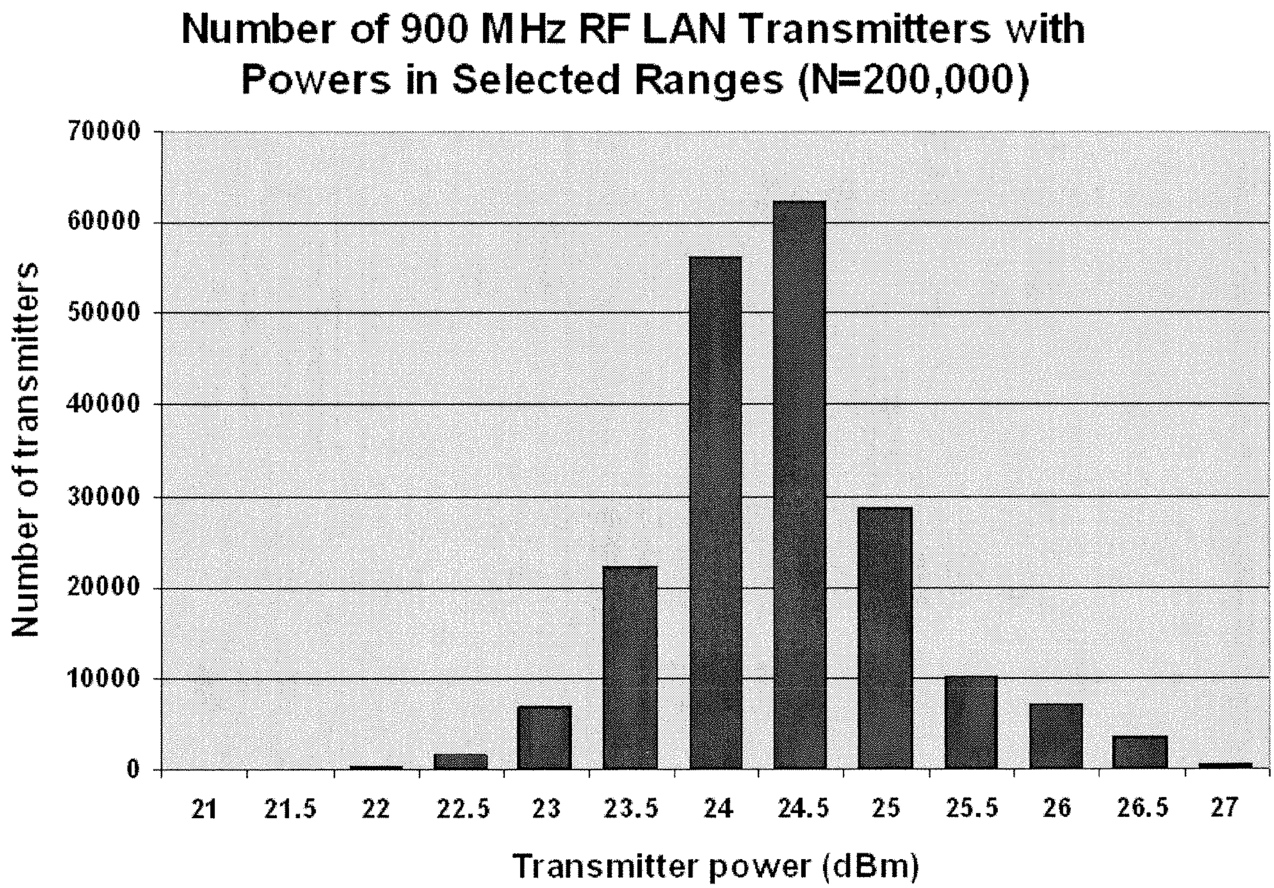


Figure 5-2
Number of 900 MHz RF LAN transmitters with powers within selected ranges. The transmitter power mode is approximately 24.5 dBm (282 mW).

These statistical data on the 900 MHz RF LAN transmitter powers indicate that the most likely power is 24.5 dBm (282 mW); an upper value of 26.0 dBm (398 mW), a value 41% greater than the most likely power, would include 99% of all transmitters.

In the case of the 2.4 GHz Zigbee transmitters, in a sample of 65,535 units used in end point meters, the mean value was found to be 18.31 dBm (67.6 mW) with a standard deviation of 0.76 dBm. This distribution would represent a 95% confidence interval of transmitter power from 16.8 dBm (47.9 mW) to 19.8 dBm (95.5 mW) and the 99% confidence interval would correspond to a power range from 16.4 dBm (43.7 mW) to 20.3 dBm (107.2 mW).

Figure 5-3 shows the accumulative fraction of transmitters having output powers across a range of power. Figure 8 illustrates the number of 2.4 GHz transmitters with powers within selected ranges. The transmitter power mode is approximately 18.5 dBm (70.8 mW).

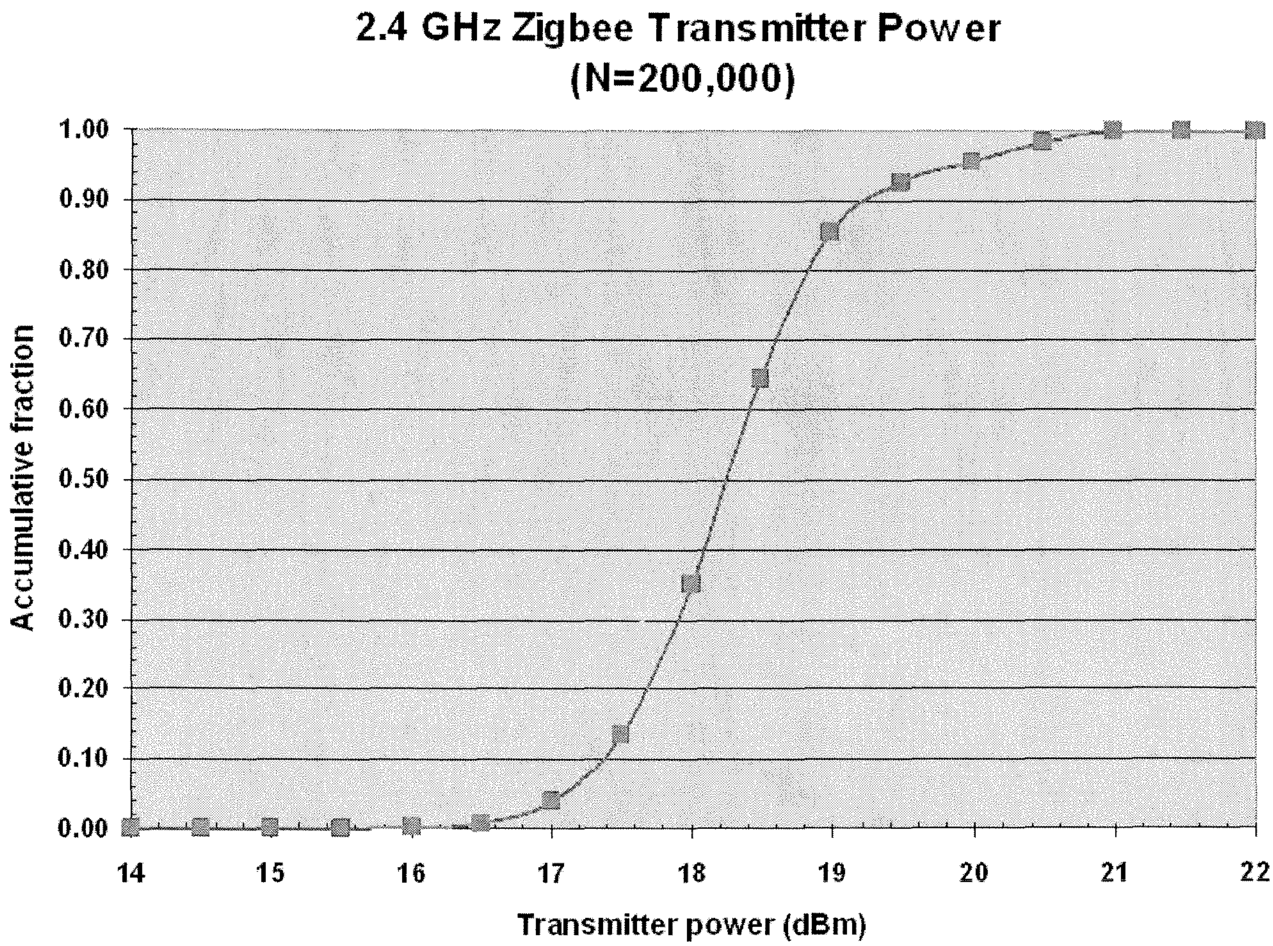


Figure 5-3
Accumulative fraction of 2.4 GHz Zigbee transmitter output power vs. transmitter power for a sample of 200,000 units. The median transmitter power is approximately 18.2 dBm (66.1 mW).

These statistical data on the 2.4 GHz Zigbee transmitter powers indicate that the most likely power is 18.5 dBm (70.8 mW); an upper value of 20.6 dBm (114.8 mW), a value 62% greater than the most likely power, would include 99% of all transmitters.

Cell relay meters contain the additional transceiver used for cellular WWAN connectivity in either the 850 MHz cellular band or 1900 MHz PCS band (personal communications service). Because these transceiver boards are produced by a different company and the units are specified to operate with specific powers and the fact that these units are separately certified by independent test labs for compliance with those specifications, Itron does not carry out additional power measurements. The transceivers, produced by Sierra Wireless operate with the following maximum powers:

Table 5-1
Sierra Wireless Transceivers Operation Maximum Powers

	GSM Modem Model MC8790 FCC ID: N7NMC8790	CDMA Modem Model MC5725 FCC ID: N7N-MC5725
Frequency Band (MHz)	Maximum power output (dBm) (mW)	
850	31.8 (1,514)	25.13 (326)
1900	28.7 (741)	24.84 (305)

Cell relays operate at the highest power of any of the meters due to their cellular/PCS modems but, similar to cellular telephones, the output power of the cellular modem is dynamically controlled by the applicable WWAN base station. This means that the actual operating power of the cellular radio in a cell relay will, generally, be less than the maximum power but will be determined by the signal strength it produces at whatever base station it is communicating with. Only one of the two modems would be active in a given deployment of Smart Meters in a neighborhood; the modem of choice is determined by the cellular wireless network service available and selected by the electric utility company.

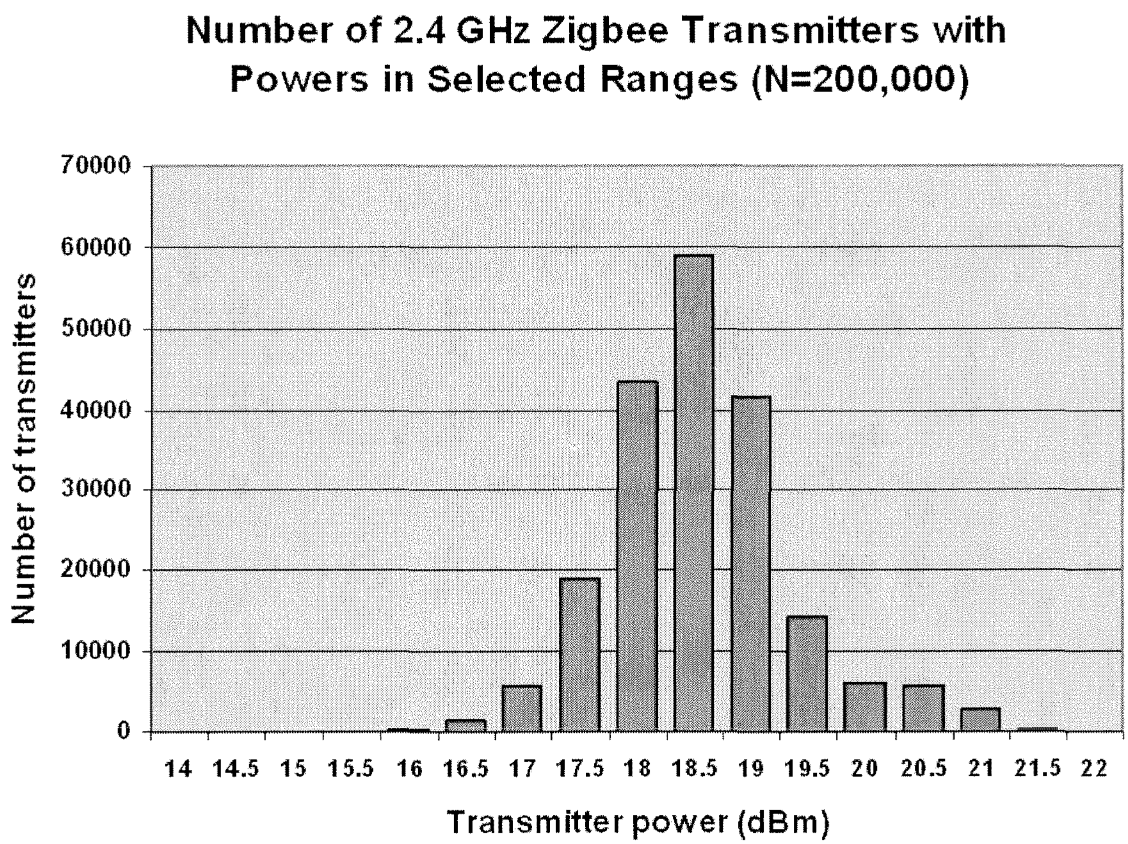


Figure 5-4
Number of 2.4 GHz Zigbee transmitters with powers within selected ranges. The transmitter power mode is approximately 18.5 dBm (70.8 mW).

Section 6: The Measurement Challenge Presented by Smart Meters

The difficulty of accurate RF field measurements near Smart Meters was discussed earlier. Low transmitted power levels in conjunction with intermittent emissions place considerable constraints on the measurement process. While a broadband measurement probe can eliminate the problem of the RF emissions occurring randomly on many different frequencies within the band, the relatively low sensitivity of broadband instruments places considerable restrictions on performing field strength measurements except within extremely close proximity of the meter. Intermittent emissions with very short duration, even if detectable, mean that it is difficult to observe when a transmission occurred. Generally, the desired measure of RF fields, from a human exposure perspective, is a measure of the average (root mean square - rms) value of the field strength or incident power density. The ratio of the average power density to the peak power density, for most Smart Meters is such that trying to measure the average field magnitude for a normally operating meter is very challenging. This can change if there exists a large aggregation of Smart Meters such that with their random on-off transmissions, much greater opportunity to "see" the emissions is possible.

Because of the rapid changes of frequency associated with the spread spectrum nature of the RF LAN and Zigbee radios in the Itron Smart Meters, an alternative approach is used to facilitate any antenna pattern and field measurements. This approach involves programming the relevant radios to transmit continuously, rather than their normal intermittent operation, and to transmit on a specific frequency within the relevant band as opposed to hopping across more than 50 channels within the 900 MHz band. Through this programming of the radios, the average signal level is now at its maximum, making it much easier to detect the RF field, and the fact that the emitted signal is now fixed on a specific and known frequency allows for ready confirmation that the measurement is of the intended signal. Since measurements under this scenario will indicate the peak value of RF field, other information is required to translate the peak field into what the equivalent average field would be. This requires a knowledge of the duty cycle of the emissions from the Smart Meter. The duty cycle can be thought of as the ratio of the amount of time that the transmitter is transmitting its signal to the total observation period. For example, if the Smart Meter were to typically transmit as much as 10 seconds during an hour (3600 seconds), the duty cycle would be 0.28%. In other words, the time-averaged power density of the RF field would be just 0.28% of the peak power density measured. The issue of Smart Meter duty cycles will be addressed later in this report.

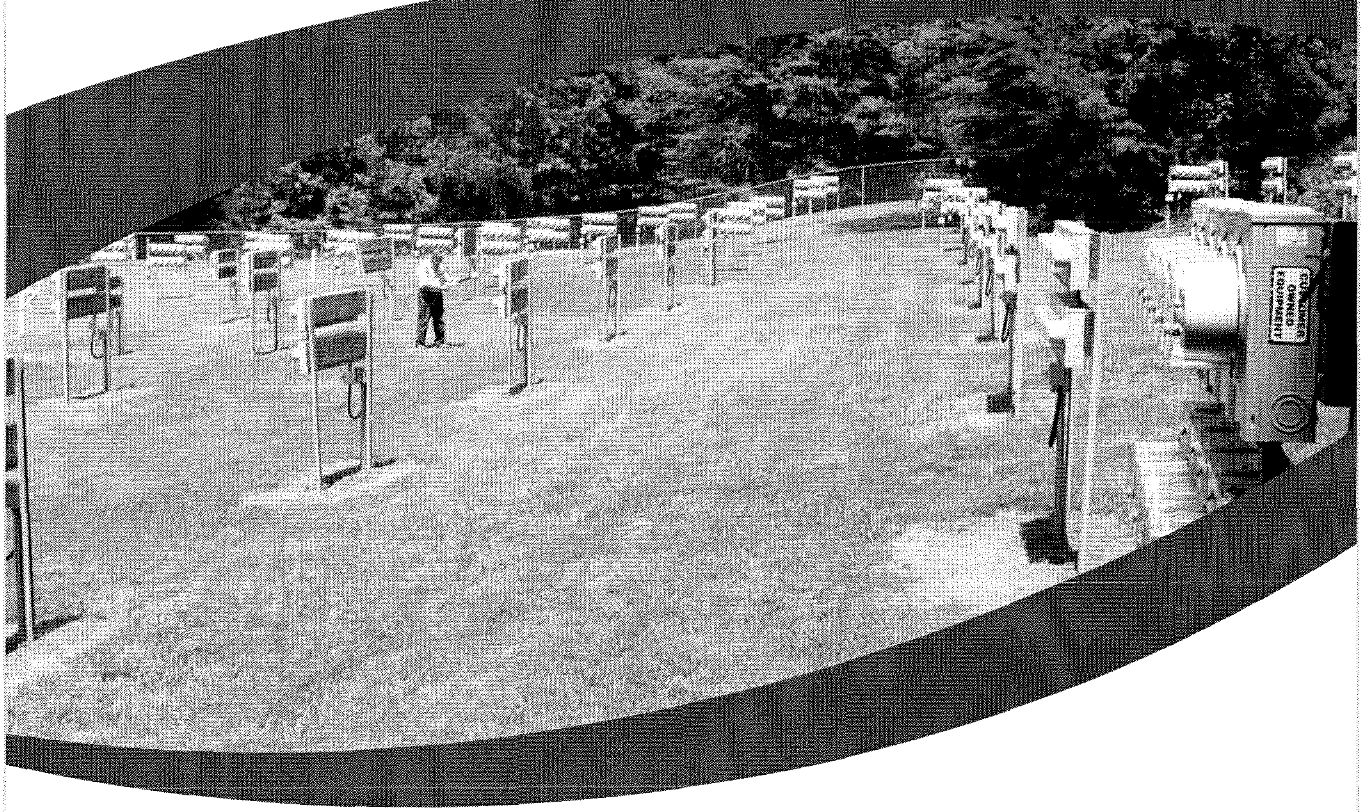
APPENDIX H
Electrical Power Research Institute, An Investigation of Radio Frequency Fields Associated with the Itron Smart Meter, Technical Report 2010

See attached.

ELECTRIC POWER RESEARCH INSTITUTE

2010 TECHNICAL REPORT

An Investigation of Radiofrequency Fields Associated with the Itron Smart Meter



An Investigation of Radiofrequency Fields Associated with the Itron Smart Meter

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1021126
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The following organization, under contract to EPRI, prepared this report:

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NOTE

For further information about EPRI, call the EPRI Customer Assistance Center at 800.313.3774 or
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Acknowledgments

The following organization, under contract to the Electric Power Research Institute (EPRI), prepared this report:

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This report describes research sponsored by EPRI and overseen by Gabor Mezei, MD, Ph.D, EPRI's Program Manager for the EMF and RF Health Assessment and Safety Program. Expertise, review and comment were provided by a cross-functional team at EPRI including Rob Kavet, D.Sc., Senior Technical Executive; Chris Melhorn, Program Manager; Kermit Phipps, Project Engineer/Scientist and Brian Seal, Senior Project Manager, EPRI.

Numerous individuals from Southern California Edison (SCE) Electric Company conducted and supported the measurement work reported here in both South Carolina and California: Glenn Sias, Manager, SCE EMF and Energy Group; Al Vazquez, Enterprise Network Architect, SmartGrid Engineering; Kevin Nesby, Project Manager in the Edison SmartConnect™ Deployment Program; Brian Thorson, EMF Specialist in the Operations Support Business Unit; Jack Sahl, Director of Operations Support in the SCE Operations Support Business Unit; and John Bubb, Manager of Product Management for SCE SmartConnect.

Background information on operational characteristics of smart meters was provided by Vijay Lakkasetty, System Engineering & Operations - Smart Meter Project, Jay Xu, Principal Engineer, and Jim Turman, Program Manager, Department & Employee Readiness, Safety and Emergency Services, all of San Diego Gas and Electric Company.

As further described within the report, testing support, facility access and cooperation was provided by Itron, which facilitated this work, particularly by Dan Lakich, Design & Development Manager, Electricity Metering; Mike Belanger, Product Line Manager, Itron OpenWay Network Communications; Sudhir Thumaty, R&D Manager; Suresh Kumar Yada, Design Engineer; Ben Smith, Engineer; Ken Prevatte, Project Director; and Matthew DeCubellis, Application Engineer.

This publication is a corporate document that should be cited in the literature in the following manner:

An Investigation of Radiofrequency Fields Associated with the Itron Smart Meter
EPRI, Palo Alto, CA: 2010. 1021126

Product Description

Smart meters represent one component of the advanced metering infrastructure (AMI). Although data to and from smart meters may be transmitted through wired connections, many smart meters make use of miniature, low power radio transceivers to wirelessly communicate with the electric utility and with the Home Area Network (HAN) that provides home owners with the ability to interact with electrical appliances and systems within the home. Deployment of smart meters has raised concerns by members of the public about possible adverse health effects that could be related to exposure to the radiofrequency (RF) emissions of the meters. As part of on-going efforts to address public concerns on this issue, this report documents the collection of information on RF exposure related to the operation of two particular models of Smart Meter produced by Itron Inc.

Results & Findings

The smart meters studied in this report are currently being deployed by two electric utilities in California. The meters are part of wireless mesh networks in which one meter is configured as a collector point, referred to as a "cell relay" by Itron, for each of approximately 500 to 750 "end point meters." The cell relay collects data from the various end point meters and conveys these data onto the cellular wireless wide area network (WWAN) for communication back to the electric utility company's data management system. Mesh network communication among the many meters is provided by the 900 MHz band transceiver RF LAN (local area network). A HAN feature is supported by a 2.4 GHz transceiver.

Data collection was carried out in a laboratory setting and at residences and in neighborhoods in southern California and Colville, Washington, supplemented with theoretical modeling studies. The results indicate that RF field from the investigated smart meter are well below the maximum permitted exposure (MPE) established by the Federal Communications Commission (FCC). For instance, at one foot, the RF field from an end point meter would be expected to not exceed 0.8% of the MPE) established by the Federal Communications Commission (FCC). For the cell relay, the RF field would not exceed 0.2% of the MPE. Even at very close distances, such as one foot directly in front of the meter, with an unrealistic assumption that the transmitters operate at 100% duty cycle, the resulting exposure is less than the FCC MPE. When viewed in the context of a typical, realistic exposure distance of 10 feet, the RF fields are much smaller, about 0.008% for the end point meter and about 0.002% of MPE for the cell relay. For occupants of a home equipped with a Smart Meter, interior RF fields would be expected to be at least ten times less intense simply due to the directional properties of the meter. When the attenuation afforded by a stucco home's construction is included, a realistic

value of the interior RF field would be about 0.023% of the MPE for an end point meter and about 0.065% for a cell relay. Regardless of duty cycle values for end point and cell relay meters, typical exposures that result from the operation of smart meters are very low and comply with scientifically based human exposure limits by a wide margin.

Challenges & Objective(s)

This report is focused on the RF aspects of smart meters and in particular, the strength of the transmitted RF fields that may be produced by the meters from a human exposure perspective. The greatest difficulty in arriving in determining realistic time-averaged exposure from smart meters is associated with determining transmitter duty cycles since the meters only emit RF radiation at intervals

Applications, Values & Use

This report documents an investigation of the characteristics of RF fields associated with Itron Smart Meter. The project was undertaken to improve understanding of public exposure to the RF emissions produced by smart meters and to respond to public concerns about potential health effects.

EPRI Perspective

Measuring electric energy consumption with so-called smart meters in residential and commercial environments is becoming more commonplace as part of the development of Advanced Metering Infrastructure (AMI) in the electric utility industry. With the deployment of smart meters public concern was raised about potential health effects associated with RF emissions from smart meters EPRI is responding to these concerns with research efforts to provide objective information on RF emissions related to smart meters.

Approach

The project team conducted laboratory and field measurements of the RF emissions of Itron smart meters. A key objective was to determine realistic estimates of the operational duty cycle of meter transmitters. The team also investigated the effectiveness of metal meshes and stucco walls in shielding smart meters.

Keywords

Smart meters
Radiofrequency emissions
EMF health assessment
Environmental issues

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Section 1: Summary

Measuring electric energy consumption with so-called Smart Meters in residential and commercial environments is becoming more commonplace. Smart Meters represent one component of what is referred to as Advanced Metering Infrastructure (AMI) in the electric utility industry. AMI systems comprise both wired and wireless technologies with each exhibiting their own advantages. Electric utility companies, thus, have options to implementing AMI systems. Even within the wireless category of AMI system, equipment can operate over a wide range of frequencies and powers and levels of activity. The Smart Meters, based on wireless technology, make use of miniature, low power radio transceivers, typically inside the meter, to wirelessly communicate with the electric utility. Two-way radio communication provided by Smart Meters allows for transmission of energy consumption data from a residence or business to the utility company and reception of data pertaining to time-of-day pricing of electric energy.

As wireless AMI technology is projected to become widely distributed, it becomes prudent to quantitatively assess the levels of RF emissions fro meters to which the public may be exposed. Nearly two dozen communities have placed moratoria on further deployment of Smart Meters in northern California and more than 2000 health-related complaints have been received by the California Public Utilities Commission[1]. This report documents the collection of information related to the operation of two particular models of Smart Meters[2] produced by Itron Inc. for purposes of supporting exposure assessment exercises that can address public concerns about exposure. The Itron products are currently being deployed by Southern California Edison Electric Company (SCE) and San Diego Gas and Electric Company (SDG&E) and both companies provided support to EPRI (the Electric Power Research Institute) for this activity. A number of companies currently manufacture different forms of Smart Meters and, most commonly, these meters employ radio transmitters that operate in Federal Communications Commission (FCC) designated license free bands[3]. The Itron meters in this study use transmitters that operate in the license free bands of 902 MHz to 928 MHz (the "900 MHz band") and 2400 MHz to 2500 MHz (the "2.4 GHz band").

The Smart Meters studied here act as nodes in wireless mesh networks consisting of approximately 500 residences (for SCE) or 750 residences (for SDG&E); these are referred to as "end point meters." Within each mesh network, one residence, designated as a "collection point," is equipped with a Smart Meter having an additional internal transmitter (referred to as a "cell relay" for communicating data to the utility over a wireless wide area network (WWAN). The cell relay collects data from the various end point meters and conveys these data onto the cellular wireless wide area network (WWAN) for communication back to the electric utility company's data management system. Mesh network communications among the many meters is provided by the 900 MHz band transceiver RF LAN (local area network). A HAN feature is supported by the 2.4 GHz transceiver. A data protocol used by the HAN called Zigbee is used to refer to the 2.4 GHz transceiver as in "the 2.4 GHz Zigbee radio".

The data collection effort included gathering of information and working with the manufacturer at their facility in West Union, South Carolina, measurements at residences and in neighborhoods in southern California and some more limited measurements in Colville, Washington. Itron graciously provided technical support and access to its facilities and personnel to assist in this effort. Data included transmitter power levels, radiation patterns, RF field strengths or power densities of individual meters and groups of meters, spatial variations of RF fields in a vertical plane near Smart Meters, attenuation of Smart

[1]See, for example, "Smart Meters - They're Smart, But Are They Safe?". http://www.publicnewsservice.org/index.php?/content/article/16846-1 (November 8, 2010).

[2] Itron model CL200 (end point meter) and model C2SORD (cell relay).

[3] Some Smart Meters are designed to operate in FCC licensed bands and may operate with higher powers.

Meter RF fields by building materials, and information potentially useful for assessing transmitter duty cycles. To characterize the systems currently operating, parallel efforts included modeling of RF fields based on measured values of maximum equivalent isotropic radiated power (EIRP) of both end point and cell relay meters and analysis of end point meter transmission statistics for estimating duty cycles. Antenna patterns were determined for the 900 MHz RF LAN and 2.4 GHz Zigbee transmitter in both end point and cell relay meter configurations. Patterns were also measured for both the 850 MHz and 1900 MHz cellular bands from a cell relay.

Antenna pattern measurements revealed that RF fields are emitted preferentially toward the frontal region of the meters; the direction of maximum EIPR, however, might not be directly normal to the front of the meter. Apparent antenna gain values were modest, ranging between 0.88 dBi and 5.08 dBi, depending on the frequency band and the configuration (end point vs. cell relay). Patterns typically exhibited a reduced RF field behind the meter of approximately 10 dB down from the maximum frontal value of field with relatively narrow notches in the pattern directly behind the meter of as much as 20-30 dB less than in front.

Transmitter power data were obtained on 200,000 RF LAN 900 MHz transmitters with a most likely value of approximately 24.5 dBm (282 mW) with a 99th percentile power of 26.0 dBm (298 mW). Based on a sample size of 200,000 2.4 GHz radios, the most likely power was found to be 18.5 dBm (70.8 mW) with a 99th percentile power of 20.8 dBm (114.8 mW). Cellular transmitters were specified as 31.8 dBm in the 850 MHz band and 28.7 dBm in the 1900 MHz band.

Because of the very intermittent nature of transmissions from Smart Meters and their frequency hopping spread spectrum transmitters, accurate measurement of RF fields can be challenging. To facilitate the measurements, Smart Meters were programmed to transmit continuously on a single frequency. RF field measurements were performed on a single meter inside the Itron anechoic chamber and on ten individual meters installed in the Itron meter farm. These measurements were obtained with two different instruments including an isotropic, broadband, frequency conformal electric field probe (Narda Model B8742D) and a spectrum analyzer based selective radiation meter (Narda Model SRM-3006). Measurement data for the 900 MHz RF LAN transmitters showed RF fields in the range of a few percent of the FCC MPE for the general public at 30 cm (approximately 1 foot) in front of the meters (0.7 to 5.5%) with the broadband probe depending on frequency. Similar measurements for the 2.4 GHz Zigbee radios at a distance of 20 cm showed 0.75% to 1.7% of the MPE, again depending on the frequency of the transmitter.

Using the SRM-3006 instrument, RF fields were measured as a function of distance from the rack of ten meters in both the 900 MHz and 2.4 GHz bands. These measurements produced readings ranging between approximately 8% at 1 foot to less than 0.1% at 75 feet from the meters in the 900 MHz band and approximately 4.5% at 1 foot to less than 0.01% at 75 feet in the 2.4 GHz band. 900 MHz field measurements showed that the emissions associated with the ten meters dropped into the background produced by other meters in the meter farm at a distance of approximately 50 feet.

By using the maximum hold and average measurement feature of the SRM-3006, a measurement in the meter farm obtained by walking along two rows of meter racks resulted in an integrated peak RF field equivalent to 0.114% of MPE and an average value of 0.00023% of MPE. The ratio of average to peak readings corresponds to an apparent duty cycle of about 0.2%. In measurements taken at two apartment houses in Downey, California, ratios of average to peak values of RF field obtained over five-minute monitoring periods resulted in estimated duty cycles of approximately 0.001%. Using a tiny USB spectrum analyzer designed specifically for just the 900 MHz band in the Itron meter farm, spectral measurements were captured for approximately one hour. This measurement resulted in an apparent duty cycle of approximately 0.02%.

Interior residential measurements were performed in two homes in Downey, California after temporarily replacing the existing Smart Meter with specially programmed units that would transmit continuously in the 900 MHz and 2.4 GHz bands. Inside measurements ranged from approximately 0.006% to 22% of MPE, the highest value associated with operation of a microwave oven in the kitchen at 2 feet from the oven. The greatest value immediately behind the Smart Meter, inside the home, was 0.009% of MPE. Wireless routers found in both homes resulted in RF fields in the range of 0.02 to 0.03% of MPE.

Residential neighborhood surveys were performed in areas with and without deployed Smart Meters while driving the streets of two communities, one in Downey, CA and one in Santa Monica, CA respectively. The exercise demonstrated that the emissions of randomly emitting Smart Meters could be detected in the Downey neighborhood but virtually no signals were detected in Santa Monica with the exception that when driving through a commercial district, the 900 MHz band came alive with noticeable activity, presumably caused by various 900 MHz sources, such as cordless telephones, etc. Spectrum measurements in several other band were also performed including the FM radio broadcast band, two cellular telephone bands and the 2.4 GHz Wi-Fi band.

The insertion loss of three different metal meshes was evaluated in California at one of the residences in which RF measurements were obtained. Three different sizes of mesh were used in the tests by inserting the mesh between a specially prepared, portable Smart Meter as a source, and the SRM-3006 meter. These measurements were performed at close range with the Smart Meter approximately six inches behind the mesh and the SRM-3006 probe approximately the same distance on the other side of the mesh. These measurements resulted in values for insertion loss ranging from 4.1 dB to 19.1 dB in the 900 MHz band and from 1.2 dB to 11.4 dB in the 2.4 GHz band, depending on mesh opening size. Additional insertion loss measurements were performed on a simulated stucco wall in Colville, WA resulting in values of 6.1 dB and 2.5 dB for the 900 MHz and 2.4 GHz bands respectively.

Since human RF exposure standards are based on spatial averages, spatially averaged values of RF fields were obtained along a vertical line at approximately one foot in front of a Smart Meter. It was found that over a six-foot vertical span, the spatially averaged RF field in the 900 MHz band corresponded to a value 23% of the measured peak value found near the height of the meter. In the 2.4 GHz band, the spatially averaged field was 18% of the spatial peak.

Using the detailed pattern measurement data described earlier, theoretical calculations of RF fields that could be associated with each of the transmitters in either end point meters or cell relays were made. A detailed analysis was developed to investigate the effect that ground reflected fields could have on the resultant field and what factors would be appropriate for including the effect of ground reflections in theoretical RF field calculations.

Human exposure to RF fields is judged by comparison to applicable exposure limits or standards. For the United States, and in regard to Smart Meters, the most applicable limits are those promulgated by the FCC, a spatially averaged and time averaged value of 610 microwatts per square centimeter ($\mu W/cm^2$) in the 900 MHz band and 1000 $\mu W/cm^2$ in the 2.4 GHz band. A proper comparison of Smart Meter produced RF fields to these limits should involve a determination of the time-averaged value where the averaging time is specified as any 30-minute period. To arrive at time-averaged values, the measurements or calculated fields reported above must be corrected for the operational duty cycle of the transmitters. This is the most complex issue connected with Smart Meter RF evaluations since transmitter activity is semi-random in nature, with only brief transmissions occurring throughout a day. The maximum value of duty cycle for end point meters has been estimated by Itron to be in the range of 5%. Actual measurements, however, tend to result in substantially smaller values, typically less than 1%. Because of the variable nature of transmitter activity, even accurate measurements of a specific meter or meters need to be repeated for some days and, possibly, weeks to obtain reliable estimates of typical duty cycles. Rather than measurements, Itron developed special software implemented by the two companies to collect transmit data gathered and reported on in this report. Such an approach represents a practical way for bracketing realistic values of meter duty cycles since it can be implemented in software and extended to a very large sample size, something that would be impractical to do via physical measurements of RF fields at the meters. Using this approach, SCE generated data were examined to identify what fraction of meters in the sample exhibited transmit durations over a range of times which are related directly to the transmitter duty cycle. This exercise, for example, supported 99th and 99.9th percentile duty cycles of 0.11% and 4.7% for the RF LAN component of end point meters. A complimentary analysis conducted by SDG&E but using a more accurate determination of transmitter activity revealed smaller duty cycles. Similarly small duty cycle values are associated with the HAN and cellular transmitters. Figure 1-1 illustrates the estimated maximum likely time-averaged RF fields that would be produced by both end point and cell relay meters.

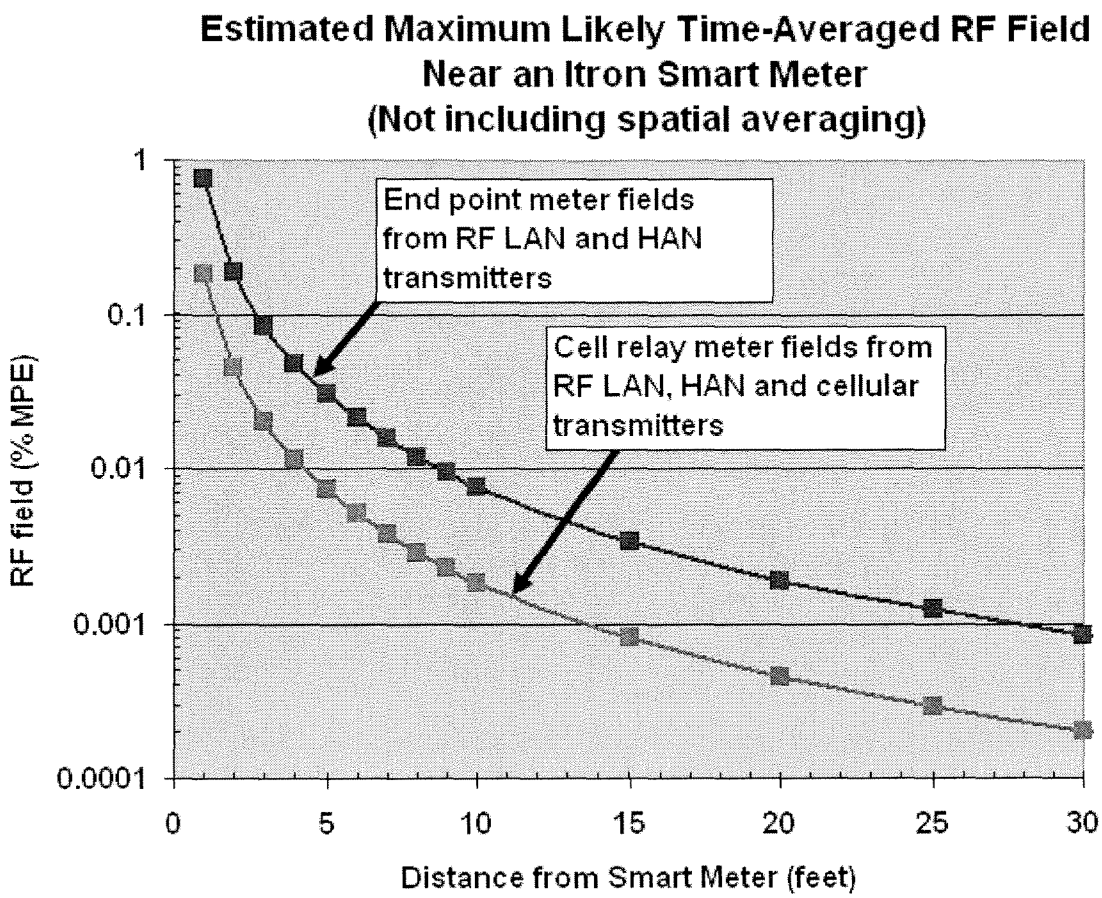


Figure 1-1
Calculated RF fields near Itron end point and cell relay meters based on 99th percentile transmitter power values, main beam exposure (point of maximum RF field), inclusion of the possibility of ground reflected fields and assumed 99th percentile duty cycles.

These data, when taken collectively, indicate that the RF emissions produced by the Itron Smart Meters evaluated in this study result in RF fields <0.06 mW/cm^2 (at least 10-fold below the FCC limit at 900 MHz). For instance, at one foot, the RF field from an end point meter would be expected to not exceed 0.8% of the MPE. For the cell relay, the RF field would not exceed 0.2% of the MPE. Even at very close distances, such as one foot directly in front of the meter, with an unrealistic assumption that the transmitters operate at 100% duty cycle (at which point the mesh network would not function) the resulting exposure is less than the FCC MPE. When viewed in the context of a typical, realistic exposure distance of 10 feet, the RF fields are much smaller, about 0.008% for the end point meter and about 0.002% of MPE for the cell relay. Spatial averaging of these "spatial maximum" fields brings the estimated values down to approximately one-fourth of these magnitudes.

For potential exposure of occupants of a home equipped with a Smart Meter, interior RF fields would be expected to be at least ten times less intense simply due to the directional properties of the meter. When the attenuation afforded by a stucco home's construction is included, a realistic value of the interior RF field would be about 0.023% of the MPE for an end point meter and about 0.065% for a cell relay meter. The WWAN operates at a far greater data throughput than the RF LAN within the mesh. Therefore, the duty cycle is correspondingly less for the cellular modem within the cell relay, despite the fact that it transmits all of the data collected from the relevant meters of its mesh network.

The most uncertainty in determining realistic time-averaged exposure from Smart Meters is associated with transmitter duty cycles. Hence, the most potentially useful avenue of future RF exposure assessment would include extensive statistical analyses of Smart Meter transmitter activity.

A detailed evaluation of possible RF fields produced by the Itron meters included in this study shows that regardless of duty cycle values for end point and cell relay meters, typical exposures that result from the operation of Smart Meters are very low and comply with scientifically based human exposure limits by a wide margin.

Section 2: Introduction and Background

As the electric utility industry in the United States moves toward implementing a "smart grid", one of the key components consists of so-called Smart Meters. These new technology electric power meters represent a part of the advanced metering infrastructure (AMI) that provides for automatic meter reading (AMR) and sophisticated control over the use of electric energy by consumers in their homes and businesses. When AMI technology is fully implemented, an enhanced balancing of power distribution throughout the various electrical grids of the country will exist and utility customers will be able to, among other things, determine when certain electrically operated appliances may operate, based on time-of-day pricing of electricity. Such advanced capability requires close to real-time data acquisition on electric energy usage and such data requirements mean that the existing, traditional electric power meters that employ manual energy consumption readings, for example, once a month, can't provide such timely data.

The modern technology of Smart Meters provides for an ability to almost instantly interrogate specific power meters as to electric energy usage. For the Smart Meters investigated in this study, this capability is accomplished via the use of data communications between the electric utility company and individual power meters through the medium of radio signals. This report is focused on the radiofrequency (RF) aspects of Smart Meters and in particular, the strength of the transmitted RF fields that may be produced by the meters from a human exposure perspective.

Smart Meters as RF Sources

A wireless Smart Meter makes use of miniature, low power (typically less than one watt) radio transceivers inside the meter to wirelessly communicate with the electric utility company. The transceivers (transmitter and receiver) allow both transmission of data as well as reception of data and instructions from the utility. These transmitters are contained within the housing of the electric meter but are not necessarily visually obvious to an observer. Antennas used for the transmitters are commonly created as slots on the various printed circuit boards that constitute the electronic makeup of the meter. A common transmitter configuration of Smart Meters includes two or three transmitters in the meter. Figure 2-1 shows a Smart Meter with its digital display that is used to indicate electric energy usage.

Figure 2-1
Photo of Itron Smart Meter.

How Smart Meters are Deployed

Radio communication by Smart Meters makes use of wireless networks whereby each Smart Meter can both transmit and receive data to and from the electric utility company. The wireless network is configured as a so-called mesh network. Mesh networks are characterized by providing a means for routing data and instructions between nodes. A mesh network allows for continuous connections and reconfiguration around broken or blocked data paths by "hopping" from node to node until the destination is reached. In the context of how Smart Meters are deployed, end-point meters are installed throughout neighborhoods, replacing existing electromechanical meters. The transceivers[4] within the Smart Meters act as wireless routers, identifying and, then, connecting with available transmission paths between themselves and a cell relay meter that collects data from the many, various meters in the region.[5] If communication between a given end-point meter and the associated cell relay cannot be achieved due to inadequate signal strength, an alternative end-point meter is used to establish communications onward toward the cell relay meter. In this sense, the mesh network is said to be self-healing in that should a particular transmission path becomes blocked, the network finds another way to get its data through the system. A simple example of this process could be that at some particular moment, a moving van travels down a street and temporarily blocks the previously preferred path from an end-point meter to the cell relay meter. In

[4] The RF devices inside the Smart Meter function as transceivers since they both transmit and receive radio signals. In this report, the term transmitter is often used in place of transceiver since the primary characteristic of the meters of interest in this study is the meter's ability to transmit radio signals.

this case, the data is rerouted via other end-point meters that act as alternative paths for the meter to initiate the data communications. This very powerful networking approach provides for good data communication reliability and can even allow communications for end-point meters that are outside the line-of-sight range to their cell relay meter. Additional end-point meters, therefore, have the ability to expand the geographical extent of a network. Figure 2-2 illustrates the concept behind a wireless mesh network implemented for a Smart Meter equipped neighborhood. Each meter communicates either directly with the cell relay meter or via multiple "hops" of the signals through other meters.

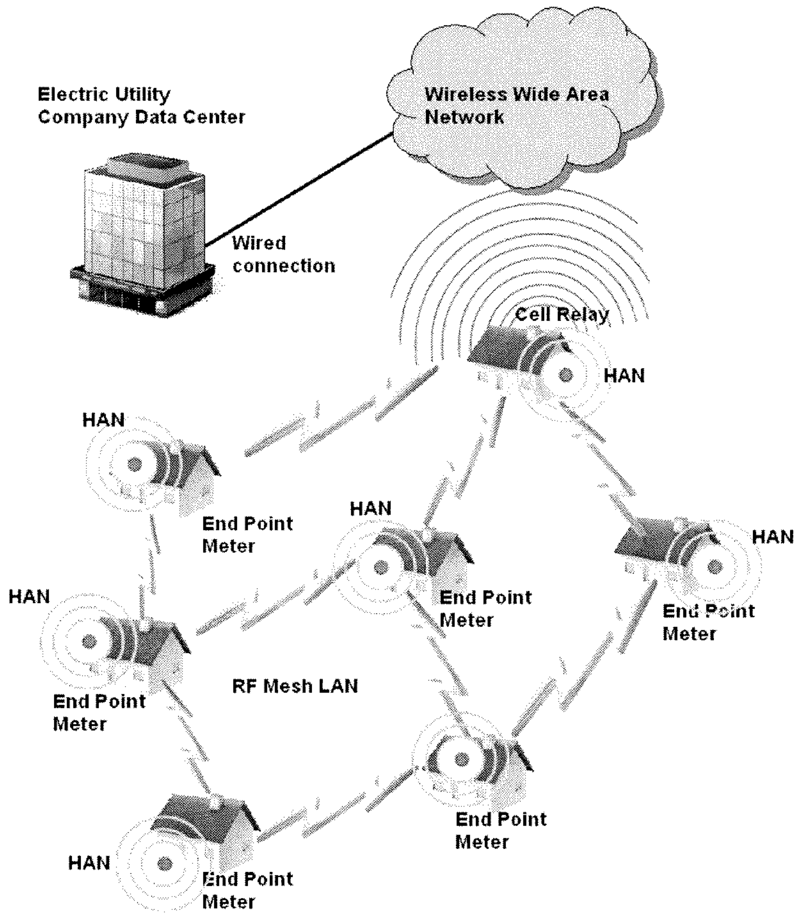


Figure 2-2
Simplistic illustrative diagram of an RF mesh network. Each end point also provides a Home Area Network (HAN) feature. The cell relay acts as a collector point for multiple meters distributed in a neighborhood and transmits received data onto a cellular wireless wide area network (WWAN).

[5] Southern California Edison Electric Company is deploying Smart Meters as part of their SmartConnect™ program with one access point for approximately every 500 end-point meters on residences. In the case of San Diego Gas and Electric Company, each access point serves for data collection from approximately every 750 end-point meters.

For the Itron equipment that was the subject of this investigation, two separate transmitters are contained in the end-point meters. The wireless mesh network can be referred to as an RF LAN (radio frequency local area network). The Itron RF LAN operates in the 902-928 MHz license free band using spread spectrum transmitting technology. A second, separate transmitter that operates in the 2.4 GHz frequency range (2405 MHz to 2483 MHz) uses direct sequence spread spectrum technology that is referred to as a Zigbee radio[6]. This second transmitter is included for use with Home Area Networks (HANs) allowing customers, for example, to control certain electric appliances or systems within the home. When fully implemented, the customers will be able to connect wirelessly with the HAN radio and set times at which various appliances and/or electrical systems may operate, thereby taking advantage of those times during which electricity rates are lowest.

The RF LAN provides data communications among the various end-point meters and an associated cell relay meter. Cell relays are end-point meters that contain yet a third transceiver that is designed for wireless connection to the cellular WWAN, i.e., relaying of the data received from the various end-point meters over a private connection to the electric utility company. The transceivers use the same frequency bands used by cell phones. Two different frequency bands are used by these cell-relay transceivers, either the 850 MHz band or the 1900 MHz band.[7] Figure 2-3 shows a cell relay with the flexible dual band antenna located on the inside surface of the meter cover.

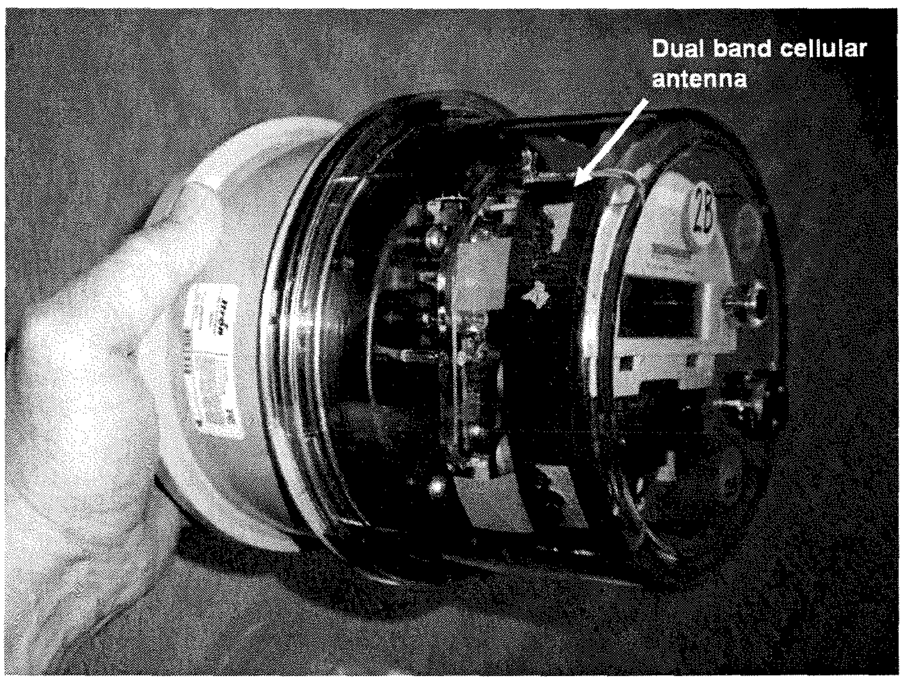


Figure 2-3
Cell relay meter with flexible, dual band (850 MHz and 1900 MHz) antenna affixed to interior surface of the meter cover.

[6]Zigbee is a name for a particular data communications protocol used in the HAN system.

[7]These frequency designations indicate the nominal frequencies used for the wireless WAN for Internet connectivity.

An important characteristic of this wireless mesh network technology is the fact that the RF emissions produced by Smart Meters, i.e., the signals that represent the data being transmitted, are not continuous but very intermittent in nature. For example, an electric utility company may interrogate the Smart Meters multiple number of times a day to acquire electric energy usage by the customer. While the Smart Meter may remain in stand-by in terms of transmissions at other times of the day, when an instruction is received to transmit energy consumption data, the meter transmits and proceeds to deliver the requested data to the cell relay meter. Hence, for the most part, Smart Meter transmissions are relatively infrequent during the day and may only consist of emissions for a few milliseconds during each of the interrogations throughout the day. This means that while the transceivers stand ready to transmit, there may be very little or no activity during most of the time. In addition to those periods during which data on electricity usage has been requested, however, Smart Meters must insure that they have a mesh network connection with at least one other Smart Meter so that, when necessary, it can deliver the data requested. Maintaining this connectivity within the mesh network requires periodic transmissions to alert the cell relay meter and other meters to its availability to be interrogated for data. So, Smart Meters spend part of their time in a so-called stand-by mode in which they issue beacon signals[8] to signify their identity to other nodes of the network with the objective of establishing a connection with the network. These beacon signals last for very brief periods of, nominally, 7.5 milliseconds and occur at various intervals. Finally, there are other instances during which certain network maintenance activities are accomplished and during which, again, various, very short duration and intermittent emissions exist. The cumulative effect of these transmissions is that while the total time spent transmitting signals from a Smart Meter is generally very modest within a day, the signals are very intermittent. They are not continuous in the same sense as the signal received from an FM radio broadcast station but, rather, exist as very short duration signals scattered throughout the day. This intermittency contributes to the difficulty in accurately measuring the strength of the emissions.

In practice, homes in a Smart Meter equipped neighborhood will have end-point Smart Meters installed that communicate with a cell relay meter either directly or though the medium of multiple end-point meter radio signal hops. Approximately every 500th (in the case of SCE) or 750th (in the case of SDG&E) residence may be equipped with a cell relay that not only handles the normal RF LAN communications but, also, relays these data onward, wirelessly, to the electric utility. All of these data communications proceed intermittently throughout each day.

The fact that the Itron Smart Meters studied here contain RF transmitters, albeit low power transmitters, means that relatively weak ambient RF fields exist in the vicinity of the meters. At the surface of the meter, the RF field strengths will be greatest with rapidly decreasing field strengths with increasing distance from the meter. While these low power transmitters cannot produce extremely intense RF fields, nonetheless, the issue of potential human exposure to these RF fields has, in some areas, become a question by the public.[9] A concern expressed by some has been the potential for adverse health effects that might be caused by exposure to the weak RF fields produced by Smart Meters. This report documents an investigation of the characteristics of RF fields associated with the Itron wireless Smart Meter that can assist in a better understanding of possible public exposure to the RF emissions produced by Smart Meters. Throughout this report, the term Smart Meter is intended to refer to the wireless type represented by the Itron meters discussed in this report.

[8] During the initial installation of an Itron Smart Meter, the meter enters a "discovery phase" in which it seeks to establish a link with the mesh network. During this discovery phase, beacon signals are emitted during approximately 3.5 second intervals until the meter becomes synchronized with the network or until a total time of about 6 minutes is reached after which beacons are emitted once about every 34 seconds until linked with the network or for up to 1½ hours. After this period, if a meter does not establish a link, it issues beacons once every hour during which it attempts to connect with the network. After 104 attempts, if still not linked with the network, the meter resets itself and begins the discovery sequence again. Once the meter becomes synchronized with the network, a beacon signal is emitted once every 94 seconds to 30 minutes depending on the level of other data traffic.

[9] Newspaper accounts of public reaction to Smart Meters

Section 3: Objective of Investigation

The work described in this report was focused on understanding the physical characteristics of the RF fields that are produced by Smart Meters such that an informed conclusion can be made as to the magnitude of possible human RF exposure caused by the meters. In this context, the objective of the work was to develop insight to the magnitude and spatial characteristics of Smart Meter RF fields including temporal aspects of the emissions that would allow a meaningful evaluation of possible exposures by reference to applicable RF human exposure limits.

Section 4: Technical Approach to Investigation

Characterizing RF fields produced by Smart Meters can be difficult. The intermittent nature of the emissions, addressed above, means that it is not a simple matter to simply bring instrumentation to an installed meter and be able to instantly detect the presence of the various emissions. The meter may or may not be in a transmit mode at the time when measurements are sought. Further, the spread spectrum characteristic of the emissions of the RF LAN and HAN transmitters leads to a further complication. For example, with the 900 MHz RF LAN transmitter, the emitted signal, at any particular instant in time, may be on any specific frequency within the 902 to 928 MHz band. When using narrow-band instrumentation, such as a frequency swept spectrum analyzer, the challenge is to have the analyzer on the specific frequency at the very instant in time that the emission is occurring to be able to measure its strength. Since the emissions are highly intermittent, this may take considerable time to insure that any such emissions have been captured by the instrumentation.

After careful consideration of the complexities associated with these kinds of measurements, it was decided that direct support of the testing by Itron, the manufacturer of the Smart Meter, could prove to be the most expedient approach to collecting the data useful to a complete exposure assessment study. As the manufacturer, Itron would have the knowledge and ability to control the Smart Meter to allow for meaningful measurements, avoiding the complications and uncertainties associated with working with already deployed meters.

Measurements at Itron

During the week of July 27, 2010, an extensive series of measurements was accomplished by the Principal Investigator at the Itron facility.

While at the Itron facility, detailed antenna pattern measurements were performed by the Principal Investigator on end point (Model CL200) and cell relay (Model C2SORD) meters. This included pattern measurements for the 900 MHz RF LAN transmitters in both the end point meter and as installed in a cell relay meter, pattern measurements of the 2.4 GHz Zigbee transmitter in both an end point meter and a cell relay meter and pattern measurements of the cell relay cellular transceiver operating in both the 850 MHz and 1900 MHz bands.

In addition to pattern measurements, Itron provided access to their Smart Meter farm, an area of some 20 acres in which approximately 7000 Smart Meters are installed. The ability to access this field provided insight to the cumulative RF field environment of multiple Smart Meters in close proximity with one another, and whether aggregate exposure produced by a multiplicity of Smart Meters concentrated in one area raises exposure risks.

Measurements in residential locations

Beyond the on-site measurements performed at the Itron facility, additional Smart Meter measurements were performed in a variety of residential environments. Using two Smart Meters that had been specifically programmed by Itron to operate continuously, to facilitate the measurements of field strength, measurements were performed at two residences in Downey, CA. These specially programmed meters were temporarily installed in the electrical service panel at each home and RF measurements were accomplished in the near vicinity of the meter and throughout the interior of each home. This procedure allowed for characterizing the RF fields that might exist inside of residences equipped with a Smart Meter. As a part of the residential measurements, a brief evaluation of the insertion loss afforded by three different metallic meshes, similar to what might be used in the construction of residential stucco walls, was conducted.

In addition to residence specific measurements with pre-programmed meters, RF fields were also measured adjacent to two separate apartment buildings wherein groups of 9 and 11 Smart Meters were grouped tightly together. Finally, a general area survey was conducted by driving throughout an established route within Downey, CA representative of a Smart Meter deployed neighborhood to form general observations of the ability to detect the presence of Smart Meter emissions. The residential measurements aspect of the work reported

here was concluded with a driving survey through Santa Monica, CA within which, at the time, there had been no deployment of Smart Meters.

Measurements in Colville, WA

Separate from the measurements at the Itron facility and the residential measurements in Downey, California, some limited measurements were conducted at the author's location in Colville, WA. These measurements included an evaluation of the comparative readings of RF field obtained by both the broadband field probe and the spectrum analyzer (selective radiation meter) used in the project measurements as well as an evaluation of the attenuation effect on Smart Meter signal propagation through a simulated, residential stucco wall.

Section 5: Transmitter Powers

A crucial aspect of any RF source, relative to its ability to produce RF fields, is the power of the transmitter. At the beginning of interactions with Itron, measurement data were sought on transmitter power levels. Historically, Itron has determined the power level of every transmitter used for the 900 MHz RF LAN and the 2.4 GHz Zigbee radios. These are transmitter devices on Itron manufactured printed circuit boards. All of the transmitters used in the Itron Smart Meters operate with low power, regardless of the frequency band used, nominally one watt or less. The 900 MHz RF LAN transmitter operates at a nominal power of 24 dBm (251 mW). Using Itron test data obtained from power measurements on a sample of 200,000 RF LAN transmitters, Figure 5-1 illustrates the accumulative fraction of transmitters having output powers across a range of power.

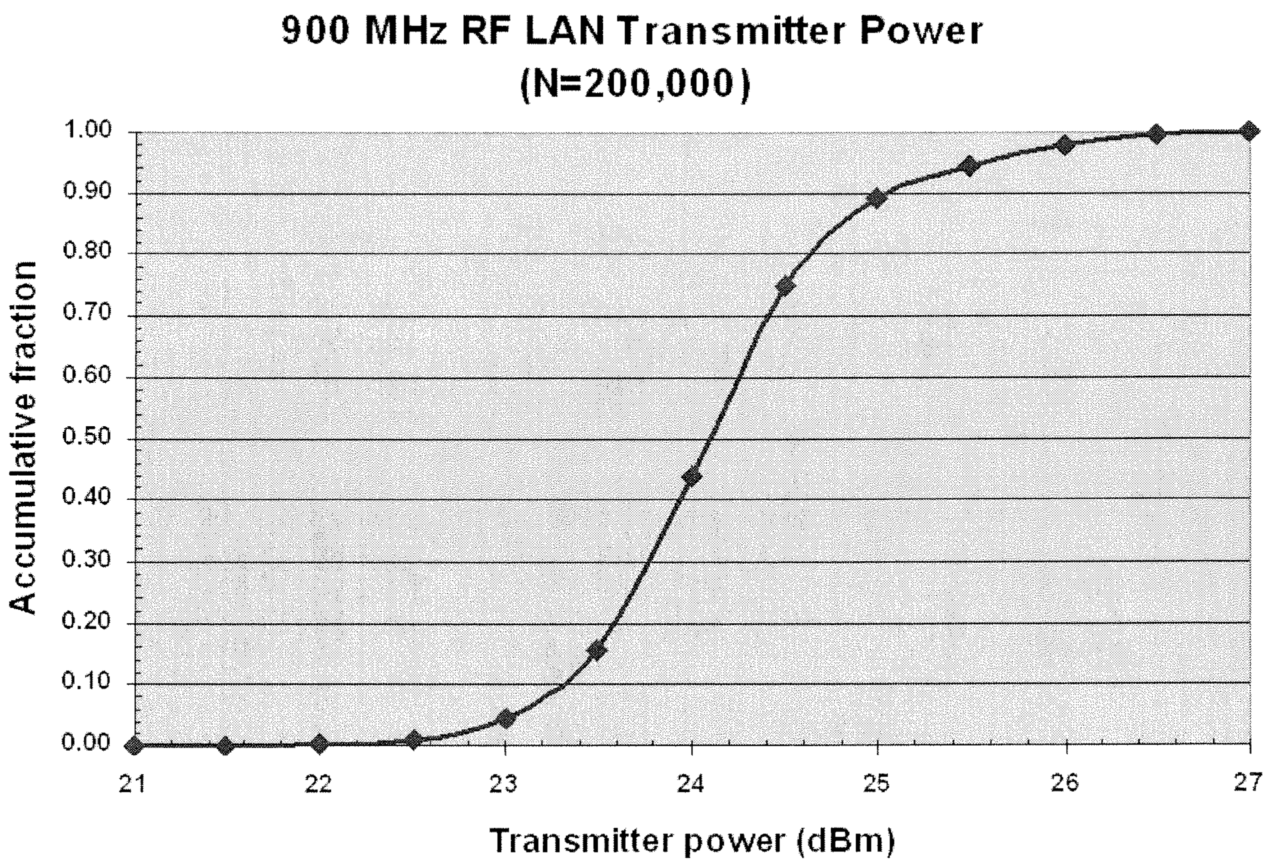


Figure 5-1
Accumulative fraction of 900 MHz RF LAN transmitter output power vs. transmitter power for a sample of 200,000 units. The median transmitter power is approximately 24.1 dBm (257 mW).

Based on a separate sample of 65,536 transmitters, used in end point meters, an average power output of 23.95 dBm (248 mW) was obtained with a standard deviation of 0.695 dBm.. Using these data, the 95% confidence interval would correspond to a range of transmitter power from 22.6 dBm (182 mW) to 25.3 dBm (339 mW) and the 99% confidence interval would correspond to a power range from 22.2 dBm (166 mW) to 25.7 dBm (372 mW).

Using the 200,000 transmitter sample, the median power level corresponds to approximately 24.1 dBm (257). The number of transmitters with power values in selected ranges is shown in Figure 5-2. The mode of transmitter power is approximately 24.5 dBm (282 mW).

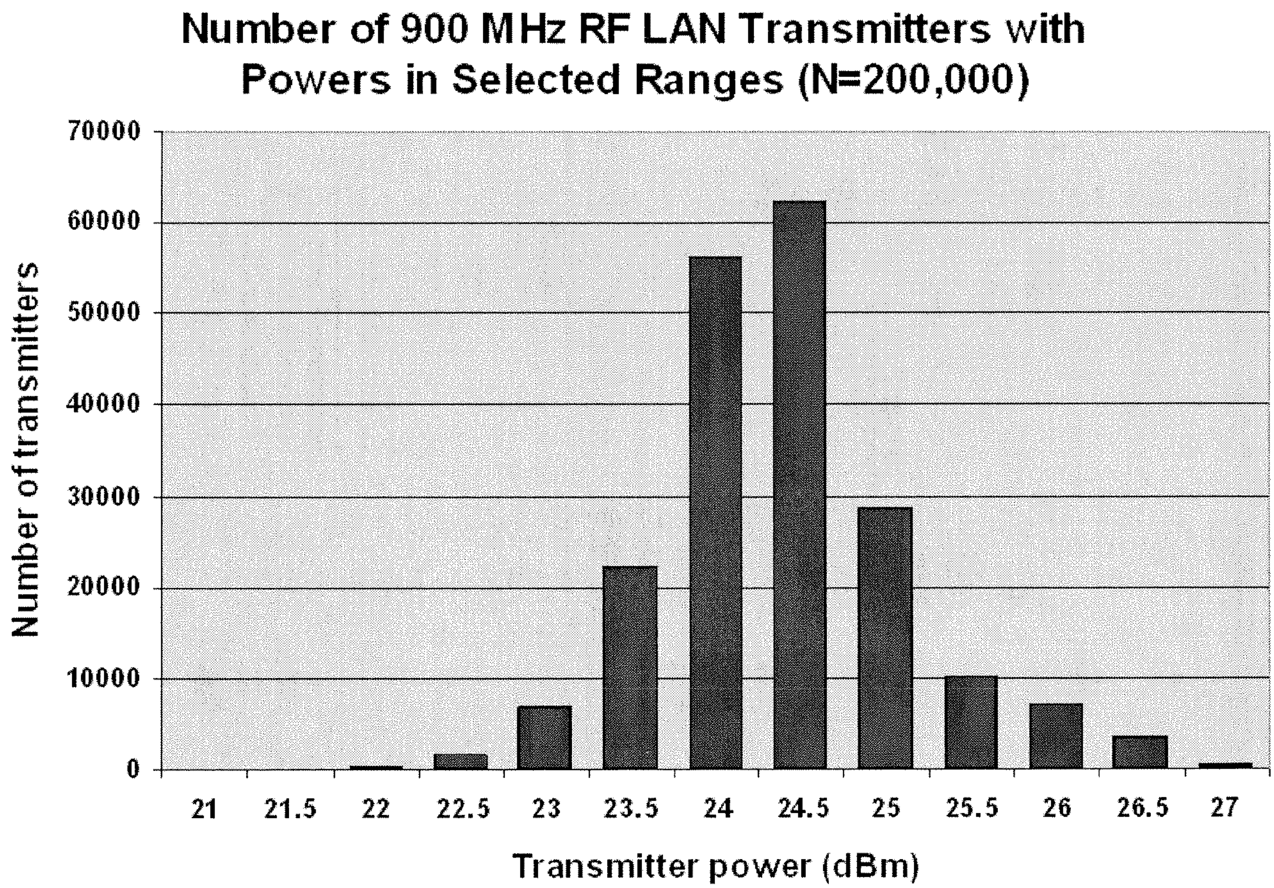


Figure 5-2
Number of 900 MHz RF LAN transmitters with powers within selected ranges. The transmitter power mode is approximately 24.5 dBm (282 mW).

These statistical data on the 900 MHz RF LAN transmitter powers indicate that the most likely power is 24.5 dBm (282 mW); an upper value of 26.0 dBm (398 mW), a value 41% greater than the most likely power, would include 99% of all transmitters.

In the case of the 2.4 GHz Zigbee transmitters, in a sample of 65,535 units used in end point meters, the mean value was found to be 18.31 dBm (67.6 mW) with a standard deviation of 0.76 dBm. This distribution would represent a 95% confidence interval of transmitter power from 16.8 dBm (47.9 mW) to 19.8 dBm (95.5 mW) and the 99% confidence interval would correspond to a power range from 16.4 dBm (43.7 mW) to 20.3 dBm (107.2 mW).

Figure 5-3 shows the accumulative fraction of transmitters having output powers across a range of power. Figure 8 illustrates the number of 2.4 GHz transmitters with powers within selected ranges. The transmitter power mode is approximately 18.5 dBm (70.8 mW).

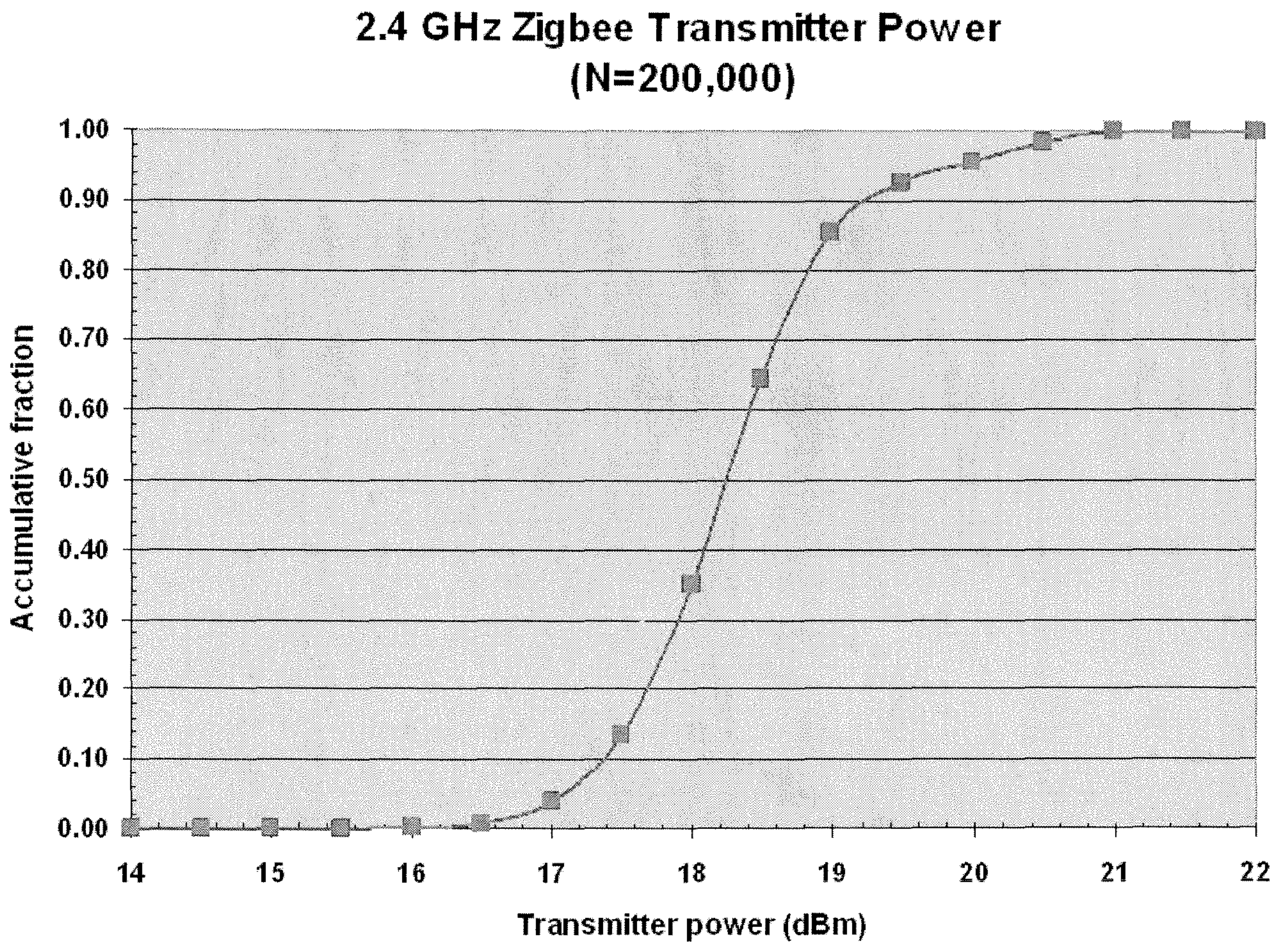


Figure 5-3
Accumulative fraction of 2.4 GHz Zigbee transmitter output power vs. transmitter power for a sample of 200,000 units. The median transmitter power is approximately 18.2 dBm (66.1 mW).

These statistical data on the 2.4 GHz Zigbee transmitter powers indicate that the most likely power is 18.5 dBm (70.8 mW); an upper value of 20.6 dBm (114.8 mW), a value 62% greater than the most likely power, would include 99% of all transmitters.

Cell relay meters contain the additional transceiver used for cellular WWAN connectivity in either the 850 MHz cellular band or 1900 MHz PCS band (personal communications service). Because these transceiver boards are produced by a different company and the units are specified to operate with specific powers and the fact that these units are separately certified by independent test labs for compliance with those specifications, Itron does not carry out additional power measurements. The transceivers, produced by Sierra Wireless operate with the following maximum powers:

Table 5-1
Sierra Wireless Transceivers Operation Maximum Powers

	GSM Modem Model MC8790 FCC ID: N7NMC8790	CDMA Modem Model MC5725 FCC ID: N7N-MC5725
Frequency Band (MHz)	Maximum power output (dBm) (mW)	
850	31.8 (1,514)	25.13 (326)
1900	28.7 (741)	24.84 (305)

Cell relays operate at the highest power of any of the meters due to their cellular/PCS modems but, similar to cellular telephones, the output power of the cellular modem is dynamically controlled by the applicable WWAN base station. This means that the actual operating power of the cellular radio in a cell relay will, generally, be less than the maximum power but will be determined by the signal strength it produces at whatever base station it is communicating with. Only one of the two modems would be active in a given deployment of Smart Meters in a neighborhood; the modem of choice is determined by the cellular wireless network service available and selected by the electric utility company.

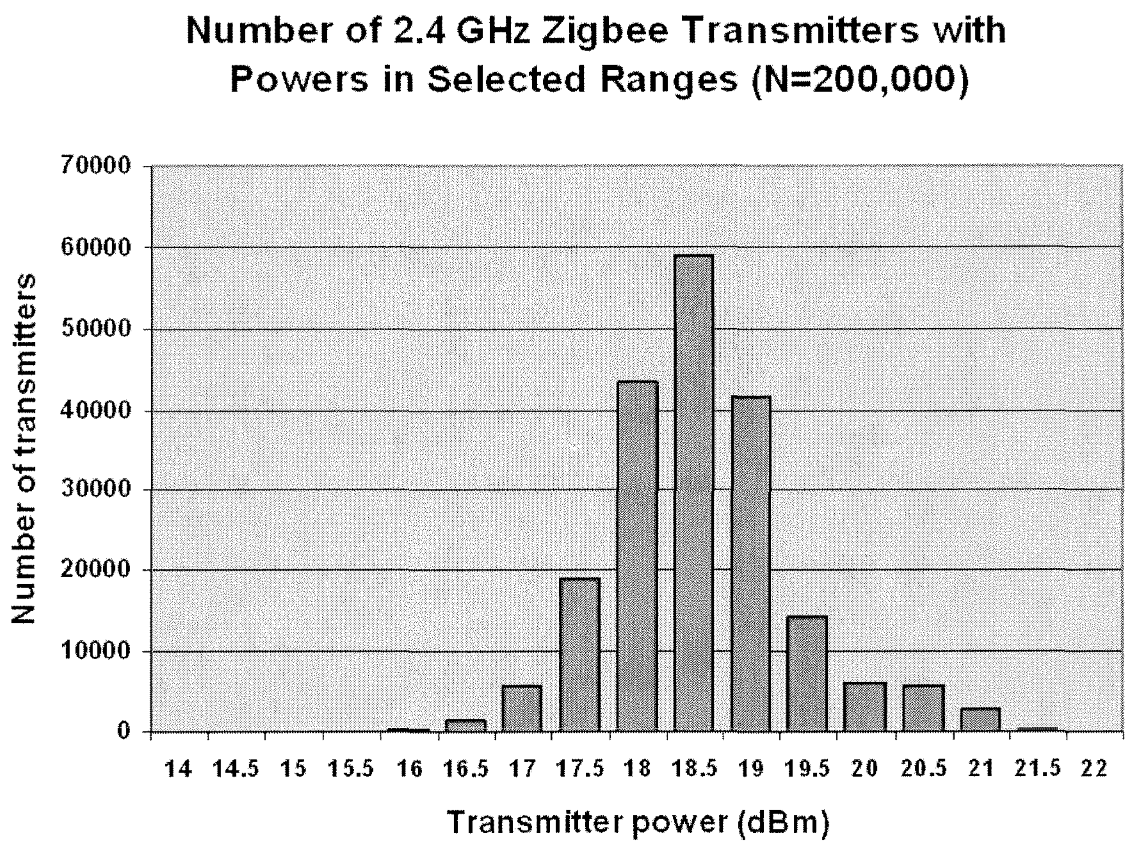


Figure 5-4
Number of 2.4 GHz Zigbee transmitters with powers within selected ranges. The transmitter power mode is approximately 18.5 dBm (70.8 mW).

Section 6: The Measurement Challenge Presented by Smart Meters

The difficulty of accurate RF field measurements near Smart Meters was discussed earlier. Low transmitted power levels in conjunction with intermittent emissions place considerable constraints on the measurement process. While a broadband measurement probe can eliminate the problem of the RF emissions occurring randomly on many different frequencies within the band, the relatively low sensitivity of broadband instruments places considerable restrictions on performing field strength measurements except within extremely close proximity of the meter. Intermittent emissions with very short duration, even if detectable, mean that it is difficult to observe when a transmission occurred. Generally, the desired measure of RF fields, from a human exposure perspective, is a measure of the average (root mean square - rms) value of the field strength or incident power density. The ratio of the average power density to the peak power density, for most Smart Meters is such that trying to measure the average field magnitude for a normally operating meter is very challenging. This can change if there exists a large aggregation of Smart Meters such that with their random on-off transmissions, much greater opportunity to "see" the emissions is possible.

Because of the rapid changes of frequency associated with the spread spectrum nature of the RF LAN and Zigbee radios in the Itron Smart Meters, an alternative approach is used to facilitate any antenna pattern and field measurements. This approach involves programming the relevant radios to transmit continuously, rather than their normal intermittent operation, and to transmit on a specific frequency within the relevant band as opposed to hopping across more than 50 channels within the 900 MHz band. Through this programming of the radios, the average signal level is now at its maximum, making it much easier to detect the RF field, and the fact that the emitted signal is now fixed on a specific and known frequency allows for ready confirmation that the measurement is of the intended signal. Since measurements under this scenario will indicate the peak value of RF field, other information is required to translate the peak field into what the equivalent average field would be. This requires a knowledge of the duty cycle of the emissions from the Smart Meter. The duty cycle can be thought of as the ratio of the amount of time that the transmitter is transmitting its signal to the total observation period. For example, if the Smart Meter were to typically transmit as much as 10 seconds during an hour (3600 seconds), the duty cycle would be 0.28%. In other words, the time-averaged power density of the RF field would be just 0.28% of the peak power density measured. The issue of Smart Meter duty cycles will be addressed later in this report.

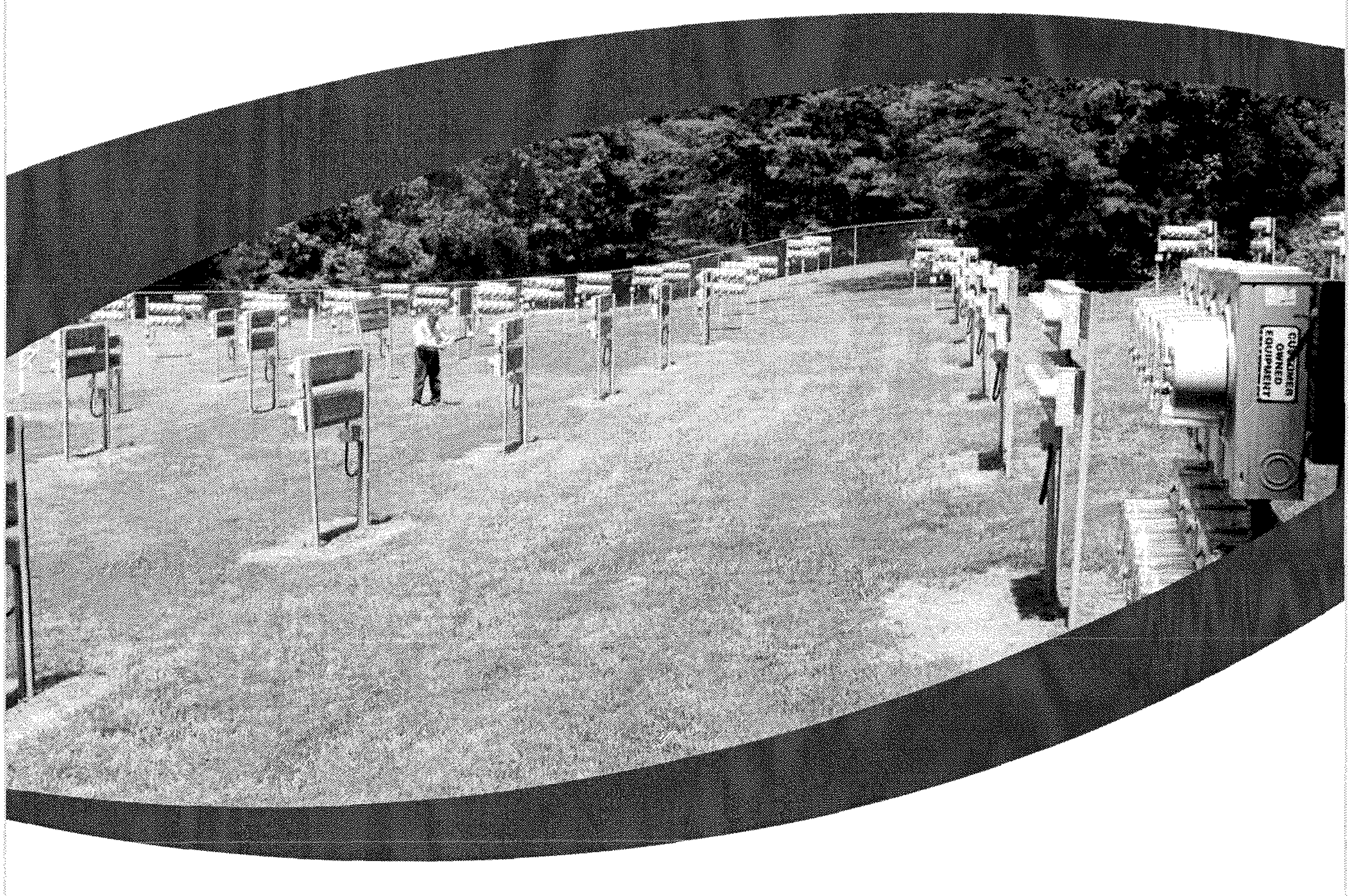
APPENDIX H
Electrical Power Research Institute, An Investigation of Radio Frequency Fields Associated with the Itron Smart Meter, Technical Report 2010

See attached.

ELECTRIC POWER RESEARCH INSTITUTE

2010 TECHNICAL REPORT

An Investigation of Radiofrequency Fields Associated with the Itron Smart Meter



An Investigation of Radiofrequency Fields Associated with the Itron Smart Meter

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Final Report, December 2010

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Richard Tell Associates, Inc.

NOTE

For further information about EPRI, call the EPRI Customer Assistance Center at 800.313.3774 or e-mail askepri@epri.com.

Acknowledgments

The following organization, under contract to the Electric Power Research Institute (EPRI), prepared this report:

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This report describes research sponsored by EPRI and overseen by Gabor Mezei, MD, Ph.D, EPRI's Program Manager for the EMF and RF Health Assessment and Safety Program. Expertise, review and comment were provided by a cross-functional team at EPRI including Rob Kavet, D.Sc., Senior Technical Executive; Chris Melhorn, Program Manager; Kermit Phipps, Project Engineer/Scientist and Brian Seal, Senior Project Manager, EPRI.

Numerous individuals from Southern California Edison (SCE) Electric Company conducted and supported the measurement work reported here in both South Carolina and California: Glenn Sias, Manager, SCE EMF and Energy Group; Al Vazquez, Enterprise Network Architect, SmartGrid Engineering; Kevin Nesby, Project Manager in the Edison SmartConnect™ Deployment Program; Brian Thorson, EMF Specialist in the Operations Support Business Unit; Jack Sahl, Director of Operations Support in the SCE Operations Support Business Unit; and John Bubb, Manager of Product Management for SCE SmartConnect.

Background information on operational characteristics of smart meters was provided by Vijay Lakkasetty, System Engineering & Operations - Smart Meter Project, Jay Xu, Principal Engineer, and Jim Turman, Program Manager, Department & Employee Readiness, Safety and Emergency Services, all of San Diego Gas and Electric Company.

As further described within the report, testing support, facility access and cooperation was provided by Itron, which facilitated this work, particularly by Dan Lakich, Design & Development Manager, Electricity Metering; Mike Belanger, Product Line Manager, Itron OpenWay Network Communications; Sudhir Thumaty, R&D Manager; Suresh Kumar Yada, Design Engineer; Ben Smith, Engineer; Ken Prevatte, Project Director; and Matthew DeCubellis, Application Engineer.

This publication is a corporate document that should be cited in the literature in the following manner:

An Investigation of Radiofrequency Fields Associated with the Itron Smart Meter
EPRI, Palo Alto, CA: 2010. 1021126

Product Description

Smart meters represent one component of the advanced metering infrastructure (AMI). Although data to and from smart meters may be transmitted through wired connections, many smart meters make use of miniature, low power radio transceivers to wirelessly communicate with the electric utility and with the Home Area Network (HAN) that provides home owners with the ability to interact with electrical appliances and systems within the home. Deployment of smart meters has raised concerns by members of the public about possible adverse health effects that could be related to exposure to the radiofrequency (RF) emissions of the meters. As part of on-going efforts to address public concerns on this issue, this report documents the collection of information on RF exposure related to the operation of two particular models of Smart Meter produced by Itron Inc.

Results & Findings

The smart meters studied in this report are currently being deployed by two electric utilities in California. The meters are part of wireless mesh networks in which one meter is configured as a collector point, referred to as a "cell relay" by Itron, for each of approximately 500 to 750 "end point meters." The cell relay collects data from the various end point meters and conveys these data onto the cellular wireless wide area network (WWAN) for communication back to the electric utility company's data management system. Mesh network communication among the many meters is provided by the 900 MHz band transceiver RF LAN (local area network). A HAN feature is supported by a 2.4 GHz transceiver.

Data collection was carried out in a laboratory setting and at residences and in neighborhoods in southern California and Colville, Washington, supplemented with theoretical modeling studies. The results indicate that RF field from the investigated smart meter are well below the maximum permitted exposure (MPE) established by the Federal Communications Commission (FCC). For instance, at one foot, the RF field from an end point meter would be expected to not exceed 0.8% of the MPE) established by the Federal Communications Commission (FCC). For the cell relay, the RF field would not exceed 0.2% of the MPE. Even at very close distances, such as one foot directly in front of the meter, with an unrealistic assumption that the transmitters operate at 100% duty cycle, the resulting exposure is less than the FCC MPE. When viewed in the context of a typical, realistic exposure distance of 10 feet, the RF fields are much smaller, about 0.008% for the end point meter and about 0.002% of MPE for the cell relay. For occupants of a home equipped with a Smart Meter, interior RF fields would be expected to be at least ten times less intense simply due to the directional properties of the meter. When the attenuation afforded by a stucco home's construction is included, a realistic

value of the interior RF field would be about 0.023% of the MPE for an end point meter and about 0.065% for a cell relay. Regardless of duty cycle values for end point and cell relay meters, typical exposures that result from the operation of smart meters are very low and comply with scientifically based human exposure limits by a wide margin.

Challenges & Objective(s)

This report is focused on the RF aspects of smart meters and in particular, the strength of the transmitted RF fields that may be produced by the meters from a human exposure perspective. The greatest difficulty in arriving in determining realistic time-averaged exposure from smart meters is associated with determining transmitter duty cycles since the meters only emit RF radiation at intervals

Applications, Values & Use

This report documents an investigation of the characteristics of RF fields associated with Itron Smart Meter. The project was undertaken to improve understanding of public exposure to the RF emissions produced by smart meters and to respond to public concerns about potential health effects.

EPRI Perspective

Measuring electric energy consumption with so-called smart meters in residential and commercial environments is becoming more commonplace as part of the development of Advanced Metering Infrastructure (AMI) in the electric utility industry. With the deployment of smart meters public concern was raised about potential health effects associated with RF emissions from smart meters EPRI is responding to these concerns with research efforts to provide objective information on RF emissions related to smart meters.

Approach

The project team conducted laboratory and field measurements of the RF emissions of Itron smart meters. A key objective was to determine realistic estimates of the operational duty cycle of meter transmitters. The team also investigated the effectiveness of metal meshes and stucco walls in shielding smart meters.

Keywords

Smart meters
Radiofrequency emissions
EMF health assessment
Environmental issues

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Section 1: Summary

Measuring electric energy consumption with so-called Smart Meters in residential and commercial environments is becoming more commonplace. Smart Meters represent one component of what is referred to as Advanced Metering Infrastructure (AMI) in the electric utility industry. AMI systems comprise both wired and wireless technologies with each exhibiting their own advantages. Electric utility companies, thus, have options to implementing AMI systems. Even within the wireless category of AMI system, equipment can operate over a wide range of frequencies and powers and levels of activity. The Smart Meters, based on wireless technology, make use of miniature, low power radio transceivers, typically inside the meter, to wirelessly communicate with the electric utility. Two-way radio communication provided by Smart Meters allows for transmission of energy consumption data from a residence or business to the utility company and reception of data pertaining to time-of-day pricing of electric energy.

As wireless AMI technology is projected to become widely distributed, it becomes prudent to quantitatively assess the levels of RF emissions fro meters to which the public may be exposed. Nearly two dozen communities have placed moratoria on further deployment of Smart Meters in northern California and more than 2000 health-related complaints have been received by the California Public Utilities Commission[1]. This report documents the collection of information related to the operation of two particular models of Smart Meters[2] produced by Itron Inc. for purposes of supporting exposure assessment exercises that can address public concerns about exposure. The Itron products are currently being deployed by Southern California Edison Electric Company (SCE) and San Diego Gas and Electric Company (SDG&E) and both companies provided support to EPRI (the Electric Power Research Institute) for this activity. A number of companies currently manufacture different forms of Smart Meters and, most commonly, these meters employ radio transmitters that operate in Federal Communications Commission (FCC) designated license free bands[3]. The Itron meters in this study use transmitters that operate in the license free bands of 902 MHz to 928 MHz (the "900 MHz band") and 2400 MHz to 2500 MHz (the "2.4 GHz band").

The Smart Meters studied here act as nodes in wireless mesh networks consisting of approximately 500 residences (for SCE) or 750 residences (for SDG&E); these are referred to as "end point meters." Within each mesh network, one residence, designated as a "collection point," is equipped with a Smart Meter having an additional internal transmitter (referred to as a "cell relay" for communicating data to the utility over a wireless wide area network (WWAN). The cell relay collects data from the various end point meters and conveys these data onto the cellular wireless wide area network (WWAN) for communication back to the electric utility company's data management system. Mesh network communications among the many meters is provided by the 900 MHz band transceiver RF LAN (local area network). A HAN feature is supported by the 2.4 GHz transceiver. A data protocol used by the HAN called Zigbee is used to refer to the 2.4 GHz transceiver as in "the 2.4 GHz Zigbee radio".

The data collection effort included gathering of information and working with the manufacturer at their facility in West Union, South Carolina, measurements at residences and in neighborhoods in southern California and some more limited measurements in Colville, Washington. Itron graciously provided technical support and access to its facilities and personnel to assist in this effort. Data included transmitter power levels, radiation patterns, RF field strengths or power densities of individual meters and groups of meters, spatial variations of RF fields in a vertical plane near Smart Meters, attenuation of Smart

[1]See, for example, "Smart Meters - They're Smart, But Are They Safe?". http://www.publicnewsservice.org/index.php?/content/article/16846-1 (November 8, 2010).

[2] Itron model CL200 (end point meter) and model C2SORD (cell relay).

[3] Some Smart Meters are designed to operate in FCC licensed bands and may operate with higher powers.

Meter RF fields by building materials, and information potentially useful for assessing transmitter duty cycles. To characterize the systems currently operating, parallel efforts included modeling of RF fields based on measured values of maximum equivalent isotropic radiated power (EIRP) of both end point and cell relay meters and analysis of end point meter transmission statistics for estimating duty cycles. Antenna patterns were determined for the 900 MHz RF LAN and 2.4 GHz Zigbee transmitter in both end point and cell relay meter configurations. Patterns were also measured for both the 850 MHz and 1900 MHz cellular bands from a cell relay.

Antenna pattern measurements revealed that RF fields are emitted preferentially toward the frontal region of the meters; the direction of maximum EIPR, however, might not be directly normal to the front of the meter. Apparent antenna gain values were modest, ranging between 0.88 dBi and 5.08 dBi, depending on the frequency band and the configuration (end point vs. cell relay). Patterns typically exhibited a reduced RF field behind the meter of approximately 10 dB down from the maximum frontal value of field with relatively narrow notches in the pattern directly behind the meter of as much as 20-30 dB less than in front.

Transmitter power data were obtained on 200,000 RF LAN 900 MHz transmitters with a most likely value of approximately 24.5 dBm (282 mW) with a 99th percentile power of 26.0 dBm (298 mW). Based on a sample size of 200,000 2.4 GHz radios, the most likely power was found to be 18.5 dBm (70.8 mW) with a 99th percentile power of 20.8 dBm (114.8 mW). Cellular transmitters were specified as 31.8 dBm in the 850 MHz band and 28.7 dBm in the 1900 MHz band.

Because of the very intermittent nature of transmissions from Smart Meters and their frequency hopping spread spectrum transmitters, accurate measurement of RF fields can be challenging. To facilitate the measurements, Smart Meters were programmed to transmit continuously on a single frequency. RF field measurements were performed on a single meter inside the Itron anechoic chamber and on ten individual meters installed in the Itron meter farm. These measurements were obtained with two different instruments including an isotropic, broadband, frequency conformal electric field probe (Narda Model B8742D) and a spectrum analyzer based selective radiation meter (Narda Model SRM-3006). Measurement data for the 900 MHz RF LAN transmitters showed RF fields in the range of a few percent of the FCC MPE for the general public at 30 cm (approximately 1 foot) in front of the meters (0.7 to 5.5%) with the broadband probe depending on frequency. Similar measurements for the 2.4 GHz Zigbee radios at a distance of 20 cm showed 0.75% to 1.7% of the MPE, again depending on the frequency of the transmitter.

Using the SRM-3006 instrument, RF fields were measured as a function of distance from the rack of ten meters in both the 900 MHz and 2.4 GHz bands. These measurements produced readings ranging between approximately 8% at 1 foot to less than 0.1% at 75 feet from the meters in the 900 MHz band and approximately 4.5% at 1 foot to less than 0.01% at 75 feet in the 2.4 GHz band. 900 MHz field measurements showed that the emissions associated with the ten meters dropped into the background produced by other meters in the meter farm at a distance of approximately 50 feet.

By using the maximum hold and average measurement feature of the SRM-3006, a measurement in the meter farm obtained by walking along two rows of meter racks resulted in an integrated peak RF field equivalent to 0.114% of MPE and an average value of 0.00023% of MPE. The ratio of average to peak readings corresponds to an apparent duty cycle of about 0.2%. In measurements taken at two apartment houses in Downey, California, ratios of average to peak values of RF field obtained over five-minute monitoring periods resulted in estimated duty cycles of approximately 0.001%. Using a tiny USB spectrum analyzer designed specifically for just the 900 MHz band in the Itron meter farm, spectral measurements were captured for approximately one hour. This measurement resulted in an apparent duty cycle of approximately 0.02%.

Interior residential measurements were performed in two homes in Downey, California after temporarily replacing the existing Smart Meter with specially programmed units that would transmit continuously in the 900 MHz and 2.4 GHz bands. Inside measurements ranged from approximately 0.006% to 22% of MPE, the highest value associated with operation of a microwave oven in the kitchen at 2 feet from the oven. The greatest value immediately behind the Smart Meter, inside the home, was 0.009% of MPE. Wireless routers found in both homes resulted in RF fields in the range of 0.02 to 0.03% of MPE.

Residential neighborhood surveys were performed in areas with and without deployed Smart Meters while driving the streets of two communities, one in Downey, CA and one in Santa Monica, CA respectively. The exercise demonstrated that the emissions of randomly emitting Smart Meters could be detected in the Downey neighborhood but virtually no signals were detected in Santa Monica with the exception that when driving through a commercial district, the 900 MHz band came alive with noticeable activity, presumably caused by various 900 MHz sources, such as cordless telephones, etc. Spectrum measurements in several other band were also performed including the FM radio broadcast band, two cellular telephone bands and the 2.4 GHz Wi-Fi band.

The insertion loss of three different metal meshes was evaluated in California at one of the residences in which RF measurements were obtained. Three different sizes of mesh were used in the tests by inserting the mesh between a specially prepared, portable Smart Meter as a source, and the SRM-3006 meter. These measurements were performed at close range with the Smart Meter approximately six inches behind the mesh and the SRM-3006 probe approximately the same distance on the other side of the mesh. These measurements resulted in values for insertion loss ranging from 4.1 dB to 19.1 dB in the 900 MHz band and from 1.2 dB to 11.4 dB in the 2.4 GHz band, depending on mesh opening size. Additional insertion loss measurements were performed on a simulated stucco wall in Colville, WA resulting in values of 6.1 dB and 2.5 dB for the 900 MHz and 2.4 GHz bands respectively.

Since human RF exposure standards are based on spatial averages, spatially averaged values of RF fields were obtained along a vertical line at approximately one foot in front of a Smart Meter. It was found that over a six-foot vertical span, the spatially averaged RF field in the 900 MHz band corresponded to a value 23% of the measured peak value found near the height of the meter. In the 2.4 GHz band, the spatially averaged field was 18% of the spatial peak.

Using the detailed pattern measurement data described earlier, theoretical calculations of RF fields that could be associated with each of the transmitters in either end point meters or cell relays were made. A detailed analysis was developed to investigate the effect that ground reflected fields could have on the resultant field and what factors would be appropriate for including the effect of ground reflections in theoretical RF field calculations.

Human exposure to RF fields is judged by comparison to applicable exposure limits or standards. For the United States, and in regard to Smart Meters, the most applicable limits are those promulgated by the FCC, a spatially averaged and time averaged value of 610 microwatts per square centimeter ($\mu W/cm^2$) in the 900 MHz band and 1000 $\mu W/cm^2$ in the 2.4 GHz band. A proper comparison of Smart Meter produced RF fields to these limits should involve a determination of the time-averaged value where the averaging time is specified as any 30-minute period. To arrive at time-averaged values, the measurements or calculated fields reported above must be corrected for the operational duty cycle of the transmitters. This is the most complex issue connected with Smart Meter RF evaluations since transmitter activity is semi-random in nature, with only brief transmissions occurring throughout a day. The maximum value of duty cycle for end point meters has been estimated by Itron to be in the range of 5%. Actual measurements, however, tend to result in substantially smaller values, typically less than 1%. Because of the variable nature of transmitter activity, even accurate measurements of a specific meter or meters need to be repeated for some days and, possibly, weeks to obtain reliable estimates of typical duty cycles. Rather than measurements, Itron developed special software implemented by the two companies to collect transmit data gathered and reported on in this report. Such an approach represents a practical way for bracketing realistic values of meter duty cycles since it can be implemented in software and extended to a very large sample size, something that would be impractical to do via physical measurements of RF fields at the meters. Using this approach, SCE generated data were examined to identify what fraction of meters in the sample exhibited transmit durations over a range of times which are related directly to the transmitter duty cycle. This exercise, for example, supported 99th and 99.9th percentile duty cycles of 0.11% and 4.7% for the RF LAN component of end point meters. A complimentary analysis conducted by SDG&E but using a more accurate determination of transmitter activity revealed smaller duty cycles. Similarly small duty cycle values are associated with the HAN and cellular transmitters. Figure 1-1 illustrates the estimated maximum likely time-averaged RF fields that would be produced by both end point and cell relay meters.

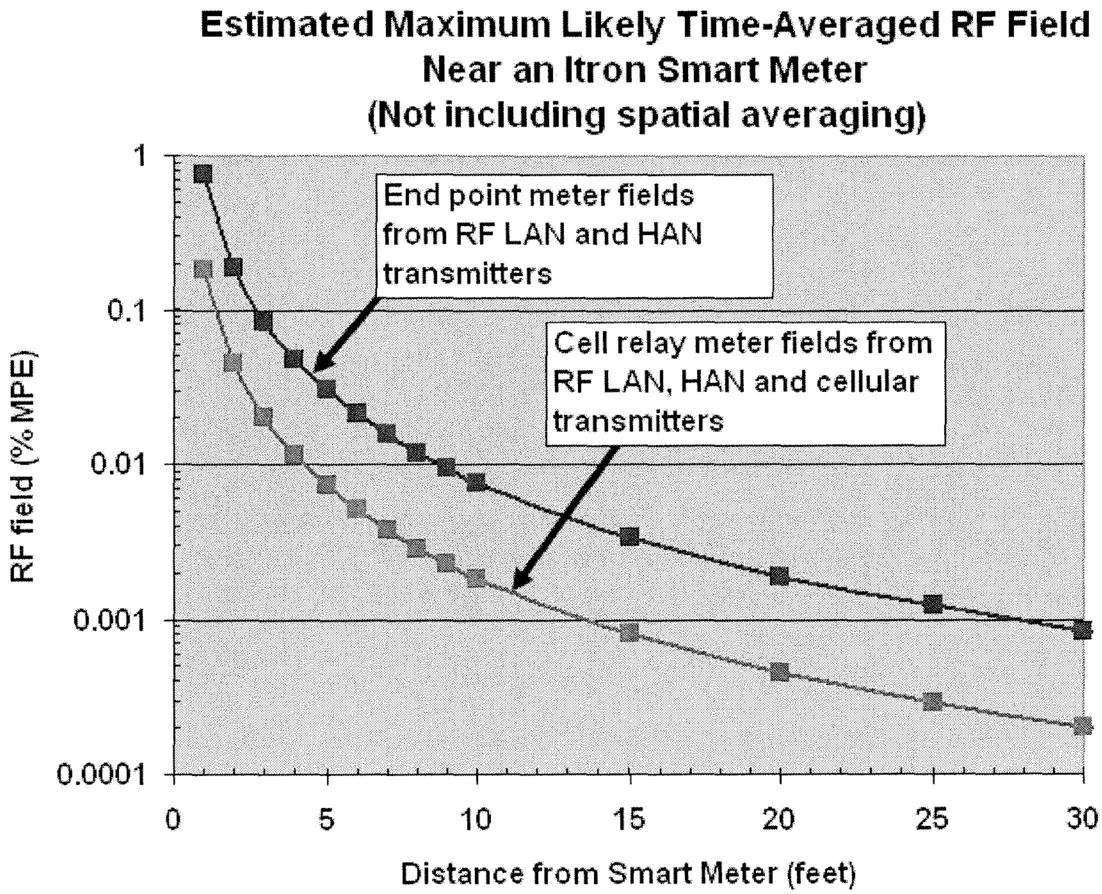

Figure 1-1
Calculated RF fields near Itron end point and cell relay meters based on 99th percentile transmitter power values, main beam exposure (point of maximum RF field), inclusion of the possibility of ground reflected fields and assumed 99th percentile duty cycles.

These data, when taken collectively, indicate that the RF emissions produced by the Itron Smart Meters evaluated in this study result in RF fields <0.06 mW/cm^2 (at least 10-fold below the FCC limit at 900 MHz). For instance, at one foot, the RF field from an end point meter would be expected to not exceed 0.8% of the MPE. For the cell relay, the RF field would not exceed 0.2% of the MPE. Even at very close distances, such as one foot directly in front of the meter, with an unrealistic assumption that the transmitters operate at 100% duty cycle (at which point the mesh network would not function) the resulting exposure is less than the FCC MPE. When viewed in the context of a typical, realistic exposure distance of 10 feet, the RF fields are much smaller, about 0.008% for the end point meter and about 0.002% of MPE for the cell relay. Spatial averaging of these "spatial maximum" fields brings the estimated values down to approximately one-fourth of these magnitudes.

For potential exposure of occupants of a home equipped with a Smart Meter, interior RF fields would be expected to be at least ten times less intense simply due to the directional properties of the meter. When the attenuation afforded by a stucco home's construction is included, a realistic value of the interior RF field would be about 0.023% of the MPE for an end point meter and about 0.065% for a cell relay meter. The WWAN operates at a far greater data throughput than the RF LAN within the mesh. Therefore, the duty cycle is correspondingly less for the cellular modem within the cell relay, despite the fact that it transmits all of the data collected from the relevant meters of its mesh network.

The most uncertainty in determining realistic time-averaged exposure from Smart Meters is associated with transmitter duty cycles. Hence, the most potentially useful avenue of future RF exposure assessment would include extensive statistical analyses of Smart Meter transmitter activity.

A detailed evaluation of possible RF fields produced by the Itron meters included in this study shows that regardless of duty cycle values for end point and cell relay meters, typical exposures that result from the operation of Smart Meters are very low and comply with scientifically based human exposure limits by a wide margin.

Section 2: Introduction and Background

As the electric utility industry in the United States moves toward implementing a "smart grid", one of the key components consists of so-called Smart Meters. These new technology electric power meters represent a part of the advanced metering infrastructure (AMI) that provides for automatic meter reading (AMR) and sophisticated control over the use of electric energy by consumers in their homes and businesses. When AMI technology is fully implemented, an enhanced balancing of power distribution throughout the various electrical grids of the country will exist and utility customers will be able to, among other things, determine when certain electrically operated appliances may operate, based on time-of-day pricing of electricity. Such advanced capability requires close to real-time data acquisition on electric energy usage and such data requirements mean that the existing, traditional electric power meters that employ manual energy consumption readings, for example, once a month, can't provide such timely data.

The modern technology of Smart Meters provides for an ability to almost instantly interrogate specific power meters as to electric energy usage. For the Smart Meters investigated in this study, this capability is accomplished via the use of data communications between the electric utility company and individual power meters through the medium of radio signals. This report is focused on the radiofrequency (RF) aspects of Smart Meters and in particular, the strength of the transmitted RF fields that may be produced by the meters from a human exposure perspective.

Smart Meters as RF Sources

A wireless Smart Meter makes use of miniature, low power (typically less than one watt) radio transceivers inside the meter to wirelessly communicate with the electric utility company. The transceivers (transmitter and receiver) allow both transmission of data as well as reception of data and instructions from the utility. These transmitters are contained within the housing of the electric meter but are not necessarily visually obvious to an observer. Antennas used for the transmitters are commonly created as slots on the various printed circuit boards that constitute the electronic makeup of the meter. A common transmitter configuration of Smart Meters includes two or three transmitters in the meter. Figure 2-1 shows a Smart Meter with its digital display that is used to indicate electric energy usage.

Figure 2-1
Photo of Itron Smart Meter.

How Smart Meters are Deployed

Radio communication by Smart Meters makes use of wireless networks whereby each Smart Meter can both transmit and receive data to and from the electric utility company. The wireless network is configured as a so-called mesh network. Mesh networks are characterized by providing a means for routing data and instructions between nodes. A mesh network allows for continuous connections and reconfiguration around broken or blocked data paths by "hopping" from node to node until the destination is reached. In the context of how Smart Meters are deployed, end-point meters are installed throughout neighborhoods, replacing existing electromechanical meters. The transceivers[4] within the Smart Meters act as wireless routers, identifying and, then, connecting with available transmission paths between themselves and a cell relay meter that collects data from the many, various meters in the region.[5] If communication between a given end-point meter and the associated cell relay cannot be achieved due to inadequate signal strength, an alternative end-point meter is used to establish communications onward toward the cell relay meter. In this sense, the mesh network is said to be self-healing in that should a particular transmission path becomes blocked, the network finds another way to get its data through the system. A simple example of this process could be that at some particular moment, a moving van travels down a street and temporarily blocks the previously preferred path from an end-point meter to the cell relay meter. In

[4] The RF devices inside the Smart Meter function as transceivers since they both transmit and receive radio signals. In this report, the term transmitter is often used in place of transceiver since the primary characteristic of the meters of interest in this study is the meter's ability to transmit radio signals.

this case, the data is rerouted via other end-point meters that act as alternative paths for the meter to initiate the data communications. This very powerful networking approach provides for good data communication reliability and can even allow communications for end-point meters that are outside the line-of-sight range to their cell relay meter. Additional end-point meters, therefore, have the ability to expand the geographical extent of a network. Figure 2-2 illustrates the concept behind a wireless mesh network implemented for a Smart Meter equipped neighborhood. Each meter communicates either directly with the cell relay meter or via multiple "hops" of the signals through other meters.

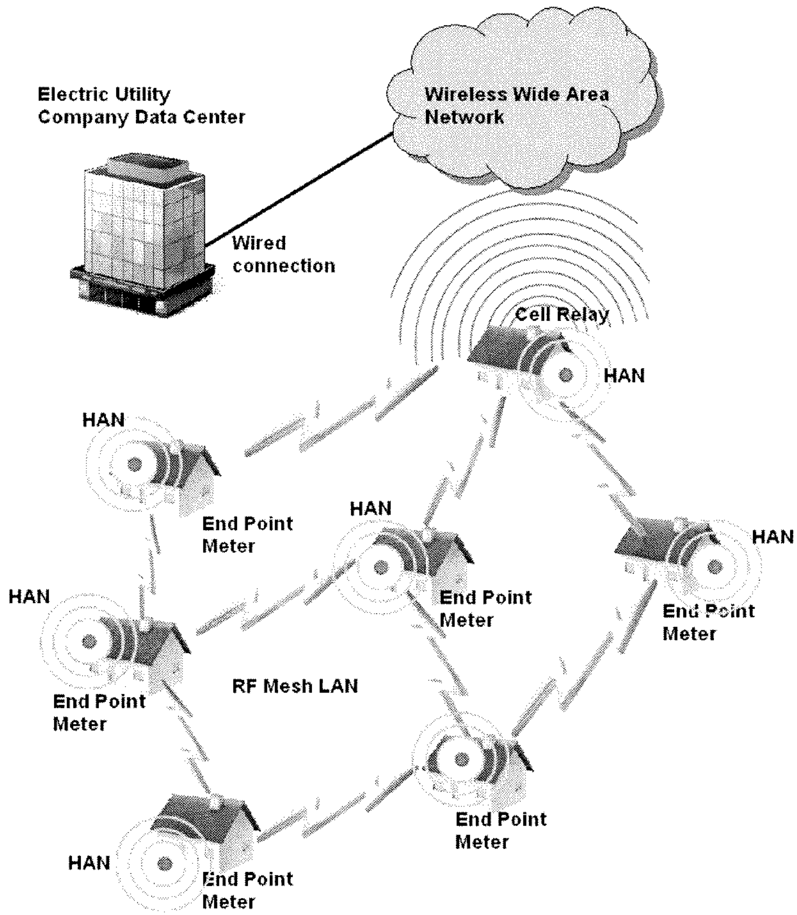

Figure 2-2
Simplistic illustrative diagram of an RF mesh network. Each end point also provides a Home Area Network (HAN) feature. The cell relay acts as a collector point for multiple meters distributed in a neighborhood and transmits received data onto a cellular wireless wide area network (WWAN).

[5] Southern California Edison Electric Company is deploying Smart Meters as part of their SmartConnect™ program with one access point for approximately every 500 end-point meters on residences. In the case of San Diego Gas and Electric Company, each access point serves for data collection from approximately every 750 end-point meters.

For the Itron equipment that was the subject of this investigation, two separate transmitters are contained in the end-point meters. The wireless mesh network can be referred to as an RF LAN (radio frequency local area network). The Itron RF LAN operates in the 902-928 MHz license free band using spread spectrum transmitting technology. A second, separate transmitter that operates in the 2.4 GHz frequency range (2405 MHz to 2483 MHz) uses direct sequence spread spectrum technology that is referred to as a Zigbee radio[6]. This second transmitter is included for use with Home Area Networks (HANs) allowing customers, for example, to control certain electric appliances or systems within the home. When fully implemented, the customers will be able to connect wirelessly with the HAN radio and set times at which various appliances and/or electrical systems may operate, thereby taking advantage of those times during which electricity rates are lowest.

The RF LAN provides data communications among the various end-point meters and an associated cell relay meter. Cell relays are end-point meters that contain yet a third transceiver that is designed for wireless connection to the cellular WWAN, i.e., relaying of the data received from the various end-point meters over a private connection to the electric utility company. The transceivers use the same frequency bands used by cell phones. Two different frequency bands are used by these cell-relay transceivers, either the 850 MHz band or the 1900 MHz band.[7] Figure 2-3 shows a cell relay with the flexible dual band antenna located on the inside surface of the meter cover.

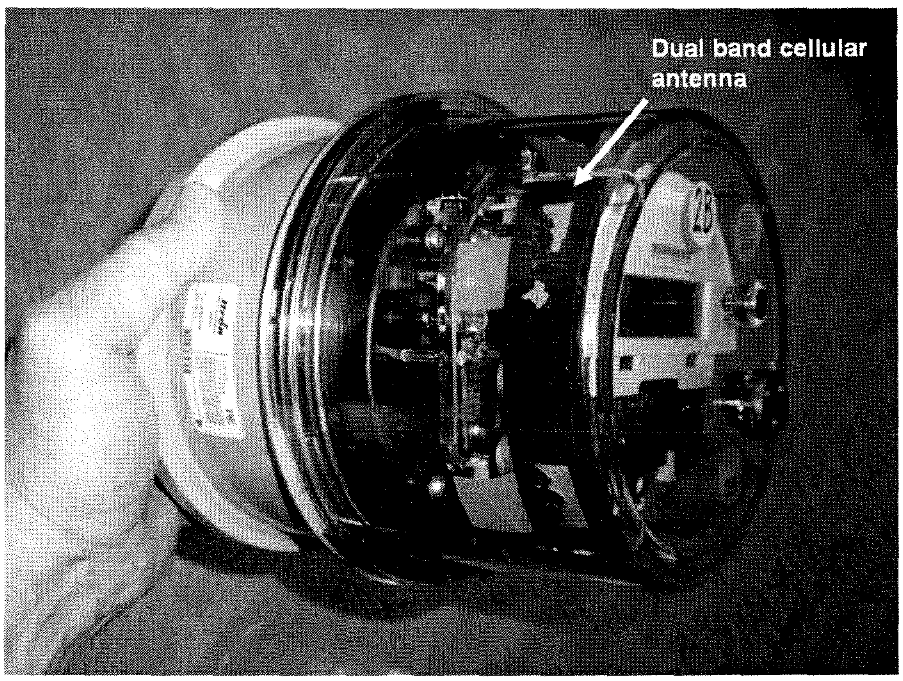

Figure 2-3
Cell relay meter with flexible, dual band (850 MHz and 1900 MHz) antenna affixed to interior surface of the meter cover.

[6]Zigbee is a name for a particular data communications protocol used in the HAN system.

[7]These frequency designations indicate the nominal frequencies used for the wireless WAN for Internet connectivity.

An important characteristic of this wireless mesh network technology is the fact that the RF emissions produced by Smart Meters, i.e., the signals that represent the data being transmitted, are not continuous but very intermittent in nature. For example, an electric utility company may interrogate the Smart Meters multiple number of times a day to acquire electric energy usage by the customer. While the Smart Meter may remain in stand-by in terms of transmissions at other times of the day, when an instruction is received to transmit energy consumption data, the meter transmits and proceeds to deliver the requested data to the cell relay meter. Hence, for the most part, Smart Meter transmissions are relatively infrequent during the day and may only consist of emissions for a few milliseconds during each of the interrogations throughout the day. This means that while the transceivers stand ready to transmit, there may be very little or no activity during most of the time. In addition to those periods during which data on electricity usage has been requested, however, Smart Meters must insure that they have a mesh network connection with at least one other Smart Meter so that, when necessary, it can deliver the data requested. Maintaining this connectivity within the mesh network requires periodic transmissions to alert the cell relay meter and other meters to its availability to be interrogated for data. So, Smart Meters spend part of their time in a so-called stand-by mode in which they issue beacon signals[8] to signify their identity to other nodes of the network with the objective of establishing a connection with the network. These beacon signals last for very brief periods of, nominally, 7.5 milliseconds and occur at various intervals. Finally, there are other instances during which certain network maintenance activities are accomplished and during which, again, various, very short duration and intermittent emissions exist. The cumulative effect of these transmissions is that while the total time spent transmitting signals from a Smart Meter is generally very modest within a day, the signals are very intermittent. They are not continuous in the same sense as the signal received from an FM radio broadcast station but, rather, exist as very short duration signals scattered throughout the day. This intermittency contributes to the difficulty in accurately measuring the strength of the emissions.

In practice, homes in a Smart Meter equipped neighborhood will have end-point Smart Meters installed that communicate with a cell relay meter either directly or though the medium of multiple end-point meter radio signal hops. Approximately every 500th (in the case of SCE) or 750th (in the case of SDG&E) residence may be equipped with a cell relay that not only handles the normal RF LAN communications but, also, relays these data onward, wirelessly, to the electric utility. All of these data communications proceed intermittently throughout each day.

The fact that the Itron Smart Meters studied here contain RF transmitters, albeit low power transmitters, means that relatively weak ambient RF fields exist in the vicinity of the meters. At the surface of the meter, the RF field strengths will be greatest with rapidly decreasing field strengths with increasing distance from the meter. While these low power transmitters cannot produce extremely intense RF fields, nonetheless, the issue of potential human exposure to these RF fields has, in some areas, become a question by the public.[9] A concern expressed by some has been the potential for adverse health effects that might be caused by exposure to the weak RF fields produced by Smart Meters. This report documents an investigation of the characteristics of RF fields associated with the Itron wireless Smart Meter that can assist in a better understanding of possible public exposure to the RF emissions produced by Smart Meters. Throughout this report, the term Smart Meter is intended to refer to the wireless type represented by the Itron meters discussed in this report.

[8] During the initial installation of an Itron Smart Meter, the meter enters a "discovery phase" in which it seeks to establish a link with the mesh network. During this discovery phase, beacon signals are emitted during approximately 3.5 second intervals until the meter becomes synchronized with the network or until a total time of about 6 minutes is reached after which beacons are emitted once about every 34 seconds until linked with the network or for up to 1½ hours. After this period, if a meter does not establish a link, it issues beacons once every hour during which it attempts to connect with the network. After 104 attempts, if still not linked with the network, the meter resets itself and begins the discovery sequence again. Once the meter becomes synchronized with the network, a beacon signal is emitted once every 94 seconds to 30 minutes depending on the level of other data traffic.

[9] Newspaper accounts of public reaction to Smart Meters

Section 3: Objective of Investigation

The work described in this report was focused on understanding the physical characteristics of the RF fields that are produced by Smart Meters such that an informed conclusion can be made as to the magnitude of possible human RF exposure caused by the meters. In this context, the objective of the work was to develop insight to the magnitude and spatial characteristics of Smart Meter RF fields including temporal aspects of the emissions that would allow a meaningful evaluation of possible exposures by reference to applicable RF human exposure limits.

Section 4: Technical Approach to Investigation

Characterizing RF fields produced by Smart Meters can be difficult. The intermittent nature of the emissions, addressed above, means that it is not a simple matter to simply bring instrumentation to an installed meter and be able to instantly detect the presence of the various emissions. The meter may or may not be in a transmit mode at the time when measurements are sought. Further, the spread spectrum characteristic of the emissions of the RF LAN and HAN transmitters leads to a further complication. For example, with the 900 MHz RF LAN transmitter, the emitted signal, at any particular instant in time, may be on any specific frequency within the 902 to 928 MHz band. When using narrow-band instrumentation, such as a frequency swept spectrum analyzer, the challenge is to have the analyzer on the specific frequency at the very instant in time that the emission is occurring to be able to measure its strength. Since the emissions are highly intermittent, this may take considerable time to insure that any such emissions have been captured by the instrumentation.

After careful consideration of the complexities associated with these kinds of measurements, it was decided that direct support of the testing by Itron, the manufacturer of the Smart Meter, could prove to be the most expedient approach to collecting the data useful to a complete exposure assessment study. As the manufacturer, Itron would have the knowledge and ability to control the Smart Meter to allow for meaningful measurements, avoiding the complications and uncertainties associated with working with already deployed meters.

Measurements at Itron

During the week of July 27, 2010, an extensive series of measurements was accomplished by the Principal Investigator at the Itron facility.

While at the Itron facility, detailed antenna pattern measurements were performed by the Principal Investigator on end point (Model CL200) and cell relay (Model C2SORD) meters. This included pattern measurements for the 900 MHz RF LAN transmitters in both the end point meter and as installed in a cell relay meter, pattern measurements of the 2.4 GHz Zigbee transmitter in both an end point meter and a cell relay meter and pattern measurements of the cell relay cellular transceiver operating in both the 850 MHz and 1900 MHz bands.

In addition to pattern measurements, Itron provided access to their Smart Meter farm, an area of some 20 acres in which approximately 7000 Smart Meters are installed. The ability to access this field provided insight to the cumulative RF field environment of multiple Smart Meters in close proximity with one another, and whether aggregate exposure produced by a multiplicity of Smart Meters concentrated in one area raises exposure risks.

Measurements in residential locations

Beyond the on-site measurements performed at the Itron facility, additional Smart Meter measurements were performed in a variety of residential environments. Using two Smart Meters that had been specifically programmed by Itron to operate continuously, to facilitate the measurements of field strength, measurements were performed at two residences in Downey, CA. These specially programmed meters were temporarily installed in the electrical service panel at each home and RF measurements were accomplished in the near vicinity of the meter and throughout the interior of each home. This procedure allowed for characterizing the RF fields that might exist inside of residences equipped with a Smart Meter. As a part of the residential measurements, a brief evaluation of the insertion loss afforded by three different metallic meshes, similar to what might be used in the construction of residential stucco walls, was conducted.

In addition to residence specific measurements with pre-programmed meters, RF fields were also measured adjacent to two separate apartment buildings wherein groups of 9 and 11 Smart Meters were grouped tightly together. Finally, a general area survey was conducted by driving throughout an established route within Downey, CA representative of a Smart Meter deployed neighborhood to form general observations of the ability to detect the presence of Smart Meter emissions. The residential measurements aspect of the work reported

here was concluded with a driving survey through Santa Monica, CA within which, at the time, there had been no deployment of Smart Meters.

Measurements in Colville, WA

Separate from the measurements at the Itron facility and the residential measurements in Downey, California, some limited measurements were conducted at the author's location in Colville, WA. These measurements included an evaluation of the comparative readings of RF field obtained by both the broadband field probe and the spectrum analyzer (selective radiation meter) used in the project measurements as well as an evaluation of the attenuation effect on Smart Meter signal propagation through a simulated, residential stucco wall.

Section 5: Transmitter Powers

A crucial aspect of any RF source, relative to its ability to produce RF fields, is the power of the transmitter. At the beginning of interactions with Itron, measurement data were sought on transmitter power levels. Historically, Itron has determined the power level of every transmitter used for the 900 MHz RF LAN and the 2.4 GHz Zigbee radios. These are transmitter devices on Itron manufactured printed circuit boards. All of the transmitters used in the Itron Smart Meters operate with low power, regardless of the frequency band used, nominally one watt or less. The 900 MHz RF LAN transmitter operates at a nominal power of 24 dBm (251 mW). Using Itron test data obtained from power measurements on a sample of 200,000 RF LAN transmitters, Figure 5-1 illustrates the accumulative fraction of transmitters having output powers across a range of power.

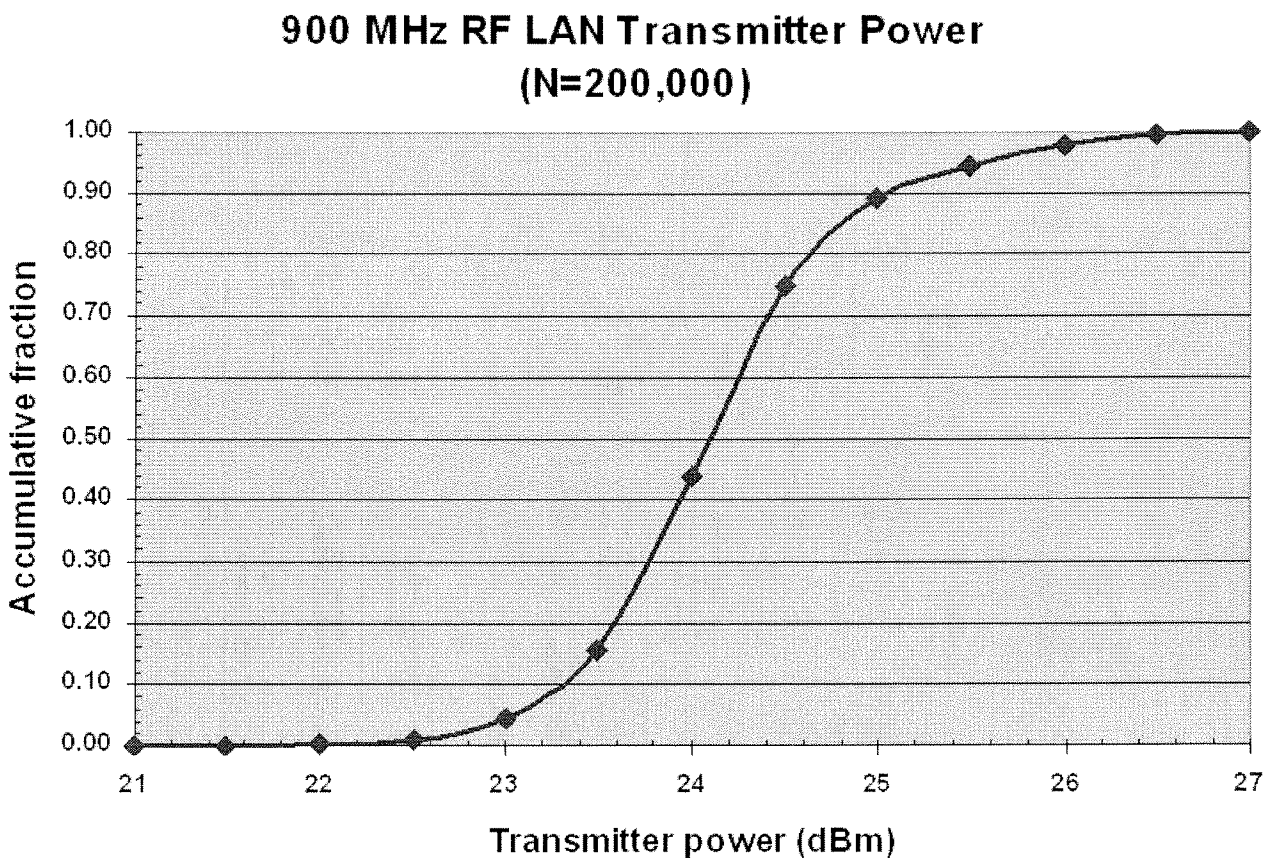

Figure 5-1
Accumulative fraction of 900 MHz RF LAN transmitter output power vs. transmitter power for a sample of 200,000 units. The median transmitter power is approximately 24.1 dBm (257 mW).

Based on a separate sample of 65,536 transmitters, used in end point meters, an average power output of 23.95 dBm (248 mW) was obtained with a standard deviation of 0.695 dBm.. Using these data, the 95% confidence interval would correspond to a range of transmitter power from 22.6 dBm (182 mW) to 25.3 dBm (339 mW) and the 99% confidence interval would correspond to a power range from 22.2 dBm (166 mW) to 25.7 dBm (372 mW).

Using the 200,000 transmitter sample, the median power level corresponds to approximately 24.1 dBm (257). The number of transmitters with power values in selected ranges is shown in Figure 5-2. The mode of transmitter power is approximately 24.5 dBm (282 mW).

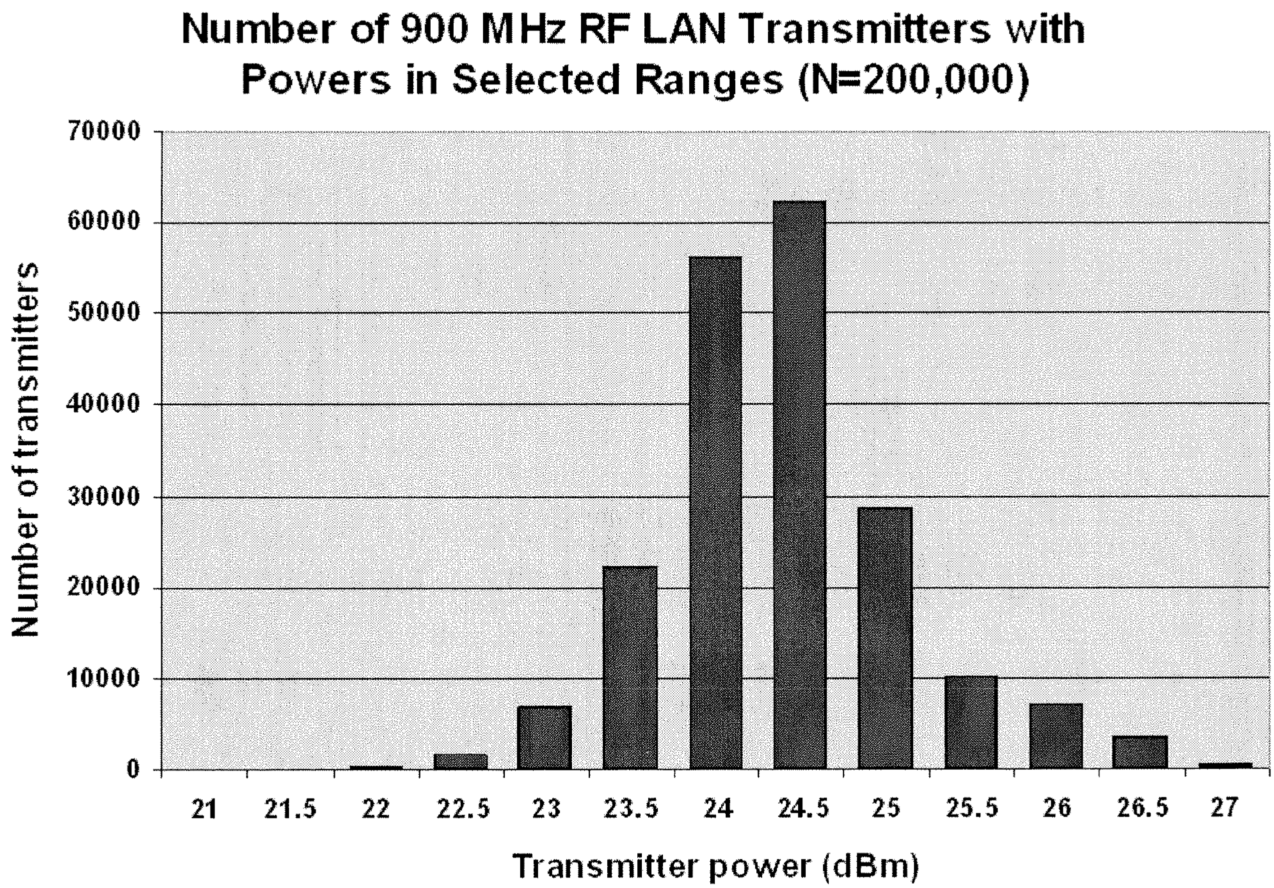

Figure 5-2
Number of 900 MHz RF LAN transmitters with powers within selected ranges. The transmitter power mode is approximately 24.5 dBm (282 mW).

These statistical data on the 900 MHz RF LAN transmitter powers indicate that the most likely power is 24.5 dBm (282 mW); an upper value of 26.0 dBm (398 mW), a value 41% greater than the most likely power, would include 99% of all transmitters.

In the case of the 2.4 GHz Zigbee transmitters, in a sample of 65,535 units used in end point meters, the mean value was found to be 18.31 dBm (67.6 mW) with a standard deviation of 0.76 dBm. This distribution would represent a 95% confidence interval of transmitter power from 16.8 dBm (47.9 mW) to 19.8 dBm (95.5 mW) and the 99% confidence interval would correspond to a power range from 16.4 dBm (43.7 mW) to 20.3 dBm (107.2 mW).

Figure 5-3 shows the accumulative fraction of transmitters having output powers across a range of power. Figure 8 illustrates the number of 2.4 GHz transmitters with powers within selected ranges. The transmitter power mode is approximately 18.5 dBm (70.8 mW).

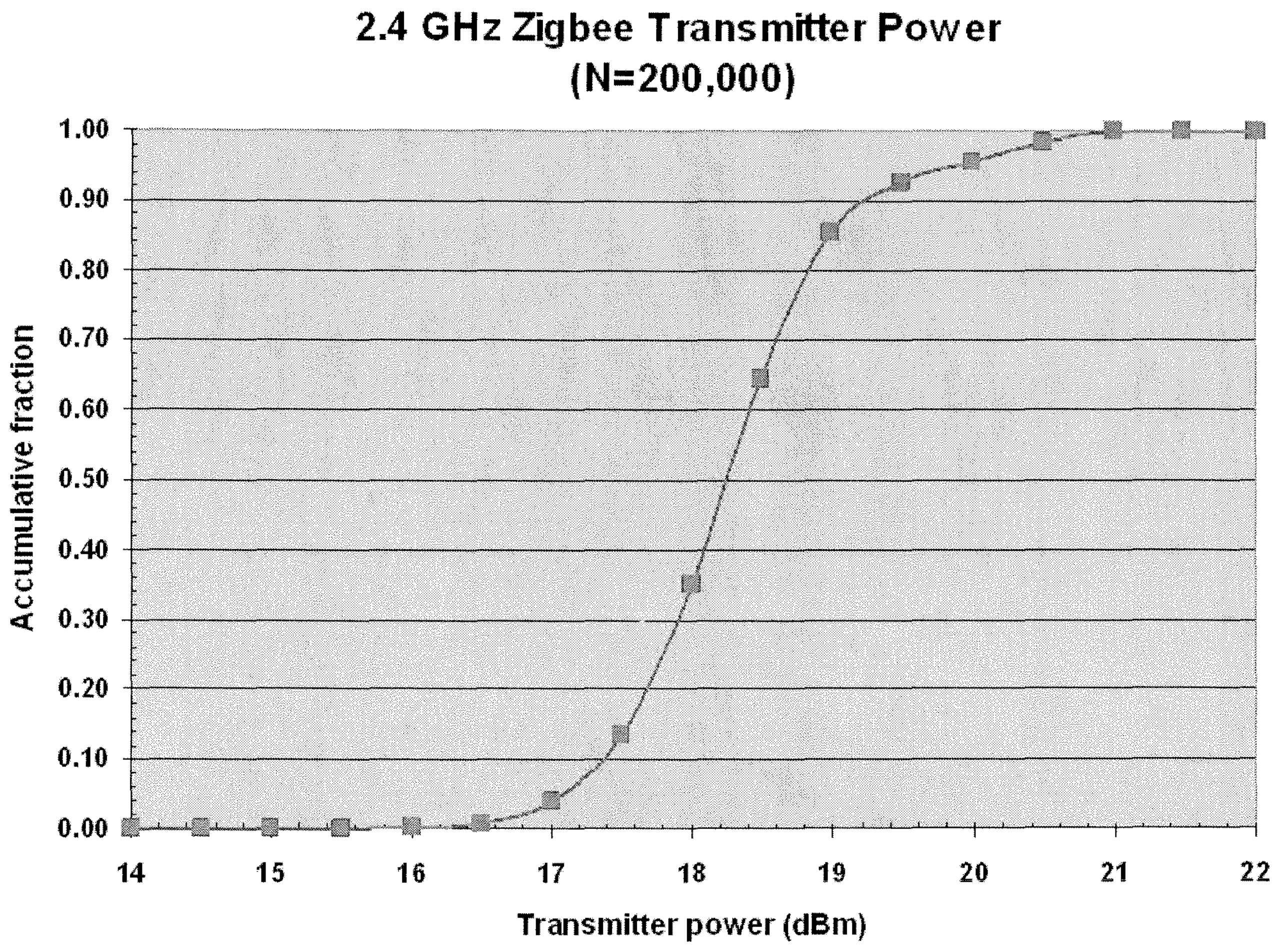

Figure 5-3
Accumulative fraction of 2.4 GHz Zigbee transmitter output power vs. transmitter power for a sample of 200,000 units. The median transmitter power is approximately 18.2 dBm (66.1 mW).

These statistical data on the 2.4 GHz Zigbee transmitter powers indicate that the most likely power is 18.5 dBm (70.8 mW); an upper value of 20.6 dBm (114.8 mW), a value 62% greater than the most likely power, would include 99% of all transmitters.

Cell relay meters contain the additional transceiver used for cellular WWAN connectivity in either the 850 MHz cellular band or 1900 MHz PCS band (personal communications service). Because these transceiver boards are produced by a different company and the units are specified to operate with specific powers and the fact that these units are separately certified by independent test labs for compliance with those specifications, Itron does not carry out additional power measurements. The transceivers, produced by Sierra Wireless operate with the following maximum powers:

Table 5-1
Sierra Wireless Transceivers Operation Maximum Powers

	GSM Modem Model MC8790 FCC ID: N7NMC8790	**CDMA Modem Model MC5725 FCC ID: N7N-MC5725**
Frequency Band (MHz)	Maximum power output (dBm) (mW)	
850	31.8 (1,514)	25.13 (326)
1900	28.7 (741)	24.84 (305)

Cell relays operate at the highest power of any of the meters due to their cellular/PCS modems but, similar to cellular telephones, the output power of the cellular modem is dynamically controlled by the applicable WWAN base station. This means that the actual operating power of the cellular radio in a cell relay will, generally, be less than the maximum power but will be determined by the signal strength it produces at whatever base station it is communicating with. Only one of the two modems would be active in a given deployment of Smart Meters in a neighborhood; the modem of choice is determined by the cellular wireless network service available and selected by the electric utility company.

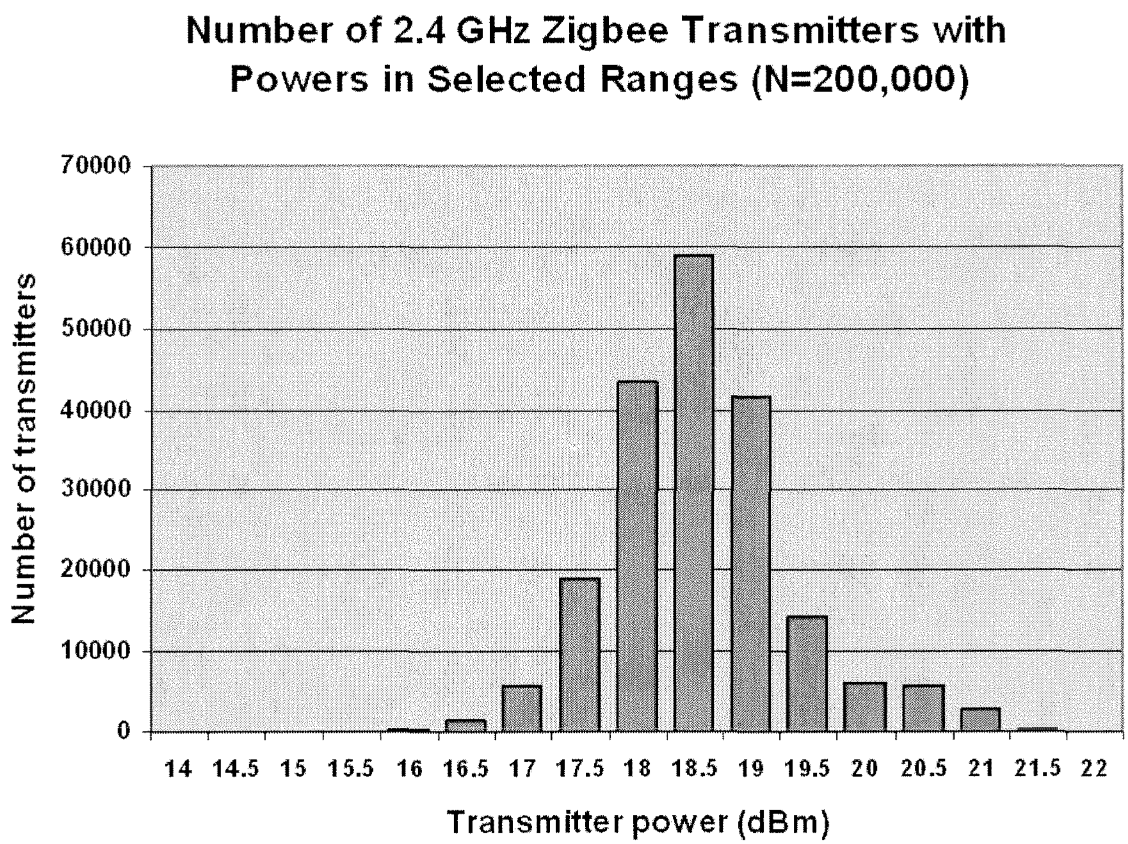

Figure 5-4
Number of 2.4 GHz Zigbee transmitters with powers within selected ranges. The transmitter power mode is approximately 18.5 dBm (70.8 mW).

Section 6: The Measurement Challenge Presented by Smart Meters

The difficulty of accurate RF field measurements near Smart Meters was discussed earlier. Low transmitted power levels in conjunction with intermittent emissions place considerable constraints on the measurement process. While a broadband measurement probe can eliminate the problem of the RF emissions occurring randomly on many different frequencies within the band, the relatively low sensitivity of broadband instruments places considerable restrictions on performing field strength measurements except within extremely close proximity of the meter. Intermittent emissions with very short duration, even if detectable, mean that it is difficult to observe when a transmission occurred. Generally, the desired measure of RF fields, from a human exposure perspective, is a measure of the average (root mean square - rms) value of the field strength or incident power density. The ratio of the average power density to the peak power density, for most Smart Meters is such that trying to measure the average field magnitude for a normally operating meter is very challenging. This can change if there exists a large aggregation of Smart Meters such that with their random on-off transmissions, much greater opportunity to "see" the emissions is possible.

Because of the rapid changes of frequency associated with the spread spectrum nature of the RF LAN and Zigbee radios in the Itron Smart Meters, an alternative approach is used to facilitate any antenna pattern and field measurements. This approach involves programming the relevant radios to transmit continuously, rather than their normal intermittent operation, and to transmit on a specific frequency within the relevant band as opposed to hopping across more than 50 channels within the 900 MHz band. Through this programming of the radios, the average signal level is now at its maximum, making it much easier to detect the RF field, and the fact that the emitted signal is now fixed on a specific and known frequency allows for ready confirmation that the measurement is of the intended signal. Since measurements under this scenario will indicate the peak value of RF field, other information is required to translate the peak field into what the equivalent average field would be. This requires a knowledge of the duty cycle of the emissions from the Smart Meter. The duty cycle can be thought of as the ratio of the amount of time that the transmitter is transmitting its signal to the total observation period. For example, if the Smart Meter were to typically transmit as much as 10 seconds during an hour (3600 seconds), the duty cycle would be 0.28%. In other words, the time-averaged power density of the RF field would be just 0.28% of the peak power density measured. The issue of Smart Meter duty cycles will be addressed later in this report.

APPENDIX I

American Council for an Energy-Efficient Economy, Long-term Energy Efficiency Potential: What the Evidence Suggests, John Laitner et al., January 2012

See attached.

The Long-Term Energy Efficiency Potential: What the Evidence Suggests

John A. "Skip" Laitner, Steven Nadel, R. Neal Elliott,
Harvey Sachs, and A. Siddiq Khan

January 2012

Report Number E121

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CONTENTS

About ACEEE

The American Council for an Energy-Efficient Economy (ACEEE) is a nonprofit research organization dedicated to advancing energy efficiency as a means of promoting economic prosperity, energy security, and environmental protection. For more information, see http://www.aceee.org. ACEEE fulfills its mission by:

- Conducting in-depth technical and policy assessments
- Advising businesses, policymakers, and program managers
- Working collaboratively with businesses, public interest groups, and other organizations
- Organizing technical conferences and workshops
- Publishing books, conference proceedings, and reports
- Educating consumers and businesses

Projects are carried out by staff and selected energy efficiency experts from universities, national laboratories, and the private sector. Collaboration is the key to ACEEE's ongoing success. We collaborate on projects and initiatives with dozens of organizations including international, federal, and state agencies as well as businesses, utilities, research institutions, and public interest groups.

Support for our work comes from a broad range of foundations, governmental organizations, research institutes, utilities, and corporations.

Acknowledgments

ACEEE and the authors would like to express our deep appreciation to our many allies and collaborators that have contributed to our deeper understanding of the critical role that more productive investments can have in reducing our nation's dependence on conventional energy resources and also reducing overall levels of greenhouse gas emissions. We gratefully acknowledge the contributions of our peer reviewers including David Goldstein, Danny Harvey, Steven Clemmer, and Jim McMahon. Funding for this work was provided by the Energy Foundation, the Verizon Corporation, an anonymous grant, internal ACEEE funds, and a lot of personal sweat. As always, both the analysis and the findings remain the responsibility of ACEEE and the authors of this assessment

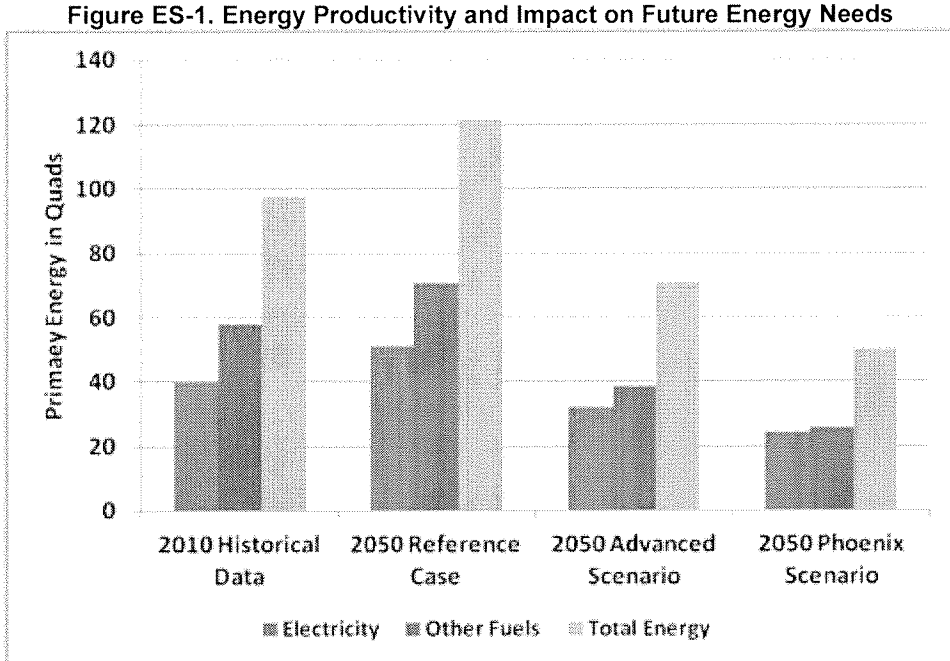
EXECUTIVE SUMMARY

In 2010 the U.S. used just under 100 Quads[1] of total energy resources to power our economy. Using the Energy Information Administration's (EIA) *Annual Energy Outlook* we project that our total energy needs might rise to about 122 quads of energy by the year 2050. In this report we explore a set of energy efficiency scenarios that emphasizes a more productive investment pattern, one that can enable the U.S. economy to substantially lower overall energy expenditures—should we choose to invest in and develop that larger opportunity. Building on the historical record of energy efficiency investments and their contribution to the nation's economic well-being, we highlight three economy-wide, long-term scenarios to explore the potential contributions that more energy-efficient behaviors and investments might play in reducing overall energy use by the year 2050. These three are:

1. Reference Case—a continuation of trends projected by EIA for the 2030-2035 period;
2. Advanced Scenario—includes penetration of known advanced technologies; and
3. Phoenix Scenario—in addition to advanced technologies, also includes greater infrastructural improvements and some displacement of existing stock to make way for newer and more productive energy efficiency technologies, as well as configurations of the built environment that reduce energy requirements for mobility.

For each scenario we separately examine the residential, commercial, industrial, transportation, and electric power sectors, and we then integrate these sectors together into a final set of impacts as shown in the chart below.

Figure ES-1. Energy Productivity and Impact on Future Energy Needs



Note: Electricity includes total energy needed to generate and distribute electricity to homes and businesses.

In total, we estimate that a more productive investment pattern might cost-effectively reduce our overall energy requirements in 2050 down to only 70 quads in the Advanced Scenario (a 42%

[1] A *quad* is a quadrillion (10^{15}) Btu's of energy, about the amount of energy used in all sectors of the economy by the state of Arkansas, Kansas, or Oregon in a year.

savings relative to the Reference Case) and 50 quads of energy in the Phoenix Scenario (59% savings).

To achieve these savings will require major changes in how we use energy in each sector. For example, in the residential and commercial sectors we estimate reductions of space heating and cooling loads due to building shell improvements of 40% (Advanced) to 60% (Phoenix) in existing buildings and 70-90% in new buildings. We eliminate duct energy losses due to conversion to water- or refrigerant-based distribution systems, or at a minimum putting ducts within the conditioned space so that duct losses contribute toward heating and cooling. We use advanced heating and cooling systems (e.g., advanced electric, gas, and ground-source air conditioners and heat pumps; and condensing furnaces and boilers), advanced solid-state lighting, and also significantly more efficient appliances. For existing buildings achieving these savings will require major retrofits, typically at the time of building renovation. One area where we made only modest improvements was in miscellaneous/other uses such as office equipment and other "plug loads." Data on energy use and savings opportunities for this equipment are limited. This area requires more attention in the future, since after heating, cooling, water heating, and lighting loads are reduced, these miscellaneous loads can be the majority of building energy use.

For the industrial sector, energy intensity is projected to improve in the Reference Case by about 1% per year through 2050, but leading companies have been achieving continued improvements at more than double this rate. In our Advanced Scenario we project a 2% per year improvement rate for overall industrial energy intensity, which increases to 2.75% in our Phoenix Scenario. Future energy efficiency opportunities will come less from seeking out individual sources of waste and more from optimization of complex systems enabled by advances in information, communication, and computational infrastructure. Most of the energy use in industry is in processes, not individual equipment, so improving processes represents the largest opportunity for energy intensity improvements. Current focus has been on process optimization, but we anticipate that even greater opportunities exist in the optimization of entire supply chains that may span many companies and supply chain integration that allows for efficient use of feedstocks and elimination of wasted production.

In the transportation sector, the Reference Case includes new light-duty vehicle fuel economy increases out to 2020, as mandated by the Energy Independence and Security Act of 2007, and minimal increases thereafter. Other transportation modes experience modest efficiency increases out to 2050. In the Advanced Scenario, fuel economy of conventional petroleum-fueled vehicles continues to grow while hybrid, electric, and fuel cell vehicles gain large shares, totaling nearly three-quarters of all new light-duty vehicles in 2050. Aviation, rail, and shipping energy use declines substantially through a combination of technological and operational improvements. The Phoenix Scenario assumes a shift toward more compact development patterns, greater investment in alternative modes of travel, and other measures that reduce both passenger and freight vehicle miles traveled. This scenario also phases out conventional light-duty gasoline vehicles entirely, increases hybrid and fuel cell penetration for heavy-duty vehicles, and reduces aviation energy use by 70% from the Reference Case.

While end-use electricity represents a fraction of the total energy use in the U.S. economy, currently it takes more than three units of fuel to produce a unit of electricity. The delivered efficiency of the U.S. electricity sector is projected to improve modestly in our Reference Case. Part of this increase is due to improvements in generation efficiency and reductions in transmission and distribution (T&D) losses, combined with a significant increase in the share of electricity produced by Combined Heat and Power (CHP), whose power output is predominately near its point of use thus avoiding some of the T&D losses. As we dramatically reduce the electricity use in the other sectors of the economy in our Advanced and Phoenix Scenarios, we anticipate that these reductions will result in important shifts in the generation mix in the electric sector, with many old plants retiring. We also anticipate that the delivered electricity efficiency will improve as we invest in more efficient new generation and highly-efficient CHP accounts for a greater share of the overall generation mix. We project that the delivered electric system efficiency in 2050 will increase from about 36% in the Reference Case to about 40% in the Advanced Scenario and approach 48% in the Phoenix Scenario. This improvement in overall delivered efficiency greatly reduces the losses associated with supplying electricity to other sectors of the economy.

The greater emphasis on energy efficiency would sharply reduce total energy requirements within the U.S. (especially for fuels such as natural gas and petroleum). However, we project that end-use demand for electricity will decline less than direct fuel use. The reason for this apparent difference is that the many more demands for high-quality electrical energy would hold power consumption steady as more of our economic activity is driven by a greater share of electric generation resources. By improving the delivered efficiency of electricity, we can actually hold electricity demand relatively steady and end up using significantly less total energy while meeting our overall electricity needs.

Overall, as noted previously, we estimate that energy use in 2050 can be reduced by 42% in the Advanced Scenario and 59% in the Phoenix Scenario. Savings are roughly similar in each sector. The 2050 industrial sector savings, for example, range between 36 and 51% for the two policy cases while residential and commercial buildings might realize overall energy savings from 45 to 69% savings. Transportation savings, moving closer to buildings in the scale of efficiency improvements, fall in between with suggested savings of 38 to 56%, respectively.

The levels of efficiency improvements in either the Advanced Scenario or the Phoenix Scenario will generate a productive boost to the economy. There are two primary ways in which this will happen. First, households and businesses will see lower energy bills as the level of energy efficiency improves over time. As they maintain (or even increase) their own economic activity through these productivity improvements, the growing energy bill savings will act much like an extra form of income that provides an important stimulus for other sectors of the U.S. economy. Second, and related to this first improvement, the efficiency gains will allow households and businesses to redirect the flow of spending away from the more costly energy sectors. The net result is that households and businesses will have more money available for the purchase of other goods and services. As it turns out, those other sectors of the economy tend to be more labor intensive. Hence, the increased spending, in turn, provides a larger net employment benefit for the nation's economy—we estimate that the combined effect of the efficiency investments over time, together with a growing energy bill savings, will drive a steady increase in the demand for labor so that by the year 2050 the economy will provide a net increase of 1.3 to 1.9 million jobs. Net gains to the nation's Gross Domestic Product (GDP) in 2050 are estimated to be on the order of 100 to 200 billion dollars per year. Both the employment and GDP benefits are on the order of tenths of a percent above the 2050 Reference Case. Table ES-1 highlights these and other economy-wide impacts of the two energy efficiency scenarios.

Table ES-1. Key Economic Impacts from Efficiency Improvements

Financial and Economic Indicators	Advanced Scenario	Phoenix Scenario
Energy Savings from 2050 Reference Case	42%	59%
Cumulative Financial Impacts 2012-2050 (Billion 2009 Dollars)		
Program Cost	500	1,200
Total Investments	2,400	5,300
Annual Payments on Investments	2,900	6,400
Energy Bill Savings	15,000	23,700
Net Energy Bill Savings	11,600	16,200
Net Macroeconomic Impacts in the Year 2050		
Employment (millions of jobs)	1.3	1.9
Percent from Reference Case	0.4%	0.6%
GDP (billion 2009 dollars)	100	200
Percent from Reference Case	0.3%	0.4%

Implementation of the Advanced and Phoenix Scenarios depends on our willingness to make the needed investments in higher performance buildings, equipment, industrial processes and transportation systems. At the same time, it takes money to make money. Over the period 2012 through 2050 the nation will have to provide the funding for the array of programs that will be necessary to catalyze a more productive pattern of investments. And as those investments are made over time, households and businesses will likely need to borrow the money that will enable us to upgrade the nation's infrastructure. Hence, there will be an ongoing series of annual payments necessary to pay for those improvements.

But the good news is that the investments will generate a significant return in the form of large energy bill savings. After paying for the program costs and making the necessary investments as we pay for them over time, the economy will benefit from a net energy bill savings that ranges from 12 to 16 trillion dollars cumulatively over that 39-year time horizon (that is, a period of time that extends from 2012 through 2050). In other words, these two high-performance energy efficiency scenarios will spur an annual net energy bill savings that might range from about $297 billion to $415 billion per year (with all values expressed in constant 2009 dollars).

In effect, the two ACEEE energy efficiency scenarios highlighted in this study represent a different recipe of investments compared to the standard Reference Case. It is a recipe built on a more productive investment pattern. These investments, in turn, enable the economy to reduce overall energy expenditures in ways that also provide a greater employment benefit—again, should we choose to develop that larger opportunity. The question that remains is whether we will actually choose the more productive investment path, or will we simply "muddle through" by following the standard business-as-usual assumptions?

I. INTRODUCTION

Notwithstanding the current sluggishness of the United States economy, the standard forecasts suggest that economic activity is likely to grow at a reasonably robust level of about 2.7% annually over the next 40 years. Based on estimates published by the Energy Information Administration (EIA 2011), the nation's GDP (Gross Domestic Product) is expected to increase from about $14.6 trillion in 2010 to perhaps $41 trillion in 2050 (with all values expressed in constant 2010 dollars to eliminate the effects of inflation). This is almost a tripling of today's economy. While the increase is expected to slow compared to the expansion we witnessed in past decades (the growth in GDP averaged more than 3% in the period 1980-2005, for example), our per capita income is still expected to nearly double by 2050. This anticipated economic expansion presumes, among other things, a conventional pattern of energy production and consumption. It also presumes a straightforward extension of how we produce our goods and services. Yet the evidence suggests that without a greater emphasis on the more efficient use of energy resources, there may be as many as three jokers in the deck that will likely constrain the robustness of our nation's future economy. These include the many uncertainties surrounding the availability of conventional and relatively inexpensive energy supplies, a slowing rate of energy and therefore economic productivity, and a variety of pending climate constraints that may create further economic impacts of their own.

The first of the emerging constraints involves the many aspects of energy production and consumption. Starting prior to the recent offshore oil drilling disaster in the Gulf of Mexico (New York Times 2010), a variety of snags continue to hinder the safe and timely production of many energy resources (Elliott 2006). There is also convincing evidence we are approaching the sunset of the oil era in the first half of the 21st century (Deffeyes 2010; Rifkin 2011). Drawing on the BP *Statistical Review of World Energy* (BP 2011), we note that the global "per capita peak oil production" occurred in 1979 when we produced 15.1 barrels of oil per person compared to 2010 when we managed only 12 barrels of oil per day. Total production has already peaked in most non-OPEC countries (that occurred for the U.S. in 1970) and is expected to peak in most of the others before 2030—and this despite an assumed steady increase in world oil prices forecasted by the International Energy Agency (IEA/OCE 2011). With that inevitability, there will be a huge shift in the way most of humanity interacts with the global energy system. The realization of imminent limitations on our fossil fuel resources has generated a rush of interest in energy efficiency and renewable energy technologies while aggravating the financial and investment pressures that are necessary to maintain the integrity of the world energy market.

The second of the constraints follows from slowing growth in energy productivity. The U.S. economy has tripled in size since 1970 and three-quarters of the energy needed to fuel that growth came from an amazing variety of efficiency advances—not new energy supplies (Laitner forthcoming). Indeed, the overwhelming emphasis in current policy debates on finding new energy supplies is such that emphasis on new supplies may be "crowding out" investments and innovations that can help to achieve greater levels of energy productivity. Going forward, the current economic recovery, and our future economic prosperity, will depend more on new energy efficiency behaviors and investments than we've seen in the last 40 years (Laitner forthcoming).

The third of the three emerging problems to complicate standard growth projections is climate change. The average temperatures in the earth's atmosphere are on an upward trajectory that is largely irreversible over the next century (even if we meet ambitious emissions reduction goals). The trend is driven by the cumulative effect of rising concentrations of greenhouse gas (GHG) emissions, primarily carbon dioxide emissions (CO_2), which are generated by the combustion of fossil fuels. This trend has profound implications for the world's climate. Leading U.S. climatologist James Hansen and his colleagues (Hansen et al. 2008) say that current global CO_2 concentrations are now at about 390 parts per million (ppm) and could rise to 550 ppm or more by the year 2100 unless ambitious efficiency investments such as those recommended here occur. The IEA Chief Economist, Fatih Birol, commented on the release of the IEA's *World Energy Outlook* that "[a]s each year passes without clear signals to drive investment in clean energy, the "lock-in" of high-carbon infrastructure is making it harder and more expensive to meet our energy security and climate goals." The IEA is raising the alarm that the world is locking itself into an unsustainable energy future that would have far-reaching consequences. If left unchecked, the changing climate could seriously weaken the global and the U.S. economy (IEA/OCE 2011).

Americans may have an overly optimistic impression of how energy efficient the United States is—even as they believe in the importance of greater levels of energy efficiency (Maibach et al. 2010). Despite the enormous strides achieved in the last four decades, Ayres and Warr (2009) estimate that the U.S. economy is about 14% energy efficient, with the other 86% wasted. By way of comparison, Ayres and Warr note that Japan and several European countries are about 20% efficient, a factor of 1.5 higher than the U.S. Even so, all economies are underperforming in this regard.

At the same time that we face these critical environmental and energy challenges, the United States is on the verge of losing its competitive edge (Atkinson and Andes 2011). Competition from rapidly growing countries with employees marching up the skill ladder is a big reason for America's economic strain, but not the only one. Inspired by its uniquely democratic political culture, the U.S. economic growth miracle has been nurtured by its openness to new ideas. For over two centuries, the United States has catalyzed an array of new institutional and technological innovations. Yet, as professor of management Leon Megginson suggested, drawing on the ideas of Charles Darwin, it is not the strongest of the species that survives, nor the most intelligent that survives. It is the one that is most adaptable to change. (Megginson 1964). Thus, it is especially troubling when a number of observers are suggesting we may be losing our resourcefulness—especially against the backdrop of these multiple challenges. As former Chief Technology Officer at Cisco Systems, Judy Estrin (2008) observes: "To be honest, we had a problem with innovation [in this country] even before the [current climate, energy, and] economic crisis. . . We're focusing on the short term and we're not planting the seeds for the future" (see also Rae-Dupree 2008, Florida 2004, and Holdren 2006). Harvard professor and award winning physicist John Holdren (1999) asks pointedly, "can we afford 'business as usual' any more?"

In the United States, and around the globe, there is a clear need for real, affordable, short-term (but also long-term) alternatives that can reduce our inefficient use of energy resources. More productive and cost-effective investments in greater levels of energy efficiency can reduce the upward pressures on and the volatility of energy prices as well as reduce the GHG emissions burden (Laitner 2009b). Furthermore, energy efficiency investments can do all this while maintaining the production of the many goods and services demanded by our economy, and according to many analyses, actually increase net employment opportunities (Laitner and McKinney 2008; Houser et al. 2010; Laitner et al. 2010).

Although energy efficiency is seen by many stakeholders as a highly effective investment, it also tends to be viewed as a short-term resource. This view is now changing. California, for example, established energy efficiency as the first choice in the loading order for new energy resources (Grueneich 2008). Other states, including Connecticut, Massachusetts, Rhode Island, and Washington, have established similar policies. This emerging perception has been instrumental in the selection of energy efficiency as a cost-effective resource for energy utilities (Molina et al. 2010). Indeed, as we show in the discussion that follows, energy efficiency may well prove to be a more dynamic and longer-term resource than many now assume (see Lovins et al. 2011 for a discussion on this issue). There is a strong historical record to suggest that energy efficiency can provide perhaps the largest single wedge of GHG emissions reductions (Laitner et al. 2010; see also Harvey 2010; Committee on America's Energy Future 2010; McKinsey 2009; Gold et al. 2009; American Physical Society 2008; Ehrhardt-Martinez and Laitner 2008; and McKinsey 2008). Yet, the question remains, just how big of a resource is energy efficiency—especially when we examine its potential over the next four decades through the year 2050?

The balance of this report seeks to accomplish three separate tasks. First, it provides an overview of the historical record on energy efficiency and discusses how that set of insights might inform our expectations of its future economic potential—specifically in the context of how energy efficiency investments might positively impact economic and climate policy outcomes. As part of this discussion it describes the critical role of energy efficiency in advancing the larger economic productivity within the United States. Second, the report highlights two economy-wide, long-term scenarios to explore the potential contributions that more energy-efficient behaviors and investments might play in reducing overall energy use by 2050. We separately examine the residential, commercial, industrial, transportation, and electric power sectors and then integrate these sectors together. As the report characterizes the future opportunities, it appears that energy efficiency writ large—including conservation behaviors, informed choices, improved devices, structural change within the economy, and more productive systems and infrastructure—might generate as much as 42 to 59% of the deep emissions reduction that most scientists agree are needed by 2050.[2] Finally, we examine the implications of this economic opportunity as it is affected by relevant policy choices.

II. THE HISTORICAL RECORD ON ENERGY EFFICIENCY

Energy efficiency has played a surprisingly enduring and critical role in our nation's economy. In the sections that follow, this report documents the past scale of the energy efficiency resource as it has powered the nation's economy. It also examines what we know about the costs and energy-saving benefits of the array of energy efficiency technologies and behaviors. The benefits include both reduced energy bills and a surprisingly large set of non-energy benefits ranging from reduced operations and maintenance costs to improved quality and speed of tasks. From there we examine how the resources that are freed up might drive a small but net positive gain benefit for the nation's unemployed or underemployed.

A. Placing Energy Efficiency into the Economic Context

As one of the richest and more technologically advanced regions of the world, the United States has expanded its economic output by more than threefold since 1970. Per capita incomes are also twice as large today compared to incomes in 1970. Notably, however, the demand for energy and power resources grew by only 50% during the same period.[3] This decoupling of economic growth and energy consumption is a function of increased energy productivity: in effect, the ability to generate greater economic output, but to do so with less energy. Having achieved these past gains with an intermittent, haphazard, and often counterproductive approach to energy efficiency and energy policy, there is compelling evidence to suggest that even greater energy productivity benefits can be achieved. Indeed, business leaders and policymakers may be surprised to learn just how big a role that energy efficiency has already played in supporting the growth of our economy over time. Indeed, Smil (2010) suggests that "sensible policies aimed at reducing wasteful energy use were completely (and indefensibly) abandoned." Figure 1 examines the historical context of efficiency gains estimated through 2010 as they compare to the development of new energy supplies since 1970. Figure 1 also illustrates the level of new energy supply that would have been needed in the absence of energy productivity gains due to efficiency measures. In effect, it compares the projected level of energy consumption in 2010 to that which might have been necessary had the economy continued to rely on 1970 technologies and market structure.[4]

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[2] Drawing on the emerging scientific evidence, for example, a 2009 declaration by the leaders of the G8 nations called for an 80% or more reduction of aggregate greenhouse gas emissions by 2050 in developed countries compared to 1990 or more recent levels (G8 Leaders 2009).

[3] These and other economic and energy-related data cited are the authors' calculations as they are drawn from various resources available from the Energy Information Administration (EIA 2011a, 2011b).

[4] Strictly speaking, the term energy efficiency as used here can be more broadly defined as a reduction in energy intensity; that is, a reduction in the number of Btus needed to support a dollar of economic activity. This change results from two key drivers. The first is a change in market structure as we move away from energy-intensive industries as a source of income to higher value-added services. The second is what we typically think of as energy efficiency—more efficient lighting and consumer products, greater fuel economy in our vehicles, and more efficient power plants and industrial processes. The United States has benefited from both economic drivers; both were made possible by a combination of behaviors, innovations, and productive technology investments. From a macroeconomic perspective the evidence suggests that anything we can do that positively reduces energy use while maintaining incomes and economic prosperity can be termed "energy efficiency." It is in that larger sense that the term is used in this report.

In 1970 Americans consumed an estimated 68 quadrillion Btus (quads) for all uses of energy.[5] These different uses of energy run the gamut from heating and cooling our homes, schools, and businesses to powering our many industrial processes and transporting both people and freight to the various places they needed to go. If we converted all forms of energy consumed in 1970 to an equivalent gallon of gasoline—whether coal, natural gas, or electricity, it turns out that the U.S. economy required about 2,700 gallons of gasoline equivalent for each man, woman, and child living in the U.S. at that time. Had the United States continued to rely on 1970 market structure and technologies to maintain its economic growth, in 2010 we would have consumed an estimated 210 quads of energy resources. In per capita terms, that would be equal to roughly 5,400 gallons of gasoline per person. But in fact, the actual level of consumption estimated for 2010 appears to be just short of 98 quads of energy (in rounded numbers). Again on a per capita basis, this means that the U.S. economy now requires no more than about 2,500 gallons of gasoline per resident—about 200 gallons less than needed in 1970.

In examining these numbers more closely, however, several important observations deserve to be highlighted. First, although we currently enjoy a much broader set of goods and services in today's economy, we have been able to achieve this expanded level of economic output while maintaining constant levels of energy use per capita. This has been achieved through investments in energy efficiency. Second, although the same level of goods and services hypothetically could have been achieved through the consumption of 210 quads of energy per year, we have been able to achieve this level of output with less than half that amount of energy. In effect, investments in energy efficiency have allowed us to reduce total energy use by the equivalent of 112 quadrillion Btus in 2010 (relative to what our energy use would have been without those efficiency gains). Even when we make adjustments to reflect the large number of goods and services that have been imported—things that required energy outside our borders to produce and ship those goods into the United States, the demand for energy services is still 203 quads in 2010. That means energy efficiency has "fueled" about 106 quads, or roughly three-fourths of the *new* growth for energy-related services since 1970. The conventional energy resources, on the other hand, satisfied only one-quarter of the new demands (or about 30 quads, shown as the difference in Figure 1 between the 2010 consumption of 98 quads compared to the 1970 consumption of 68 quads).[6]

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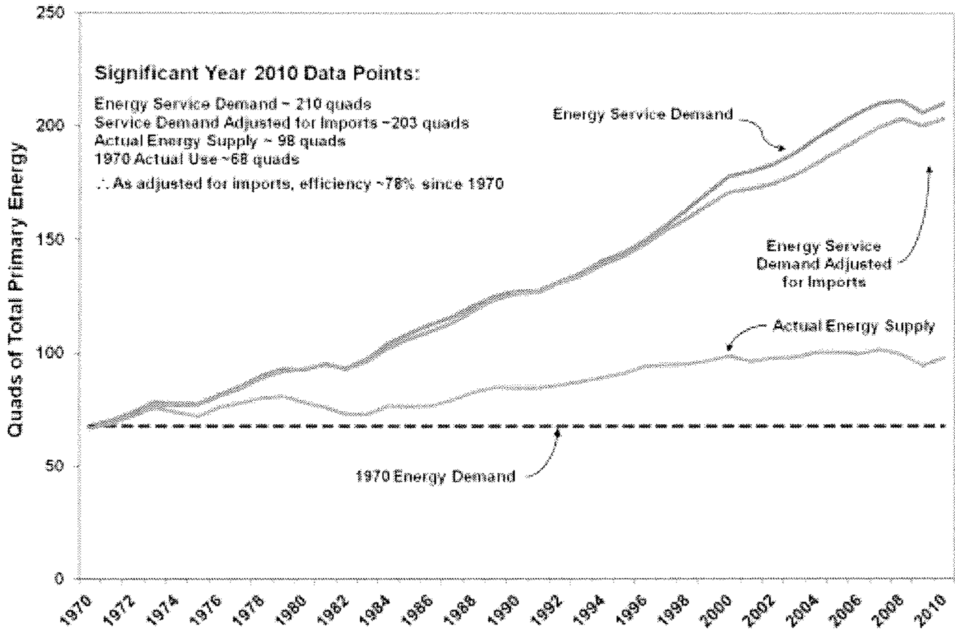
[5] One quadrillion British thermal units is 1,000,000,000,000,000 Btus (10 to the fifteenth power). In today's markets, one quad is the amount of energy contained in 8 billion gallons of gasoline. One quad is sufficient energy to power more than 15 million cars in the U.S. for one year (at today's average fuel economy and typical driving distances). One quad contains sufficient heat to also provide the total energy needs for more than 5 million homes in the U.S.

[6] As one of our reviewers (David Goldstein) suggested, it would be interesting to try to reconstruct what a 210 Quad economy would look like. What would we have invested in nuclear energy to get there and what would electricity prices have been? What would world oil prices have been and where would the oil have come from? While this would, indeed, be a very useful exercise, it is beyond the scope of this particular inquiry. Still, we might speculate that without the very large historical efficiency gains, energy supplies might be significantly tighter and energy costs would likely be higher and much more volatile than we've seen to this point. This, in turn, would likely have constrained our nation's economic productivity and resulted in a smaller level of economic activity than we've seen to date. One important conclusion from this thought experiment is that today's economy would likely have not been possible but for the historical gains in efficiency as we've previously discussed.

Figure 1. U.S. Energy Service Demands, Energy Efficiency Gains, and Energy Supplies



Source: ACEEE calculations based on data from the Energy Information Administration (2011a)

One often unappreciated aspect of the growth in energy consumption is what might have been had we previously chosen to develop our energy efficiency resources more completely. For example, a minimum attention to greater energy productivity in the last decades might have kept current energy demands closer to the 1970 level of consumption—even with a growth in both the population and the size of the economy. In that case, the historical growth in high efficiency improvements might have kept total energy demand closer to 70 quads by 2010.[7] Perhaps more interesting is the set of the many previous studies that have suggested we might have done (and might still do) even better. We explore these past studies in the section that follows.

B. Where Energy Efficiency Might Have Taken Us and Where We Might Head

The market tends to be more dynamic than policy assessments generally concede, especially when given an appropriate mix of policies and guidance. In the late 1970s, as the United States was assessing its various energy options following the 1973-1974 Oil Embargo, the National Research Council published an authoritative report called *Energy in Transition 1985–2010* (NRC 1979). It was one of the more thorough assessments of its time, but certainly not atypical of the many past studies that explored future technology. The report suggested that, if one assumed a doubling in the size of the U.S. economy, and if energy prices (adjusted for inflation) stayed roughly the same, U.S. energy consumption would rise from about 72 quads in 1975 to about 135 quads by 2010. The NRC study further indicated that if real energy prices were to double instead, then U.S. energy demand might grow to only 94 quads by 2010. The demand pattern that actually emerged since 1975 provides an especially useful insight as policymakers and business leaders turn their attention to the growing problems of climate change and energy security.

[7] This so-called "Historical High Efficiency" scenario is generally patterned after a series of low range energy efficiency that explored such possibilities over the period 1975 through 2010. For more details, see DOE (1980) and the discussion that accompanies Figure 2.

As it turned out, the economy didn't doubled, but nearly tripled in volume over the last 35 years. And while energy prices did not remain at the 1975 levels, neither did they double in size. In fact, it appears that real energy prices since 1975 have grown on average by only 70% compared to the comparable prices seen in 1975. And what of the nation's actual use of energy? Returning to the data in Figure 1, the latest forecast from the Energy Information Administration (EIA 2011b) suggests that total energy use this year will be just under 100 quads. So we've grown the economy much bigger than we anticipated and energy prices have less than doubled, but as Figure 2 below suggests, total energy demand has stayed closer to what analysis in the mid-1970s thought would be an unlikely low energy future. What is the difference? The evidence suggests two very big factors have made the economy more energy efficient than anticipated in the 1970s. The first is that we have deployed more productive technologies than we thought possible from a 1970s vantage point. But a further investigation also suggests that more informed behaviors and a more dynamic market also played critical roles.

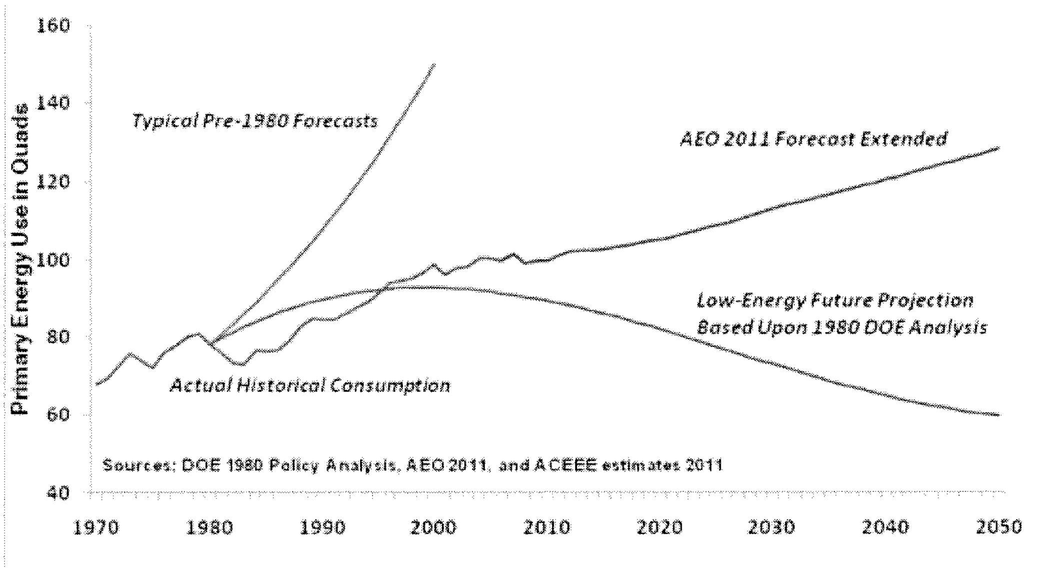
One interesting comparison to emerge from Figure 2 (below) is an early attempt at characterizing just how the energy consumption might look in the event that emerging energy efficiency technologies developed significant market share. Based on a review of 20 earlier studies that explored that same possibility, the U.S. Department of Energy (DOE 1980) provided what it termed an "approximate envelope of low energy futures." As illustrated by the solid green line in Figure 2, the envelope of projections extended all the way out to the year 2050. The projection peaked roughly in 2005 at a little more than 90 quads and then sloped gently downward. The overall conclusion of the study was that "if these efficiency improvement measures could be widely and rapidly adopted across all sectors of the economy, the combined and cumulative effects are estimated by most of the studies reviewed to result in negative future growth in U.S. primary energy use—possibly approaching 60 quads."[8]

Figure 2 also provides two other important comparisons. The first is a line representing the standard forecast assumption before 1980 with an indication that energy use by the year 2000 might reach as much as 150 quads. The irony here is that, both for expected and for unexpected reasons, the nation's actual energy consumption (highlighted by the jagged red line in Figure 2) more closely reflected what was characterized in 1980 as a "low energy future." In other words, the combination of technology investments, informed behaviors, and supportive energy policies enabled a more dynamic market response than energy modelers anticipated in previous years. Perhaps even more compelling, the economy itself also proved to be more robust than the modelers originally thought likely.

As a final comparison highlighted in Figure 2, the *Annual Energy Outlook 2011* projection for total primary energy (EIA 2011b)—extended to 2050 by incorporating additional data from Economy.com (2011)—nicely splits the difference between the pre-1980 forecasts and what DOE in 1980 referred to as an envelope of low energy futures. The question for policymakers is whether there are opportunities to close the gap between the current projection of business-as-usual and that low energy future first suggested by the 20 studies reviewed in 1980.[9] As we examine next, the evidence continues to underscore that possibility—if we choose to act on the full set of opportunities to increase our nation's energy productivity.

[8] An interesting side note is that the 1980 DOE report specifically excluded from its more in-depth analysis a 1979 study with a projection of 33 quads in 2050 "because it assumes major lifestyle changes."
[9] Not to be lost in the comparison, the gap between the pre-1980s projections and what actually occurred by the year 2000 is approximately the same magnitude as the comparison between the extended AEO 2011 forecast for the year 2050 and the 60-quad low energy future.

Figure 2. Energy Scenarios: Differences in Technology and Behavioral Assumptions?



Since the useful compendium and analysis provided by DOE in 1980, there have been a number of other studies that have further explored the feasibility of greater investments in the nation's energy productivity. Two significant studies include *America's Energy Choices* (AEC 1991) and *Energy Innovations* (Interlaboratory Working Group 1997). These two highly detailed studies, sponsored by a association of nonprofit organizations and research groups, suggested that—with the right mix of policies and investments—it was technically and economically possible to reduce the nation's total primary energy consumption to between 60 and 70 quads by the year 2050. Harvey (2010) provides almost encyclopedic detail that further reinforces such prospects. In effect, these past assessments of long-term energy efficiency improvements envisioned the substitution of innovation and productive capital as a smart substitution for the inefficient use of energy. Two major studies by a consortium of the nation's national energy laboratories generally reinforce these finding although over a shorter time horizon (see Interlaboratory Working Group 1997, 2000).

C. Cost-Effectiveness of the Efficiency Resource

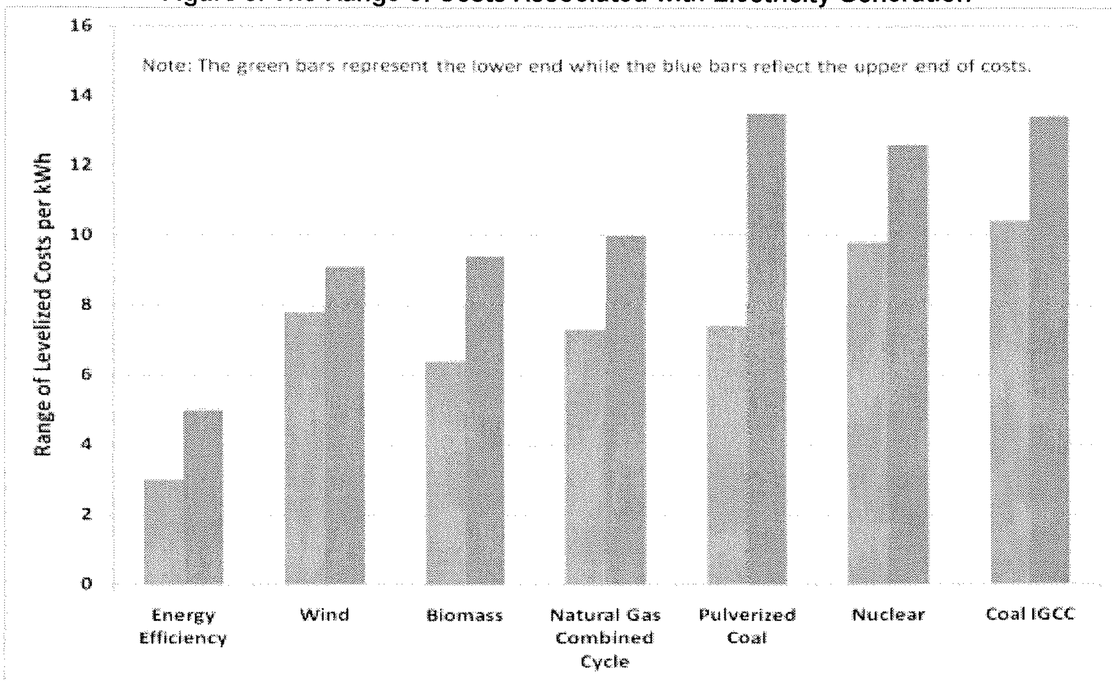
The question at this point becomes one of cost-effectiveness. Can the substantial investments that might be required in the more energy-efficient technologies save money for businesses and consumers? In the subsections that follow, we again turn to the evidence as we first explore what we might call the engineering estimates of energy efficiency compared to conventional energy resources. We then examine how these costs might progress over time. Finally we explore the reality of energy efficiency costs compared to the standard and more narrowly defined range of cost estimates.

1. Engineering-Economic Cost Estimates

Figures 3 and 4 offer two initial but different assessments of the "first cost" comparison of energy efficiency compared to other investments. Lazard (2009) presented a mix of levelized costs—that is, the cost of investments as they are amortized and operated over time—associated with electricity generation expenditures. These are summarized in Figure 3 as they cover the annual costs associated with a variety of new power plants. The left green bars represent the lower end of the costs while the right blue bars represent the higher end of the estimated costs. Included are estimates for conventional coal-fired power plants, coal units that rely on integrated gasification combined cycle technologies or IGCC, nuclear units, and natural gas combined cycle power plants. Also shown are costs for wind and biomass systems together with both Lazard and ACEEE estimates for the range of costs associated with energy efficiency measures (including program-operator and end-user costs).

With efficiency costing the equivalent of 3-5 cents per kilowatt-hour of electricity service demand, the resulting electricity savings are clearly the more cost-effective option.[10]

Figure 3. The Range of Costs Associated with Electricity Generation



Sources: Lazard (2009); Friedrich et al. (2009)
Note: For energy efficiency this includes both utility and customer costs.

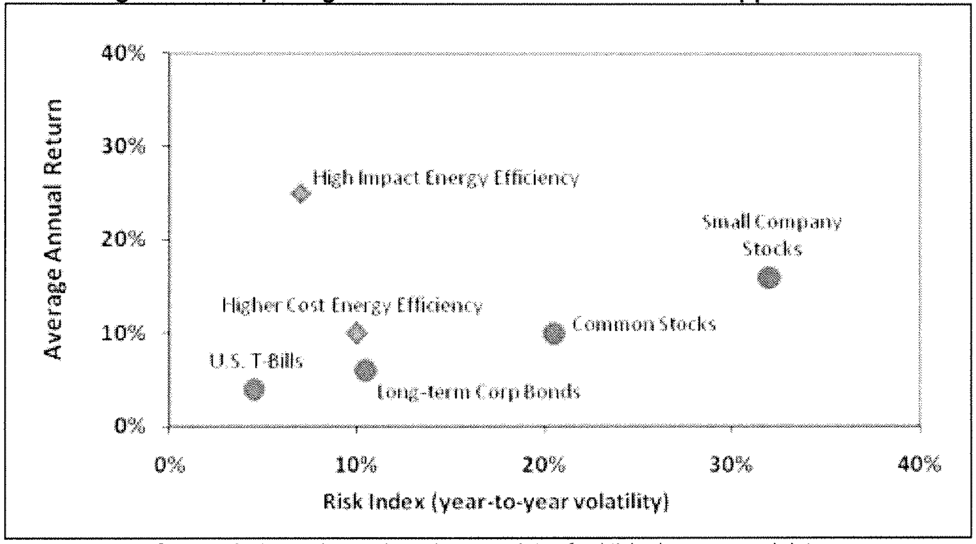
Figure 4 provides a different look, comparing energy efficiency investments to other opportunities for generating investment returns. This is done in two ways. The first is an annual return on investment. The second is an examination of risk associated with a given investment opportunity. In exploring the prospective returns on investments in efficiency upgrades, McKinsey & Company (2008) reviewed an array of energy efficiency options that had at least a 10% return on the investment dollar. When spread out globally over an annual $170 billion energy efficiency market potential, McKinsey suggests an average 17% return might be expected across that spread of annual investments. Rather than a return on investment, we can also explore the amortized cost of electricity, for example, and determine a prospective return compared to the expected average cost of electricity.

At five cents per kWh, we might envision the spending of 36 cents upfront to save one kWh each year for perhaps 15 years. When amortized over the life of that one-time investment, at a real 7% interest rate, the annual cost is estimated as $0.04/kWh. If we think of the time it takes for that investment to pay for itself, and if we know the monthly electricity cost is 9 cents per kWh, we might then suggest the investment would pay for itself over four years. In that case, the investment is approximated to have the equivalent of a 25% annual return. As shown on the vertical axis in Figure 4, a typical range of efficiency investments is suggested as having one of the more durable and better annual returns compared to other investments—whether in treasury bills or common stock. Even more interesting is the stability of the investment as shown on the horizontal axis. Although data is not collected on risk

[10] Not included in Figure 3 is a significant supply of negative cost measures. These are essentially measures that rely on changes in procedures that require no capital outlays. In effect, they are so-called "housekeeping" improvements that only require things to be done differently.

associated with institutional investments in energy efficiency in any systematic way, it appears to provide a more stable investment opportunity compared to normal market instruments.[11]

Figure 4. Comparing Risk and Return on Investment Opportunities



Source: Author estimates based on a variety of published sources and data

We can extend this issue of cost effectiveness even further to examine policy rather than discrete technologies. Laitner and McKinney (2008) provided a meta-review of 48 past policy studies that were undertaken primarily at the state or regional level. The set of studies included in this assessment generally examined the costs of economy-wide efficiency investments made over a 15-25 year time horizon. The analysis found that even when both program costs and technology investments were compared, the savings appeared to be twice the cost of the suggested policies.

In a similar way, the AEC (1991) and the Energy Innovations (1997) reports show a benefit-cost ratio that also approached two to one. More recently, the Union of Concerned Scientists (Cleetus, Clemmer & Friedman 2009) published a detailed portfolio of technology and program options that would lower U.S. heat-trapping greenhouse gas emissions 56% below 2005 levels in 2030. The result of their analysis indicated an annual $414 billion savings for U.S. households, vehicle owners, businesses, and industries by 2030. After subtracting out the annual $160 billion costs (constant 2006 dollars) of the various policy and technology options, the net savings is on the order of $255 billion per year. Over the entire 2010 through 2030 study period, the net cumulative savings to consumers and businesses was calculated to be on the order of $1.7 trillion under their so-called Blueprint case.

2. The Progression of Cost Estimates

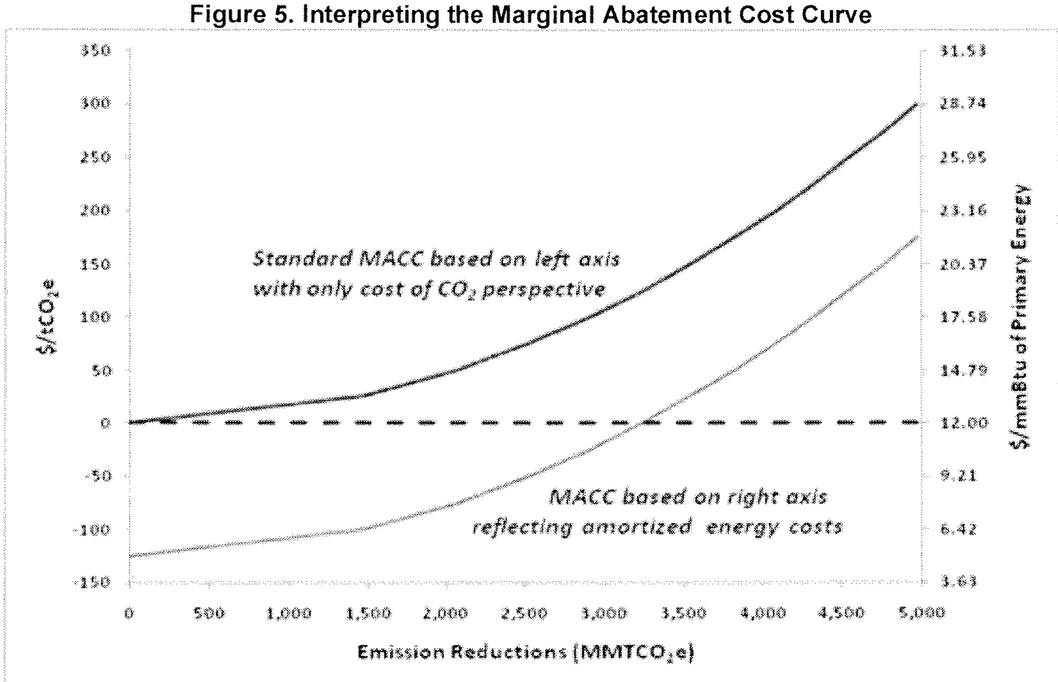
Figure 5 highlights yet another aspect of the cost-effectiveness of energy and climate policy—the so-called marginal abatement cost curves.[12] Many economic modelers are uncomfortable with the idea

[11] Peretz (2009) has a useful paper that further explores the scale of the investment potential in energy efficiency and the need for financial metrics that might help the market improve its evaluation of such investment opportunities.

[12] What one of us (Laitner) sometimes refers to as "the Big MACC." While the curves in Figure 5 are not drawn to any specific set of technologies, the red abatement curve reflects the approximate scale of the more conventional policy models that assume no returns from investments in abatement technologies. The green abatement curve generally reflects an assumption that as much as 40% of the emissions might be reduced with a net savings—given today's technologies and prices. Presumably, greater investments in research and development, coupled with greater levels of innovation over time, might shift both curves to the right.

of negative costs and tend to assume that all abatement measures have only positive costs. This implies that marginal abatement cost curves must, therefore, start at zero and can only rise as more of the abatement opportunities are used up. The figure illustrates, however, the availability of a large supply of emission reductions that could be achieved today at negative cost; that is, with economic savings that result from the value of reduced energy expenditures, based on currently available technology and current costs. Of further interest is that when one compares the cost of carbon dioxide reductions with the cost of energy, in fact, there is no negative cost as such. Any investment in an energy efficiency technology has a positive energy cost, as suggested earlier by the data in Figure 3. The difference is that the levelized cost of the technology is less than the purchased price of energy. Hence, what appears as a negative cost on the left or Y1 axis of Figure 5 is really an amortized cost of energy efficiency on the right of the Y2 axis.

Figure 5. Interpreting the Marginal Abatement Cost Curve



Source: Author's illustration of supply curves showing comparability of CO_2 on the Y1 or left axis costs with equivalent energy costs on the Y2 or right axis.

There are two final aspects of the evidence to briefly review. The first is associated with the non-energy benefits that typically accrue to energy efficiency investments. The second reflects the changes one might normally expect in the cost and performance of technologies over time. The evidence for these two added benefits is summarized next.

When energy efficiency measures are implemented in industrial, commercial, or residential settings, several "non-energy" benefits such as maintenance cost savings and revenue increases from greater production often result in addition to the anticipated energy savings. Often, the magnitude of non-energy benefits from energy efficiency measures is significant. These added savings or productivity gains range from reduced maintenance costs and lower waste of both water and chemicals to increased product yield and greater product quality. In one study of 52 industrial efficiency upgrades, all undertaken in separate industrial facilities, Worrell et al. (2003) found that these non-energy benefits were sufficiently large that they lowered the aggregate simple payback for energy efficiency projects from 4.2 years to 1.9 years. Unfortunately, these non-energy benefits from energy efficiency measures are often omitted from conventional performance metrics. This omission leads, in turn, to overly modest payback calculations and an imperfect understanding of the full impact of additional efficiency investments.

Several other studies have quantified non-energy benefits from energy efficiency measures and numerous others have reported linkages from non-energy benefits and completed energy efficiency projects. In one, the simple payback from energy savings alone for 81 separate industrial energy efficiency projects was less than 2 years, indicating annual returns higher than 50%. When non-energy benefits were factored into the analysis, the simple payback fell to just under one year (Lung et al. 2005). In residential buildings, non-energy benefits have been estimated to represent between 10 to 50% of household energy savings (Amann 2006). If the additional benefits from energy efficiency measures would be captured in conventional performance models, such figures would make them more compelling.

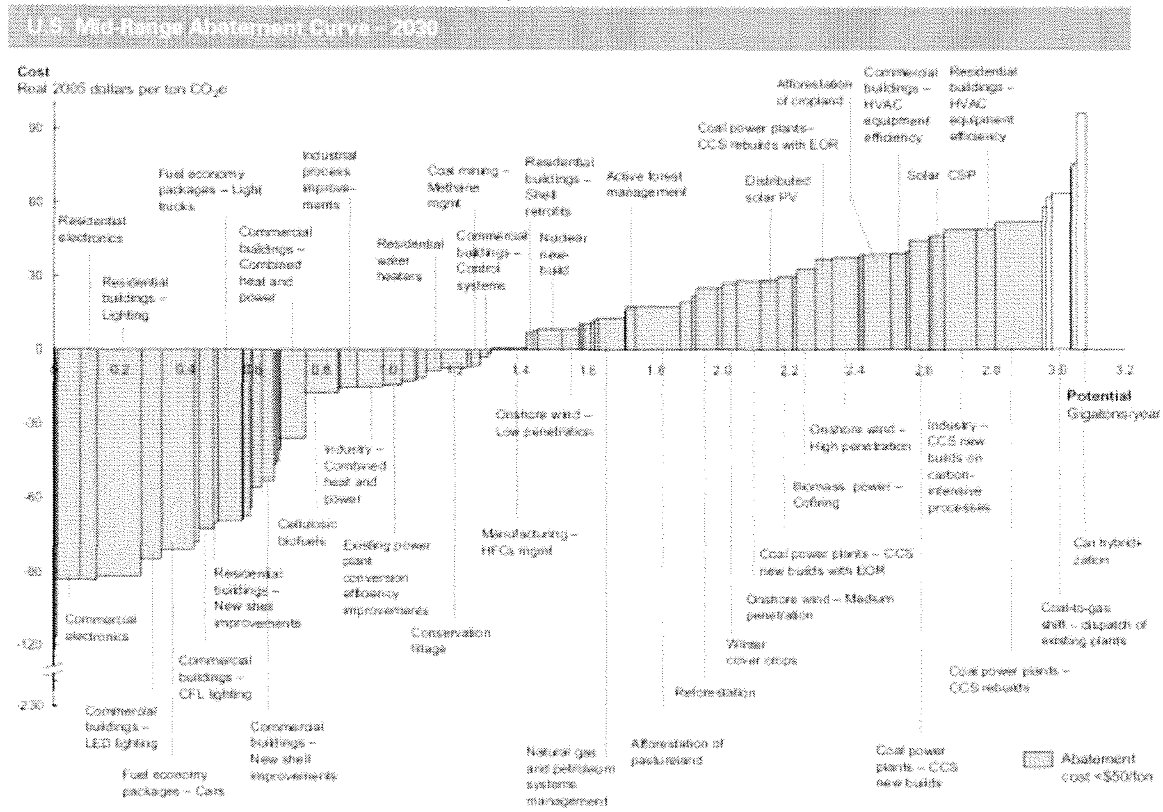
As a strong complement to the likelihood of large-scale non-energy benefits typically omitted from most energy policy assessments, there is also a significant body of evidence that indicates that technology is hardly static and non-dynamic. Laitner and Knight (Forthcoming), for example, cite more than three dozen examples of recent technologies with noteworthy declines in prices coupled with increased technology performance. Their review covers a multitude of end-uses including transportation, appliances, and consumer electronics. The rapid technological change seen especially in semiconductor-enabled technologies has led to cheaper, higher performing, and more energy-efficient technologies (Laitner et al. 2009). The increasing penetration of information and communication technologies interacting with energy-related behaviors and products suggests that energy efficiency resource may become progressively cheaper and more dynamic as the 21st century moves on (Laitner and Ehrhardt-Martinez 2008).

3. The Reality Versus Theory of Cost Estimates

Standard economic policy models have been a favorite methodological approach to evaluate energy and climate policy dating back to the 1970s and before. These models represent linkages among the many sectors of the economy as well as between the supply and demand for energy as well as other goods and services. While these models can provide some insights, in particular in elucidating the indirect effects of policies, in many ways they are inherently biased against the type of bold energy and climate policies that are consistent with sound economic policy and necessary to avoid the most deleterious impacts of global warming. They fail to value the many co-benefits associated with climate solutions, such as those we have discussed as being associated with energy efficiency measures, i.e., improved energy security, air quality, and public health. But this is a common limitation that the current analysis does not seek to remedy. More to the point, most of the standard economic policy models operate under an optimality assumption that obscures a range of important sub-optimal behaviors. Essentially, these models assume that people, firms, and markets are perfectly rational, and that markets are perfectly competitive (Laitner 2009c).

In fact, because of a range of market imperfections and market barriers, real world behavior leaves substantial room for public policy to induce behavior changes that produce economic benefits. The entire negative cost range of reductions found in the well-known McKinsey abatement cost curve exists because price signal alone is not enough. Carbon pricing, the correction of the current under-pricing of fossil fuel-based energy due to the failure of our current economic system to account for the costs of greenhouse gas emissions (i.e., internalization of the current carbon pollution externality), is a necessary but not sufficient condition for the most cost-effective package of policies. Without a robust set of complementary policies, in particular ones targeting energy efficiency gains, a host of negative and low cost emission reductions will be missed. The more stylized "top-down economic models" fail to illuminate this important lesson for policymakers.

Figure 6. The McKinsey Carbon Abatement Cost Curve



Source: McKinsey analysis
Note: The McKinsey report only examines a scenario through 2030. NRDC recommends a goal of 80 percent emissions reductions by 2050.

One classic example is the misaligned incentive that exists for those living in rental units when the renter pays the energy bills but the landlord purchases the large appliances such as refrigerators and water heaters. In this case, the purchaser of the durable good does not reap the benefits of greater energy efficiency. The Market Advisory Committee of the California Air Resources Board (2007) provides a nice short overview of key market failures.[13] A deeper exploration of the types of market barriers is beyond the scope of this report, but others have done work to map this terrain (Levine et al. 1995; Brown 2001; Levinson and Niemann 2004; Sathaye and Murtishaw 2004; Murtishaw and Sathaye 2006; Geller et al. 2006; Natural Resources Defense Council 2009; Brown et al. 2009).

It is worth noting that some economists cling to their belief of the magic of the market—and tend to dismiss the amount of negative cost emission reductions available (Goldstein 2007; Levine et al. 1995). That said, this is hardly a monolithic view. Other economists certainly do recognize the significance of market failures and imperfections beyond the lack of a price on carbon. The importance of reflecting policies that might be directed at market failures was explored, in part, by

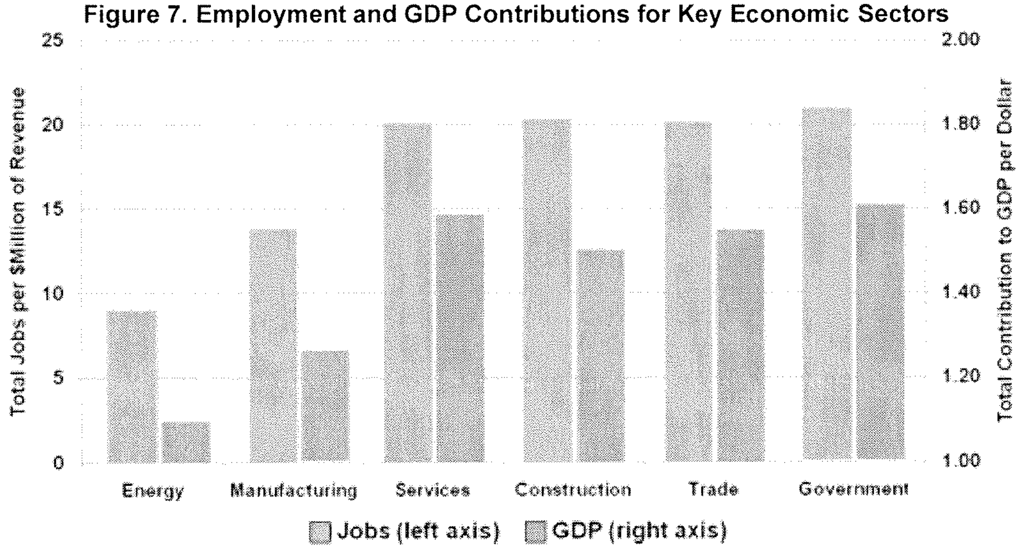
[13] Following are examples of important market failures: (1) Step-Change Technology Development—where temporary incentives will be needed to encourage companies to deploy new technologies at large scale to the public good, because there is otherwise excessive technology, market, and policy risk. Examples of remedies are renewable portfolio obligations, biofuel requirements, and the Low-Carbon Fuel Standard. (2) Fragmented supply chains—where economically rational investments (for example, energy efficiency in buildings) are not executed because of the complex supply chain. Examples of remedies are building codes. (3) Consumer behavior—where individuals have demonstrated high discount rates for investment in energy efficiency that is inconsistent with the public good. Examples of remedies are vehicle and appliance efficiency standards and rebate programs (California Air Resources Board 2007, p.19).

Hanson and Laitner (2004). In one of the few top-down models that explicitly reflects both policies and behavioral changes as a complement to pricing signals, they found that the combination of both price and non-pricing policies actually resulted in a significantly lower carbon permit price to achieve the same level of emissions reductions.

D. Evidence for the Larger Economy-Wide Benefits

As one might imagine, providing significant energy bill savings through cost-effective energy efficiency improvements would clearly benefit the economy. At the same time, it turns out that redirecting resources away from energy into almost any other sector of the economy will also amplify the number of jobs and even boost overall economic activity. So the good news, as we discuss below, is that if we do it smart, we might promote an even more robust economic future even as we dramatically increase overall energy productivity.

Figure 7. Employment and GDP Contributions for Key Economic Sectors



Source: 2009 IMPLAN data set for the U.S. economy (IMPLAN 2011)

Figure 7, above, shows two sets of economic impact coefficients for the United States. The first, looking at the vertical axis on the left, is the total number of jobs directly supported by spending within six major sectors of the U.S. economy. For example, revenues received by the different energy sectors require on average only 9 total jobs per million dollars of spending. All other sectors support a larger number of direct and indirect jobs for that same one million dollars of spending. The second, now looking at the vertical axis on the right, is the rate of the value-added or contribution to GDP that is supported for each of the major sectors of the economy. Here the data show each dollar spent on energy contributes about $1.13 cents of GDP return while all other sectors show a larger value-added benefit (see Appendix B for a more complete review of these sectoral differences and their implication for the national economy given changes in overall spending).

The state of California has had the most comprehensive and aggressive energy efficiency policies for decades. As a result, while per capita energy use has increased since 1970 in the rest of the country, in California it has fallen 18% below 1970 levels and the state's per capita electricity consumption is about 40% less than the country as a whole (Next 10 2009). Despite relatively high electricity rates, California has the fifth lowest electricity bill in the country as a fraction of Gross State Product. University of California Professor David Roland-Holst has investigated the historical macroeconomic effects of these policies. He concludes that California's efficiency programs from 1972 onward have created about 1.5 million full-time jobs with a payroll of over $45 billion and saved households $56 billion in energy costs over that same period. One causal factor is the same shift from energy-intensive economic activity to labor-intensive economic activity due to efficiency investments that we document in this work (Roland-Holst 2008). This work is also consistent with the meta-review of four dozen state and regional impact assessments completed by ACEEE (Laitner and McKinney 2008).

With the evidence highlighted in this discussion, together with other documented assumptions described in the remaining part of this report and the accompanying appendixes, we can evaluate how changed investment and spending patterns might positively impact energy production and consumption patterns for the U.S. economy as a whole.

III. Long-Term Energy Efficiency

At this point we now lay out a range of energy efficiency opportunities as they might be driven by productive investments and smart energy policies for the U.S. In this exercise we take a long view by examining the set of energy efficiency improvements as they might impact our nation's residential and commercial buildings and our industries as well as our transportation system and energy infrastructure by the year 2050. We build on both the *Annual Energy Outlook 2010* and the *Annual Energy Outlook 2011* published by the Energy Information Administration (EIA), extending its forecast from the 2035 end-year that it now reflects out to the year 2050. This business-as-usual or **Reference Case** scenario reflects more than 50 key variables that affect total energy use in the United States—including growth of the economy (measured in constant dollars as Gross Domestic Product), the set of prices that affect specific demands for energy (measured in constant 2009 dollars to reflect the base year of the model—further described in Appendix B), and the end-use or delivered energy that might be required or demanded by household and business consumers.[14] We provide two distinct scenarios for the four end-use sectors. The first scenario, referred to as the **Advanced Scenario**, assumes only the penetration of known but advanced technologies. The second scenario, which we call the **Phoenix Scenario,** incorporates other changes—including greater infrastructural improvements and some displacement of existing stock to make way for newer and more productive energy efficiency technologies. We are not saying that the Phoenix Scenario represents the limits of energy efficiency—for example, Goldstein (2009) discusses how even higher efficiency savings may be possible.

A. The Residential Sector

Our definition of the *residential sector* is that of the *Residential Energy Consumption Survey* (RECS, EIA 2005c). It includes all housing units occupied as primary residences, whether single-family, multi-family, or mobile homes. Basically, our Advanced Case technology scenario assumes very substantial changes in the performance of the building shell, its equipment, and the appliances and devices in the living space. These changes are constrained to high penetration levels of products and processes available today. In contrast, the *Phoenix Scenario* assumes foreseeable improvements not yet commercially available.

[14] There is one important caveat to be kept in mind when examining the emerging findings of these various sector reviews. Our sector assessments only "benchmark" to the EIA *Annual Energy Outlook* (AEO). We did not actually run the EIA's National Energy Modeling System to generate an exact match of the Reference Case assumptions typically found in the AEO. First, as noted, the AEO extends only out to the year 2035 rather than 2050. Nor does it have the capacity to integrate the kinds of changed technology assumptions and characterizations envisioned here. For these and other reasons, we looked to the AEO as a means to generate an internally consistent set of energy consumption patterns within each sector that are also linked to an expected set of economic and engineering variables. This, in turn, provides us with reasonable set of Reference Case outcomes that—given the kinds of changes we describe elsewhere in this study—enable us to compare the two alternative high efficiency energy scenarios with the business-as-usual projection. In this way we are able to evaluate the impacts of the high efficiency paths for their potential benefits to the larger economy (see Appendix A for a further discussion of this perspective). Consistent with the philosophy of Stanford University's Energy Modeling Forum (Huntington et al. 1982), we are modeling for insights rather than exact numbers—or in this case, evaluating reasonable differences between sector assumptions as we explore possible benefits to the U.S. economy.

For example, we assume that the remaining heating loads in both scenarios are met with advanced equipment and improved distribution systems (see Table 1).

Table 1. 2050 Advanced Technology and Phoenix Case Heating Technologies

	2050			
	Advanced		Phoenix	
Parameter	**Gas**	**Electric**	**Gas**	**electric**
Average AFUE	1.0		1.3	
Electric heat effectiveness		3.0		4.0
Relative system efficiency	1.5	3.8	2.0	5.0
Source Quads to meet 2010 loads	2.1	0.3	1.6	0.2
Heat Provided				
Market Share (%)	40%	60%	30%	70%
HVAC by fuel (quads)	0.4	0.4	0.2	0.5
Total heating (quads)	0.8		0.6	

Notes: AFUE is a measure of the annual efficiency of a heating season, averaged over different operating conditions. "Electric heat effectiveness" is analogous to a system coefficient of performance (COP). "Relative system efficiency" includes distribution efficiency, load following, etc.

Notice that the 2050 heating market moves from a 40%/60% share in the gas/electric mix in the Advanced Scenario, to a 30%/70% share in the Phoenix Scenario. Where gas is used, we stipulate combination gas space and water heating equipment with performance equivalent to today's condensing equipment (that is, equipment that provides useful services from more than 90% of the heat value). For Phoenix, we use a higher criterion, performance that could be achieved by gas heat pumps (engine driven or absorption), comparable to a COP of about 1.3 for gas-heated houses (COP means Coefficient of Performance, the unit-less ratio of output energy to input energy). In both , we achieve dramatic electric heat savings by eliminating resistive heating, instead using advanced air source and ground source heat pumps in the two . We did not assume any residential gas air conditioning, for either scenario.

The overall approach in the residential sector begins with estimating the housing stock changes that might be anticipated over the study time horizon, in this case 2012 through 2050. These changes include increases in the total number of households as well as the numbers of single family, multifamily, and mobile homes for both the Advanced and Phoenix . From this, we look at the building energy loads and explore feasible changes in both new construction and in retrofits to existing homes.

We start with building shell load reductions, stipulated as in Table 2.

Table 2. Percent Shell Load Reduction Relative to Today's Practice

	Heating		**Cooling**	
	New	Existing	New	Existing
Advanced	70%	40%	70%	40%
Phoenix	90%	55%	90%	60%

These large shell load reductions leave us to be relatively indifferent about the actual ratios of single-family to multi-family: As the fraction of shared walls rises, the dependency on actual insulation levels decreases, Intuitively, for the same floor space per household, given the complexities of large multifamily systems, there is probably little difference between highly efficient single family detached, town houses at 15–20 per acre, and multi-story multifamily buildings.

We postulate large improvements in the energy use of products governed—or likely to be governed—by efficiency standards. Table 3 shows our estimates of improvements in energy needed for these functions, as a fraction of our baseline.

After establishing the likely 2050 patterns for the projected housing stock (number, type, and size of homes), we then consider technologies to meet the small residual loads. Throughout, we allow ourselves to extrapolate modestly from today's emerging technologies and practices, and provide examples of technologies that could meet those needs in a more energy-efficient manner.

Some key assumptions:

- We have not changed the total number of housing units from those found in the EIA projections. In contrast, we did reduce Phoenix commercial space by 20%.
- In both , we have moved half of the present mobile home population into single family or multifamily units—effectively postulating that the pre-2030 or so mobile homes are replaced by units built to the same performance specifications as single family and multi-family homes. These could be very efficient mobile homes, or other manufactured housing. This should be possible, since the expected life of mobile homes is shorter than the other stocks. Note that we have not assumed any specific average housing density, but only that shell loads are reduced enough that it matters relatively little whether the boundaries of housing are other units or ambient air and solar loads.
- We assume different load reduction fractions associated with the building shell or envelope in the Advanced and Phoenix Scenarios, making an appropriate distinction between both new and existing housing (Table 2, above).

1. Further Details

Our analysis of the residential end-use sector begins with ACEEE's estimate of the 2050 housing stock as an extrapolation from the EIA projections for 2035. For both, we moved half the mobile home stock into single family, and half into multifamily. The mobile home stock turns over relatively quickly, so we assumed that the remaining mobile homes were built to the same shell efficiency standards as the other categories—that is, the obsolete HUD Code has given way to a proper and more efficient set of building codes. The mix of high-rise and small multi-family and their respective energy intensities is taken from the Department of Energy's Building Energy Data Book (BEDB) (DOE 2009). For the single family housing stock only, we estimate that median house size reverts to the 2010 median from the extrapolated 2050 value, but this is subsumed in the appropriate adjustments to the building shell loads.

Internal gains. Internal gains reflect heat dissipation by people, pets, appliances, lighting and all the entertainment and information equipment in the house. We have moderately reduced this in both . This assumes that further improvements in the efficiency of appliances (refrigerators, clothes washers, etc.) will be offset in part by new energy uses, such as greater use of electronic devices (such as voice-activated energy management systems).

Shell loads. For both , we could have justified starting with the assumption that all housing in 2050 was built or retrofitted to roughly "Passivhaus" standards, which imply 90% reduction in total energy use (Klingenberg et al. 2008). Instead, we reserved the "Passivhaus" assumption for new construction in the Phoenix Scenario:

To achieve these reductions in the shell load in existing houses, we assumed external insulation would be required in some houses. However, the most common, post-war, types of residential units could generally be done with proper internal work to insulate walls and all other edges of the thermal envelope. We explicitly assume that there are no ducts or other energy carriers external to the building shell in 2050. These changes reduce shell loads to a fraction of or small multiple of the internal gains from lighting, appliances, other electricity-using gear, and people. Note that internal gains/loads reduce heating energy required, but add to cooling energy required to remove the internal loads and maintain comfort.

With today's construction and retrofit technologies, and current energy prices, the aggressive new construction and retrofit technologies we assume might have paybacks measured in scores of years. Thus, our assumptions rest on some future combination of three assumptions: (a) higher energy prices that are perhaps due to carbon constraints or the simple depletion of high-grade natural resources; (b) other benefits, discussed below, that go a long way to offset the higher energy efficiency premium cost; and (c) a re-invention of the construction industry that generates significant cost savings. Other benefits can be substantial and include improved occupant comfort from homes without drafts and cold spots, easier-to-clean windows, and reduced fabric fading as new windows generally reduce ultraviolet light that causes fading. Cost savings can be readily visualized for new construction, where "stick-built" homes will give-way to "mass customization" using industrial processes which lead to "installer-proof," high-performance, building shells that require relatively little equipment to satisfy comfort needs. For existing construction, we anticipate great savings from economies of scale as the industry learns the least-cost ways to achieve high performance for all the different building stocks.

Non-energy code end uses. We made estimates based on trends and best available current technologies for loads covered by present or anticipated energy standards (refrigeration, cooling, dryers, freezers, lighting, clothes washers, dishwashers, TVs, set-top boxes, PCs and related), and for "other miscellaneous uses." Together, these groups are projected to need 9 quads, almost ¾ of the total estimated use in 2050. Of this, "other" or "miscellaneous loads" is 5 quads by itself, about 40% of the total of 13 quads. "Other uses" includes set-top boxes, televisions, other audio and video equipment, ceiling fans, coffee machines, microwave ovens, portable electric spas, rechargeable electronics, and security systems (TIAX 2006). It would also include hobby equipment (power tools, sewing machines, home ceramic kilns), and hot tubs.

Heating, ventilating, and air-conditioning. We assume that gas and electricity are both still used as "prime movers" for space conditioning and water heating, in both scenarios in 2050. All equipment, whether gas or electric, is multi-function (e.g., ventilation + space and water heating; space conditioning and water heating. All has variable output to match loads with minimum cycling. In general, modulation improves equipment efficiency by giving larger effective heat exchanger surface areas at loads lower than the design peak. As important, in 2050 there are no longer any low-performance ducts in any buildings. Ductwork has been brought inside the thermal envelope or abandoned in favor of hydronic equipment (with local fan-coil units) or "multi-splits" that carry energy via refrigerant phase-changes.

We implicitly assume that multi-function appliances are prevalent by 2050, with gas appliances providing space and service water heating where natural gas is used. Electric heat pumps provide air conditioning, as well. The incremental savings from reduced equipment cycling for combo appliances do not show up in the granularity of this analysis. For the Advanced Scenario, the equivalent seasonal heating efficiency moves from <0.81 today (including distribution losses) to 1, reflecting abandonment of non-condensing heat appliances, with some penetration of triple-function gas heat pumps. The Phoenix Scenario assumes widespread use of advanced gas HP with an equivalent 1.3 AFUE (Annual Fuel Utilization Efficiency),[15] Similarly, resistance electricity is essentially completely replaced by advanced heat pumps, both air-source and ground-source. We assume "fleet" average for the Advanced and Phoenix Scenarios that are respectively 3.0 and 4.0 times higher than the current electric fleet consumption, with its high penetration of resistance heat (including electric furnaces).

By 2050, distribution energy losses have been essentially eliminated primarily due to a fairly large shift from duct work to energy delivery in hydronic and refrigerant-based (multi-split) systems. With

[15] AFUE (Annual Fuel Utilization Efficiency) is the federal efficiency metric. It is a seasonal value.

greatly reduced shell loads, energy distribution to avoid hot and cold spots is less important, but we visualize both multi-split and fan-coil of zoned hydronic heat pump systems as handling energy distribution in most housing units. The remaining ducted systems are entirely within the thermal envelope by design or from retrofits to the existing stock.

Traditionally, houses used window-opening and spot fans (bath and kitchen) for ventilation. New energy standards require or credit mechanical ventilation. Today, (excess) ventilation is considered to account for 1/3 to ½ of average annual HVAC cost. Tightening buildings and installing mechanical ventilation will reduce this cost significantly, but the effect is implicitly included in our HVAC treatment.

Furnace fans & pumps. These move energy and introduce ventilation air. For 2050, we greatly reduce the fraction of houses with forced-air distribution systems. To compensate, water-based energy distribution almost doubles, and "other" systems increase greatly. This reflects large expected growth of energy distribution by refrigerants/phase changes (multi-split systems). This will proceed because the systems require less space in the house, perform well, and have no distribution losses (more specifically, distribution energy is fully reflected in the efficiency rating). In addition, it is much easier to abandon ductwork in favor of hydronic and refrigerant energy distribution, because the latter systems have much smaller size and "footprint" in the building, facilitating installation with minimum décor disruption.

Water heating. We assumed gas, electricity, and solar contributions for water heating. For gas use, we are implicitly considering integrated space and water heating appliances, with EF (Energy Factor) of condensing appliances in the Advanced Case (EF 0.85 from a mixture of tank and tankless approaches), and gas heat pumps in the Phoenix Case (EF 1.3). We assign an effective EF of 5 to solar, corresponding roughly to a solar fraction of 0.8.

Our water heating energy treatment also includes significant improvements in distribution efficiency, that is, the losses of hot water energy in the distribution pipes of a house. We use conservative values (in the range of 80%), with different values for new construction than for the existing stock. Similarly, we assume moderate further improvements to fixture (faucet, showerhead) efficiency, using the EPA WaterSense requirements as our basis. Note that we are assuming no significant market penetration of hot water uses that are not prevalent today, such as heated indoor lap pools, or much wider use of hot tubs. In both, we implicitly assume that most new construction includes drainwater heat recovery from showers, a promising heat recovery application.

What's missing? We did not explicitly include solar space heating. Passive (solar) gains are implicit in advanced glazing and overhangs where appropriate for shading, but we do not explicitly offset the small fuel requirements with a solar fraction. Given the magnitude of the residual shell loads of very well-constructed houses, we find little justification for the use of active solar systems.

2. Reference Case

With this background, we can consider how energy is used in the Reference Case. The Reference Case is based on the EIA 2010 *Annual Energy Outlook* (EIA 2010a), but since this does not extend past 2035, ACEEE has estimated energy use to 2050 by extrapolating from the growth rate over the 2030-2035 period. Table 3 builds up energy use and energy use intensity (Btu/sf) for 2050, based on this extrapolation. We have done the extrapolation by energy service (heating, cooking, etc), and the color codes isolate "Energy Code" (tan), "Standards" (pale green), and "Unregulated" (pale yellow) loads.

Table 3. Residential Building Energy Use, by Service, 2010 and 2050

Service:	Reference Case (Quads)		EUI, Btu/sf-yr		EIA Growth Factor
	2010 total	2050 Total	2010	2050	
Space Heating	5.4	4.9	28,000	13,200	-52.9%
Space Cooling	2.4	3.4	12,500	9,100	-27.2%
Water Heating	3.0	3.1	15,200	8,400	-44.7%
Ventilation (not in RECS)	0.0	0.0	-	-	
Refrigeration	1.2	1.4	6,000	3,700	-38.3%
Cooking	0.6	0.8	3,000	2,100	-30.0%
Dryers	0.9	1.1	4,800	3,100	-35.4%
Freezers	0.3	0.3	1,300	800	-38.5%
Lighting	2.3	1.3	11,800	3,500	-70.3%
Washers	0.1	0.1	500	200	-60.0%
Dish Washers	0.3	0.4	1,500	1,100	-26.7%
Television & Set-Top Boxes	1.2	1.8	6,100	4,900	-19.7%
PCs and Related	0.6	0.7	3,100	1,900	-38.7%
HVAC Fans & Pumps	0.5	0.7	2,400	1,800	-25.0%
Other Uses	3.0	5.9	15,400	16,000	3.9%
Subtotals					
"Energy Code" Loads	14	13	69,900	36,000	
"Standards" Loads	5.1	7	26,300	17,800	
Other Uses	3.0	6	15,400	16,000	
Grand Total	22.1	21.7	111,600	69,800	

The "Quads" columns are per-service expectations. "EUI" columns divide total energy by EIA 2010 total residential square footage (sf) and the ACEEE extrapolation for 2050. The right-most column, "EIA Growth Factor," reflects and extrapolates the EIA judgment of the effects of technology changes on the specific energy use category, divided by EIA's stipulation of residential building floor area and the ACEEE extrapolation. For example, space heating loads decrease from 28,0200 Btu/sf in 2010 to 13,200 in 2050.

Consider the "energy code" loads, highlighted in tan. The extrapolation from EIA 2035 indicates aggressive efficiency improvements in the baseline energy use: 27% (cooling) to 70% (lighting), resulting from EIA's assumptions on technology changes. Similarly, EIA projects large changes in the "standards" loads for equipment and appliances regulated by DOE (highlighted in light green): the typical improvements reduce energy use by one third, with much more (60%) for dryers. Only "other uses" grow modestly. This category may include water treatment and delivery, and certainly includes all of the electronics and "hobby" loads that are not subject to regulation by DOE.

3. Advanced Scenario

Table 4 presents ACEEE estimates for the Advanced Scenario. In these estimates we use today's best available technologies and those readily foreseen as commercially viable for all residential buildings. This implies an aggressive, mandatory, retrofit program to bring all existing buildings up to the level of performance shown in Table 2 by 2050. Such a program might be financed by a PACE-type mechanism,[16] with investments amortized on the property tax bill and any residual obligation at time of sale transferred with title.

[16] PACE is Property Assessed Clean Energy and refers to a mechanism to lend money to homeowners and have

Table 4. Code, Standards, and Other Loads in the Advanced Scenario

Service	Reference Case (Quads) 2010 total	Reference Case (Quads) 2050 Total	Advanced Case (Quads) 2050 total	% of 2050 Reference Case
Space Heating	5.4	4.9	0.47	10%
Space Cooling	2.4	3.4	0.54	16%
Water Heating	3.0	3.1	2.32	75%
Refrigeration	1.2	1.4	1.03	75%
Cooking	0.6	0.8	0.72	90%
Dryers	0.9	1.1	0.17	14%
Freezers	0.3	0.3	0.23	75%
Lighting	2.3	1.3	0.42	33%
Washers	0.1	0.1	0.06	71%
Dish Washers	0.3	0.4	0.37	91%
Television & Set-Top Boxes	1.2	1.8	0.84	46%
PCs and Related	0.6	0.7	0.30	42%
HVAC Fans & Pumps	0.5	0.7	0.28	42%
Subtotals				
"Energy Code" Loads	14	13	3.6	27%
"Standards" Loads	5.1	7	4.1	62%
Other Uses	3.0	5.9	5.34	90%
Grand Total	21.7	25.9	13.1	51%

Building code loads. The first observation is that about 90% of **space heating loads** are eliminated. The combination of outstanding building shells and advanced technologies allows almost all buildings to be heated by internal gains, combination water heating equipment, and other advanced technologies. We essentially eliminate duct losses by placing ducts in conditioned spaces or in favor of heat transport by refrigerants and water, dramatically reducing inefficiencies. As a corollary, the percentage **space cooling** reduction is smaller, since the internal loads of houses still must be dissipated. In this scenario, space cooling and space heating are about equal at ½ quad per year, while heating is twice as large in 2010. Conversely, we reduce water heating energy use relatively little, to 75% of the EIA extrapolation. Our Advanced Scenario looks at large-scale replacement of electric resistance with heat pump water heaters, but there are much smaller changes in the transition from atmospheric to condensing gas.

Standards loads, in our advanced projections, drop to 62% of the Base Case. Lighting loads decrease 67% from universal replacement of today's incumbent technologies with solid state lighting. In the residential sector, we do not assume additional savings from major changes in lighting "ambience." For example, we do not assume diffuse glowing ceilings providing ambient lighting, supplemented by task lighting as desired. We note that residential lighting may "turn over" more quickly than water heating or space conditioning. Dryers also improve by a remarkable 86%. In this case, was are assuming transitions to modulating gas burners and complete replacement of resistance electric dryers with heat pumps. We do *not* require "solar dryers," also known as clothes lines.

Other loads. We reduce the EIA projections for these miscellaneous energy uses by 10% in the Advanced Scenario. We can likely produce more efficient lawnmowers, electronic games, hobby equipment, and the like, but for now as a conservatism, have only included limited such changes in

the loan payment be included in property taxes.

our analysis. Additional savings in these areas can be used to make-up for areas where a reader may feel we have been too aggressive in our savings assumptions.

4. Phoenix Case

Table 5 presents ACEEE estimates for residential energy use in the Phoenix Scenario. The Phoenix Scenario deviates from the Advanced one in a few respects: First, we reduce weatherized (heated) floor space to 85% of the value used in the Base and Advanced Cases, assuming that smaller households (and more expensive energy) will reduce the fraction of very large houses. Second,, we assume more efficient technologies, such as gas heat pumps. This includes virtual elimination of equipment outside the thermal envelope (except condensers), and reduction of distribution losses to *de minimus*. For this, we substitute hydronic and refrigerant energy distribution for ducts and fans. Small fans and ducts are only used for ventilation and some air movement for comfort.

Table 5. Residential Energy Use Components in the Phoenix Scenario

Service	Reference Quads			
	2010 total	2050 total	Quads total	% of EIA 2050
Space Heating	5.4	4.9	0.2	5%
Space Cooling	2.4	3.4	0.3	10%
Water Heating	3.0	3.1	1.0	31%
Ventilation (not in RECS)	0.0	0.0		
Refrigeration	1.2	1.4	0.7	50%
Cooking	0.6	0.8	0.6	70%
Dryers	0.9	1.1	0.1	11%
Freezers	0.3	0.3	0.2	50%
Lighting	2.3	1.3	0.4	33%
Washers	0.1	0.1	0.1	71%
Dish Washers	0.3	0.4	0.4	91%
Television & Set-Top Boxes	1.2	1.8	0.8	46%
PCs and Related	0.6	0.7	0.3	42%
HVAC Fans & Pumps	0.5	0.7	0.2	28%
Subtotals				
"Energy Code" Loads	14	13	1.7	13%
"Standards" Loads	5.1	6.6	3.5	53%
Other Uses	3.0	5.9	4.8	80%
Grand Total	21.7	25.9	10.0	39%

Building code loads. The loads are dramatically reduced, with aggressive assumptions that include:

- "Perfect" building envelopes and more shared-wall construction that reduce heating loads to little more than the internal gains of the housing.
- Complete elimination of energy distribution in air (except as part of ventilation); this is replaced by refrigerant and hydronic energy distribution.
- All gas space and water heating is built around "combo" gas heat pumps that provide both services; electric space and water heating also uses multifunction heat pumps. We implicitly include solar hot water boost supplemented with point-of-use water heating, just by the aggressive efficiency multipliers we use.
- Lighting is completely solid state, and meets or exceeds 165 lumens/watt (compared to the best fluorescent lighting systems sold today which are around 100 lumens per watt.

For the "standards" loads, we take varying approaches, as shown in the table. We assume very large reductions in cooking and refrigeration, in part technology driven and also assuming increased use of foods that have been irradiated and pre-cooked, which do not require refrigeration for preservation, or conventional cooking preparation. On the other hand, we will still want some refrigeration for food that tastes better cold or frozen (ice cream, ice, white wine, orange juice). Note that we allow a margin of error by not reducing freezing energy relative to the EIA extrapolation. We assume that much of the cooking will be microwave—but that households will still have stoves for special food preparation.

Miscellaneous loads. In the Phoenix Scenario, we decrease these from the Base Case by 20%, as contrasted with the 10% reduction in the Advanced Scenario. We are conservative because we are confident that many of the existing loads (service station and medical equipment, for example) can be made more efficient, but over four decades we anticipate a host of new "other" energy consuming appliances and equipment. While these new other loads are included in the Reference or Base Case, our conservative estimate of savings here allows room for potential additional growth in miscellaneous loads.

5. Discussion

Our analysis suggests a potential reduction in residential energy use by an estimated 49 to 61% for the Advanced and Phoenix Scenarios, respectively.[17] These savings estimates are larger than are typically found in most nearer-term assessments, but with nearly 40 years to implement these, more systematic changes are possible. Actual energy use could be much higher if the policy environment and energy prices do not force major changes in how buildings are constructed, and enable deeply retrofitting the existing stock.

Figure 8 illustrates these changes as stacked bars, as labeled. The first set, EIA 2010, is the set of initial conditions. The three other bars are 2050 cases. "EIA" is ACEEE's extrapolation from the 2035 EIA projection. "Advanced" and "Phoenix" Cases are our study cases. On each bar, the uppermost (light green) segment or band represents "Standards" loads, those that are or can be regulated by standards for equipment and appliances, whether boilers or computers. Standards loads drop by 38% and 47% in the respective cases.

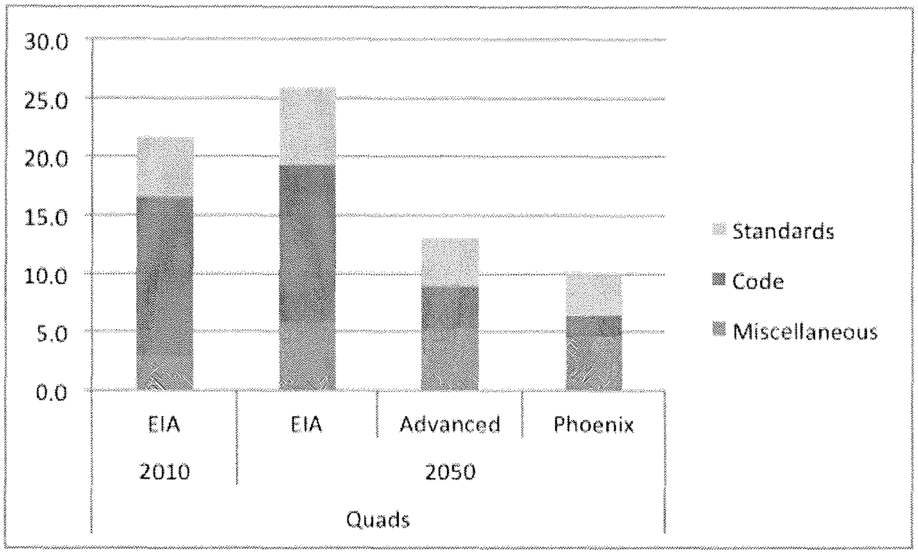
The middle band represents the loads regulated by building energy codes. It accounts for most of the changes in energy consumption in our cases, with 73% and 87% reductions. These are the direct result of our assumptions about improved envelope quality, and large changes in space conditioning and hot water services (including delivery). These changes are large in comparison with those in current energy codes that are considered aggressive, such as the IECC 2012. However, our estimates are not constrained by current cost-effectiveness but reflect our judgment of technical and economic feasibility at a large scale, given enough time. In context, they are less stringent than the current Passivhaus specification, which requires 90% reductions in *total* building energy use (Klingenberg, Kernagis, and James 2008).

Finally, note that the lowest bar segment, "miscellaneous" loads, only modestly changes—and the changes are exogenously forced by our model inputs. As discussed above, these are poorly understood and highly variable residential loads and we use conservative assumptions to allow for potential new loads not yet a part of American homes. We can characterize them as everything that has a plug, but is not a regulated appliance. Notable examples include "set-top boxes" that interface televisions and computers to high bandwidth connections (evolved from cable "boxes"), advanced game consoles, heated fish tanks (and other pet gear), battery chargers, and innumerable types of hobby and home business equipment. Thus, in the Advanced Case these miscellaneous loads are about half of residential energy consumption, and 60% in the Phoenix Case. Clearly, these areas

[17] Please note that these values are different from the values reported in Table 17 since the values reported here do not include improvements in the efficiency of the electricity generation, transmission and distribution system while the values in Table 17 do include electric system improvements.

require much further study, and the creation of mechanisms to assure that their energy use (active, standby, and off) is commensurate with their value to consumers.

Figure 8. Projected Residential Energy Use by Category in the 2010 and 2050 Cases



B. The Commercial Sector

This section provides an overview of the methods used for estimating energy use for commercial buildings in the Reference Case, in the 2050 Advanced Case and the Phoenix Case. We first extrapolate from the 2035 Energy Information Administration (EIA) forecast to 2050 (our baseline scenario), to understand the assumptions about technology improvements and other changes built into EIA's National Energy Modeling System (NEMS). Based on technology assumptions for the Advanced Scenario, we then change the energy intensity of the technology services for each end use. For the Phoenix Scenario we further adjust total expected commercial sector floor area to reflect a change in the expected demands for energy services. We also apply different improvement coefficients for some specific end-use service applications in both.

Our definition of the *commercial sector* is that of the *Commercial Building Energy Consumption Survey* (CBECS, EIA 2008). It includes all commercial buildings, in classes including education, food sales, food service, health care, lodging, mercantile, office, public assembly, public order and safety, religious worship, service, warehouse and storage, and others. Basically, our *Advanced Case* technology scenario assumes very substantial changes in the performance of the building shell, its equipment, and the appliances and devices in the living space. These changes are constrained to high penetration levels of products and processes available today. In contrast, the *Phoenix Scenario* assumes foreseeable improvements not yet commercially available.

For example, we assume that the remaining heating loads in the Advanced Scenario are met with combination gas space and water heating equipment with performance equivalent to today's condensing equipment (that is, equipment that provides useful services from more than 90% of the heat value, including latent heat, of the fuel). For Phoenix, we use a higher criterion, performance that could be achieved by gas heat pumps (engine driven or absorption), comparable to a COP of about 1.3. In both, we achieve dramatic electric heat savings by eliminating all resistive heating, instead using advanced and even more advanced (air source and ground source) heat pumps in the two . We did not assume any gas air conditioning, for either scenario.

1. Some Key Assumptions

Building characteristics. As discussed in the Methods section below, we aggregate the eight size classes and fifteen building use types of EIA (2005b) into three building categories: Small, medium, and large. In the Advanced Case, the total floor space is based on extrapolation from the NEMS 2035 estimate to 2050, as used throughout this project. For the Phoenix Case, we reduce total commercial space from 71,700 million square feet to 57,400 million sf, or 80% of the Advanced Case value. We also modestly redistribute floor area fractions among the size classes, allocating relatively more space to medium-sized, community-scale buildings than to the largest ones. This change corresponds to expected "densification" of commercial space in response to an energy- and carbon-constrained world. Some might argue that current trends in "telecommuting," and internet purchases instead of "brick and mortar" stores would allow a larger change in the projected commercial building space. They might point out trends in religious attendance decreasing that sector, and large expected changes in education as also impacting space needs. We have chosen to not make these assumptions, noting that they would allow additional savings beyond those calculated here. Table 6 summarizes our assumptions.

Table 6. 2050 Commercial Building Characteristics

Floor Area and Technology Assumptions			
Class by size	**Small, <5000 sf**	**Medium, 5000 to ~35,000 sf**	**Large, > ~35,000 sf**
Number in size class (thousands)	2600	1900	400
Percent of total buildings	54%	39%	8%
Floor area (millions of square feet)	6900	24400	40400
Floor space distribution, Advanced	10%	34%	56%
Floor space distribution, Phoenix	10%	45%	45%
New building construction	SIP-like facades or exterior insulation, super windows or restricted glazing area		
HVAC	"Residential"	Unitary	Built-up
Ventilation	HRV-ERV	HRV-ERV	Advanced
Service water heating	POU	POU	Varies
Number of floors	1 or 2	1 or 2	Multi
% of floor area with daylighting, new & existing buildings	0.6	0.5	0.1
Artificial lighting, lumens/Watt	165	165	165

Notes: 2050 Advanced Scenario uses the baseline floor area and space distributions. Changes in Phoenix Scenario noted in table. "SIP" is "Structural Insulated Panel, a well-established residential technology with analogues for larger commercial buildings. "HRV-ERV" means Heat Recovery or Energy Recovery Ventilator, depending on whether latent heat recovery is included. "POU" means point of use water heater, as contrasted with central system with distribution piping.

According to the Federal Energy Management Administration (FEMA), "[t]he effective life of an office building is 20 to 30 years, after which major renovation and updating is normally necessary" (FEMA 2004). There is certainly a "long tail" of commercial buildings that are not renovated this frequently, such as houses of worship and commercial buildings in distressed areas. We infer that short service lives between major renovations are normative. Thus, our working assumption is that commercial buildings can be brought to very high performance levels by 2050. For existing buildings, this is demonstrably feasible in almost all cases with exterior insulation of exposed walls. New buildings, even high rise, can also include exterior insulation that is thermally isolated from the structure (Lstiburek 2007).

How big is this "long tail"? For this question, we examine the "AEO 2010 Extended to 2050" Reference Case. Table 7 summarizes the calculations:

Table 7. Estimates of New Construction as Fraction of the Total 2050 Commercial Building Stock

	New Construction	
Since	Billion sq. ft.	% of 2050 stock
2010	97.3	73%
2020	77.5	58%
2035	40.9	31%

For this study, we have assumed that the 2050 stock is 46% post-2028 (and hence subject to our new construction assumptions), and 54% is existing. We further assume that major retrofitting has been done by 2050 on the existing stock, so its shell loads are only 20% greater (per unit of floor space) than those of the best codes for new construction. This leads to savings in the "[building] codes" loads of 59% in the Advanced Scenario, and 66% in the Phoenix Scenario.

HVAC and ventilation. We assume a characteristic HVAC system type for each building size class: "residential" for buildings up to about 5000 sf, "unitary" (principally roof-top units today) for medium buildings, and "applied" or built-up for buildings larger than about 35,000 sf. In both , air-based energy distribution is largely replaced by some combination of hydronic, hydronic/electric (water-source heat pump), and refrigerant-based (VRV, multi-split, etc). Roof-top units as we know them today vanish from the U.S. building stock. For our purposes, we subsume ventilation within heating and cooling. Moving air through ducts is limited to ventilation needs. In general, ventilation still requires moving air with fans, but it may also benefit from major changes in technologies. Examples include gas-phase air filtering, used in some casinos today, and liquid desiccants for latent control, particularly in humid climates (Sachs et al. 2009).

Building envelopes. We assume that we can make envelopes so good that there is no longer need for dedicated space heating, in any size of building.[18] That is, the total commercial building heating requirement is met by internal loads from lighting, people, and installed equipment. We build such a scenario around optimized advanced glazing, excellent infiltration control, and appropriate insulation of the surfaces for each building size classes. For small buildings, this is readily done, as with the PassivHaus methods successfully deployed in over 10,000 buildings in Europe (Klingenberg, Kernagis, and James 2008).

As buildings become larger, in general the surface area to volume ratio decreases, so internal heat gains meet an ever larger fraction of heating needs. Today's largest buildings combine perimeter heat losses with excessive core heat gains, so better facades and energy distribution will reduce their heat losses to values lower than the internal heat gains. So, as a first order approximation, heating energy can be driven to zero.

On the other hand, such a zero-heating building still may have significant cooling loads to dissipate the internal heat gains and residual solar gain through windows. Thus, the cooling energy requirement in an Advanced Scenario depends on changes in envelope gains and internal loads. As noted above, we assume that existing buildings have 20% higher "code" or shell loads than new buildings (see Table 7).

Other building loads. "Miscellaneous" loads that are not now subject to either building codes or equipment standards account for one-fourth of today's commercial building energy use, and more than one-third of the total in our 2050 Base Case (extrapolation from EIA 2035). As discussed below,

[18] Of course, this is not true for the smallest buildings, those in the 1000–5000 sf range. Although numerous, they are less than 10% of total commercial floor space (EIA 2008Table A1), and 11% of space heating energy use (EIA 2008, Table C1).

these loads have not been studied carefully, but include things as varied as "water services" (the embodied energy in water supply, distribution, and treatment for commercial buildings) and miscellaneous small-scale manufacturing in commercial buildings. The category inherently includes amenity and productivity loads that are pervasive by 2050, although not even thought of today. To keep these loads from dwarfing the "regulated" loads addressed by codes and standards, we have exogenously forced growth limits on these categories. We assume that these loads are 80% of the EIA 2050 extrapolation in the Advanced Scenario. For Phoenix, we decrement this by the 80% total commercial building floor area assumed for that scenario, so other loads are about two-thirds of the EIA extrapolation. These categories warrant much more study.

Lighting. Typical commercial lighting today might operate with 80 lumens per watt. We assume that the DOE solid state lighting goal of 165 lumens per Watt is achieved, and that lighting this good or better is ubiquitous. This seems feasible, particularly with our conservative assumptions about the penetration of daylighting. In addition, we do not explicitly require widespread adoption of low ambient/high task lighting strategies. With these assumptions, we do not need to worry about the "long tail" of obsolete lighting in commercial buildings, or the special needs of retail display.

Investments. We do not apply any benefit-cost test in this study. Instead, we assume that exogenous factors (resource scarcity, carbon policy, etc) increase the effective price of energy, and thus warrant major investments in redevelopment, deep retrofits, and new approaches to construction that design in quality (and efficiency) instead of attempting to "inspect in" at the job site. And as we gain better experience with deep retrofits, we will find the most cost-effective techniques, allowing these retrofits to be cost-effective at times of major building renovations, aided with advanced financing such as property-tax-based loans, as discussed in the residential section.

2. Methods

Classes of commercial buildings. In the EIA *Commercial Building Energy Consumption Survey* (CBECS), commercial buildings are divided into eight size categories from less than 5,000 square feet to more than 500,000 square feet (sf). For purposes of this assessment, we aggregated the buildings into three size-based categories as shown previously in Table 6.[19]

We should note that more than half of the commercial buildings are very small, less than about twice the size of the typical new house. Conversely, more than half of the total commercial floor space is in "skyscrapers," buildings with floor area greater than 500,000 square feet (about 11 acres) (EIA 2005b).

Although the boundaries between classes are not extremely sharp, this classification exploits some fundamental differences in building characteristics:

- Small buildings are generally low-rise, built like residential structures, and served by residential-type HVAC and water heating equipment. We doubt that many have mechanical ventilation systems, but instead they generally rely on window-opening for ventilation.
- Medium buildings are also generally low-rise (so a large fraction can install roof-based daylighting), but use unitary or applied HVAC equipment, typically "RTUs" (roof-top units).
- Large buildings are generally mid- to high-rise, and served by "applied" or "built-up" HVAC systems, typically with chillers as the prime energy converters. Because they are multi-story, there is much less daylighting potential—only perimeter areas and the top floor.

Clearly, this oversimplifies the world of commercial buildings. For example, "big box" buildings and warehouses are typically in the large size category, but can adopt daylighting where needs justify it, and are generally served by RTU HVAC systems. Conversely, a large number of elementary and

[19] We have divided number of buildings and total area in the 25,000 to 50,000 square foot CBECS class equally between the medium and large size classes.

other school buildings in the medium size category have built-up HVAC for its assumed lower life-cycle costs and integrated ventilation.

Commercial buildings also include fifteen principal activities (EIA 2005b). We have not attempted to differentiate needs separately among activity types at the level of analysis appropriate for this four decade projection.

3. The EIA Base Case

In this analysis, we examine building loads in the same aggregated categories as EIA in its National Energy Modeling System (NEMS), that is,

- Space Heating
- Space Cooling
- Water Heating
- Ventilation
- Cooking
- Lighting
- Refrigeration
- Office Equipment (personal computing and information processing)
- Other Office Equipment (servers, copiers, etc)
- Other Uses, principally service sector equipment and light manufacturing in commercial buildings, but also ATMs and telecommunications switches, etc.

For the forty year period of interest, these can logically be broken into three categories:

- "**Energy code**" loads. These are loads covered in the IECC, ASHRAE 90.1, and similar energy codes that offer prescriptive and/or performance paths for mandatory minimum energy efficiency. These codes include:
    - Envelope characteristics. Glazing, insulation, and infiltration.
    - HVAC and water heating equipment and systems.
    - Lighting, both indoor and outdoor. We implicitly include display and other retail lighting.
- "**Standards" loads**. These include appliances and equipment that can have energy standards as free-standing products. We emphasize currently regulated products, but include our estimates for products that could be regulated and for which regulations could be enforced. Examples include:
    - Refrigeration. Food service and sales, as well as conventional refrigerators. Both cooling and ice-making equipment.
    - Office equipment, notably personal computers and displays.
- **"Other" loads**
    - Water and wastewater distribution and treatment energy.
    - Elevators and escalators.
    - Medical equipment such as X-Ray and MRI.
    - ATMs, telecommunications switches, small data centers in office, education, or research spaces.
    - Service station equipment (lifts, air compressors), and analogous service industry equipment (large laundry equipment).
    - Light manufacturing in commercial spaces, such as small print shops.

To a large extent, the "energy code" and "standards" categories are subject to reasonable forecasts of efficiency improvements: Equipment in common use will asymptotically approach its thermodynamic limits. Furnaces and boilers can't exceed 100% higher heat value efficiency, and are approaching that now. Gas heat pumps probably cannot realistically expect efficiencies greater than 135–150% without going to more stages than can be justified on either space or cost. Similarly, there are foreseeable limits for all kinds of compressor-based equipment, and little on the horizon for "breakthroughs" On the other hand, large system efficiency improvements are feasible. These begin with moving from air-based energy distribution (pervasive forced air systems) to water- and phase-change energy distribution, generally with dedicated outdoor air systems for ventilation. This facilitates energy recovery, moving heat from where it is rejected to where it is needed.[20]

In contrast, "other loads" represent a very large challenge, because they are very heterogeneous and many are not necessarily proportional to total commercial square footage.

The core issue is that all of these enumerated loads, including the imputed water services, add up to one fourth of today's energy use assigned to the commercial sector. Because we do not know what they are in any detail, but we greatly reduce other loads in our projections for the Advanced and Phoenix Scenarios, *these miscellaneous loads are half of the 2050 energy use in these* .

Finally, total energy use is the product of energy use intensity multiplied by total square footage. The difference between our Advanced and Phoenix Scenarios includes different assumptions of total commercial sector space. In the Advanced Scenario, we use NEMS assumptions. In Phoenix, we allow total area and the distribution of area among building size classes to change, responding to assumed modest "densification" of both residential and commercial space in response to an energy- and carbon-constrained world.

4. The EIA 2050 Extrapolation

With this background, we can consider how energy is used in the EIA Reference Case. The EIA Reference Case does not extend past 2035, so ACEEE has estimated energy use to 2050 by extrapolating from the growth rate over the 2030–2035 period. Figure 9, at the end of this chapter, summarizes our Base Case and projections.

Table 8 below provides additional detail on energy use and energy use intensity (Btu/sf) for 2050. These data underlie Figure 9.

[20] This is one key to the high performance of ground-source heat pump systems that use a circulating water loop to move energy. It is also feasible with other systems, including chilled beam and 4-pipe.

Table 8. Commercial Building Energy Use Reference Case, by Service, 2010 and 2050

	Quads			EUI, Btu/sf-yr		
Service:	**EIA 2010**	**Baseline 2050**	**Percent of 2010 Baseline**	**EIA 2010**	**Baseline 2050**	**Percent of 2010 Baseline**
Space Heating	2.4	2.1	90%	29,200	15,800	54%
Space Cooling	1.6	2.3	141%	20,000	17,100	86%
Water Heating	0.8	1.0	125%	9,500	7,200	76%
Ventilation	1.6	2.3	138%	20,100	16,800	84%
Lighting	3.3	3.9	119%	40,400	29,000	72%
Cooking	0.3	0.3	133%	3,100	2,500	81%
Refrigeration	1.2	1.3	104%	15,400	9,700	63%
Office Equipment (PC)	0.8	0.8	101%	9,800	6,000	61%
Office Equipment: Non-PC	0.8	1.6	192%	10,400	12,100	116%
Other Uses	6.0	12.8	215%	73,600	95,600	130%
Subtotals						
"Energy Code" Loads	9.7	11.5	119%	119,200	85,900	72%
"Standards" Loads	2.3	2.4	107%	28,300	18,200	64%
Office Equipment + Other Uses	6.0	14.4	215%	73,600	95,600	130%
Grand Total	17.9	28.3	158%	221,300	199,800	90%

Note: 2010 numbers from EIA 2010. 2050 numbers projected by ACEEE based on trends from 2030-2035 in EIA 2010. "Other uses include water services, vertical transportation (elevators and escalators), medical equipment, non-road electric vehicles (fork lifts, etc.), distribution transformers, and the myriad of specialized equipment used in laundries, automobile service, etc. These loads are very diverse: The named categories from water services to distribution transformers account for only 23% of the 2050 baseline energy use of 12.8 quads.

Discussion of the 2050 Base Case. Each of the energy code and standards loads is projected to decrease, with a range from 15% to 45% of the 2010 intensity in the Base Case scenario. In contrast, the "other" loads *increase significantly*—about 30%. This limits the total savings available from current and anticipated regulations, since efficient energy code, standards, and listed "other" energy uses are only about half the NEMS 2050 energy use.

Envelope considerations (insulation, glazing) are not treated explicitly in space heating or in space cooling. We infer that EIA internalizes all expected envelope improvements as changes in heating and cooling loads. Further, note that there is no significant difference in the "growth factor" for ventilation and that for space cooling. From this we infer that NEMS does not project substantial changes in the penetration of mechanical ventilation into small buildings (which would increase loads), or that they are compensated by improvements in the technologies.

The scale of uncertainties in this kind of estimation is suggested by comparing the "energy code loads" above (119,200 Btu/sf) with other estimates. In particular, ASHRAE estimates from CBECS 2003 that the weighted average commercial building used about 90,000 Btu/sf in 2003,[21] vs. the CBECS reported energy code loads here of 119,000 Btu/sf.

The figures in Table 8 can be placed in the context of other work. Griffith et al. 2007[22] simulated the CBECS 2003 building stock, and explored the possible improvements with today's and foreseeable technology. They found:

[21] Cited in 2010 ASHRAE Energy Targets Report to the Board, p. 5
[22] Cited in 2010 ASHRAE Energy Targets Report to the Board.

- New buildings can reduce energy use per square foot (Energy Use Intensity—EUI) 43% on average (across types) without employing photovoltaics or ground source heat pumps, but using integrated design.
- Retrofitting the existing building stock to current standards would cut EUI to 70 kBtu/sf. This may be only the "energy code" loads.
- Similarly, the "MaxTech" would be about 40.3 kBtu/sf, again presumably for energy code loads.

5. Energy Use in the Advanced and Phoenix Scenarios

Figure 9 at the end of this section summarizes our projections of aggregated energy use to meet shell loads, lighting and standards-regulated equipment, and miscellaneous loads.

Table 9 presents ACEEE estimates for the Advanced Scenario.[23] In these estimates we use today's available technologies and those readily foreseen as commercially viable for all buildings. This implies an aggressive, mandatory, retrofit program to bring all buildings to within 20% of the performance of the most recent code available in 2050. Such a program might be financed by a PACE-type mechanism,[24] with investments amortized on the property tax bill and any residual obligation at time of sale transferred with title.

Table 9. Code, Standards, and Other Loads in 2050 in the Advanced Scenario

Advanced Technology	Quads		EUI, Btu/sf-yr	Advanced		
				Values		% of 2050 Baseline
Service:	EIA 2010	Baseline 2050	Baseline 2050	Quads	EUI	Quads
Space Heating	2.4	2.1	15,800	0.34	4,200	16%
Space Cooling	1.6	2.3	17,100	0.85	10,500	37%
Water Heating	0.8	1.0	7,200	0.42	5,200	43%
Ventilation	1.6	2.3	16,800	0.90	11,100	40%
Lighting	3.3	3.9	29,000	1.77	21,800	45%
Cooking	0.3	0.3	2,500	0.30	3,700	90%
Refrigeration	1.2	1.3	9,700	0.78	9700	60%
Office Equipment (PC)	0.8	0.8	6,000	0.40	5,000	50%
Office Equipment: Non-PC	0.8	1.6	12,100	1.62	19,900	100%
Other Uses (Ref. Case. Comm)	6.0	12.8	95,600	10	126,700	80%
Subtotals						
"Energy Code" Loads	9.7	11.5	85,900	4.29	52,800	37%
Adjusted Energy Code Loads	9.7	11.5	85,900	4.75	58,500	41%
"Standards" Loads	2.3	2.4	18,200	1	18,400	61%
Office Equipment + Other Uses	6.8	14.4	27,800	11.9	146,600	82%
Total	18.8	28.4	211,900	18.1	217,800	64%

[23] As noted earlier in the residential discussion, the savings described below for commercial buildings are different from the values reported in Table 17 since the values reported here do not include improvements in the efficiency of the electricity generation, transmission and distribution system while the values in Table 17 do include electric system improvements.

[24] PACE is Property Assessed Clean Energy. PACE would finance energy efficiency upgrades with money repaid as part of the property tax. The justification is that improvements remain with the real property—and that this would give access to low interest rates commensurate with the low risks of these investments and municipal bonds.

The first observation is that **space heating** loads are reduced to about one-quarter of the baseline, due to greatly reduced shell losses combined with continuing internal gains. The residual heating loads are small because all resistive heating has been eliminated, substituting heat pumps in smaller buildings and heat recovery in larger buildings. In this scenario, we do not introduce gas heat pumps, which will penetrate the market in the Phoenix Scenario. However, no non-condensing gas equipment remains to provide heating services. In the smallest buildings that have some residual heat load that cannot be recovered from waste heat, combination gas appliances serve both space and water heating loads.

Space cooling loads are cut by almost two-thirds, but not eliminated. Loads remain relatively large because of internal gains from people (60–100 watts/person), advanced lighting, and the sum of other "standards" and "other" loads. Forced air energy distribution is eliminated throughout the sector, replaced by refrigerant phase change (mini-split and multi-split) in smaller buildings and water-based energy distribution in larger ones (technologies including 4-pipe terminal units, water-loop and ground-source heat pumps, and chilled beams for cooling.

Ventilation, decreases less than cooling loads, but is reduced by more than half. That is interpreted as residual internal loads offsetting the need to heat ventilation air (assuming appropriate heat exchange and distribution strategies), while substantial amounts of air still must be cooled and dehumidified in the cooling season.

Lighting, in the Advanced Scenario, uses less than half as much energy as forecast in the baseline NEMS extrapolation. This is a very conservative estimate, since we only assume that all commercial lighting will work at 1.0 w/sf, half of our assumption of present practice.[25] The additional reduction forecast results from more daylighting than in the Advanced Scenario, and occupancy controls, the former as applicable for the small and medium size classes, and the latter for all categories.

"Standards." Cooking, refrigeration, and office equipment all drop from readily foreseeable technology improvements. For refrigeration, our estimates may be conservative, if (for example) room-temperature of irradiated foods supplants refrigeration for preservation (so refrigerators preserve leftovers and provide amenities (ice, chilled food).

Miscellaneous or "other" loads. We have made some assumptions about the potential for improvement of the named "other uses," typically for a 33% system efficiency improvement. These are attributed to more efficient drives and controls, and (for water services) reduced demand attributable to more efficient fixtures (low-flow showers, waterless urinals, better housekeeping methods). We derive the savings from a sensitivity analysis by Ecos Consulting and the New Buildings Institute (Heller, Heater, and Frankel 2011). Much more attention is needed to better understand these "other uses" and then to develop techniques and approaches for reducing this energy use.

In contrast, for the large loads that are not accounted for elsewhere in the tables, we have made reasonable but arbitrary assumptions about efficiency improvements and changes in service demand. In the Advanced Case, we reduce these loads to 80% of the value in the Reference case. Some parts may have large changes. For example, advanced textiles may require much less in laundry services; less printing may be required for commerce, including advertising—but this promise has not been met in the past decades.

[25] The ratio of watts per square foot calculated from CBECS data is about 3.7 w/sf, but this includes display lighting, and seems to include outdoor lighting. We assume 2.0 w/sf as our baseline. For the Advanced Case we assume overall lighting efficiency of 1 W/sf, comparable to today's codes.

6. Energy Use in the Phoenix Scenario

Table 10 presents ACEEE estimates for building floor space in the Phoenix Scenario. The Phoenix Scenario deviates from the Advanced Scenario in two respects: First, we alter the relative amounts of space in small, medium, and large buildings. Second, we reduce the overall amount of commercial space to 80% of the EIA forecast (and Advanced Scenario), to reflect anticipated life style changes in response to very high carbon or energy prices. These include greater density of residences and commercial structures, and less expansive spaces for merchandising, warehousing, and assembly. These changes are summarized in the table below:

Table 10. Space Allocations Among Size Classes in the Advanced and Phoenix

	Class by size	Small, <5,000 sf	Medium, 5,000 to ~35,000 sf	Large, > ~35,000 sf	Total
Adv. Tech	Millions of sf	6,900	24,400	40,400	71,700
	Percent	10%	34%	56%	
Phoenix	Millions of sf	5,700	25,800	25,800	57,400
	Percent	10%	45%	45%	

Notes: Advanced Scenario uses the extrapolated EIA floor space estimates, while Phoenix reduces total commercial building space by 20% from that projection, and slightly redistributes the classes, allocating relatively more space to medium-sized, community-scale buildings than to the largest ones.

With these changes in place, we can project energy use by service for the Phoenix Scenario. This follows in Table 11 below.

Table 11. Energy Use in the Phoenix Scenario

Phoenix	Quads		EUI, Btu/sf-yr	Phoenix		
				Values		% of 2050 Baseline
Service:	EIA 2010	Baseline 2050	Baseline 2050	Quads	EUI	Quads
Space Heating	2.4	2.1	15,800	0.15	1,900	7%
Space Cooling	1.6	2.3	17,100	0.62	7,700	27%
Water Heating	0.8	1.0	7,200	0.62	7,700	64%
Ventilation	1.6	2.3	16,800	0.72	8,900	32%
Lighting	3.3	3.9	29,000	1.70	21,000	44%
Cooking	0.3	0.3	2,500	0.19	2,300	56%
Refrigeration	1.2	1.3	9,700	0.52	6,400	40%
Office Equipment (PC)	0.8	0.8	6,000	0.32	4,000	40%
Office Equipment: Non-PC	0.8	1.6	12,100	1.29	16,000	80%
Other Uses (Ref. Case. Comm)	6.0	12.8	95,600	8	101,300	64%
Subtotals						
"Energy Code" Loads	9.7	11.5	85,900	3.82	47,200	33%
Adjusted Energy Code Loads	9.7	11.5	85,900	4.23	52,300	37%
"Standards" Loads	2.3	2.4	18,200	1.03	12,700	42%
Office Equipment + Other Uses	6.8	14.4	27,800	9.5	117,300	66%
Total	18.8	28.4	211,900	14.8	182,300	52%

7. Differences Between Advanced and Phoenix

As in the Advanced Scenario, **space heating** loads are virtually eliminated. In the Phoenix Scenario, we adopt gas heat pumps. Of course, no non-condensing gas equipment remains to provide heating services. However, even though we reduced heating loads from 15,800 Btu/sf (EIA) to 1800 in the Advanced Scenario, the further reduction to 1100 Btu/sf in this scenario saves relatively little additional energy, since so little is used.

Space cooling loads are cut to 27% of the EIA projection, but not eliminated.

Ventilation, as in the Advanced Case, tracks closely with cooling loads.

in the Advanced Scenario, **lighting** uses about 4% as much energy as forecast in the Reference Case. Unspecified but expected further technology advances move lighting beyond 165 lumen/watt, and we expect less retail display space and lighting in the Phoenix Sector. Together these factors give a modest further improvement of 20%, in energy per square foot.

The "**standards**" loads (**cooking, refrigeration**, and **office equipment**) all drop from the readily foreseeable technology improvements of the Advanced Scenario. For refrigeration and cooking, our estimates may be conservative, if (for example) room-temperature storage of irradiated foods displaces significant refrigeration for preservation.

We have made more aggressive (but largely unsubstantiated) assumptions about the potential for improvement of the named "other uses." These changes are attributed to more efficient drives and controls, and (for water services) additional demand reduction attributable to more efficient fixtures (low-flow showers, waterless urinals, better housekeeping methods), and to new infrastructure.

In contrast, for the large loads that are not accounted for elsewhere in the tables, we have simply asserted an efficiency improvement and/or changes in service demand that reduces these to 2/3 of the Reference case loads. Some parts may have larger changes.

8. Discussion

It is plausible and feasible over four decades to greatly upgrade the building stock. "Code" loads for HVAC and lighting can be cut by a factor of three. We can readily reduce the loads of equipment not now covered by standards by one-third. However, without much more work to uncover the nature and technical potential of the loads that are not now accounted for, we cannot reduce overall energy consumption by much more than 50% in the Phoenix Scenario.

By way of comparison, we also note a study published by the National Renewable Energy Laboratory (Griffith et al. 2007) which suggested that if all commercial buildings were rebuilt by applying a comprehensive package of energy efficiency technologies and practices, they could reduce their typical energy use by 60%. This implies that our Phoenix Scenario, while aggressive, it not pushing the envelope.

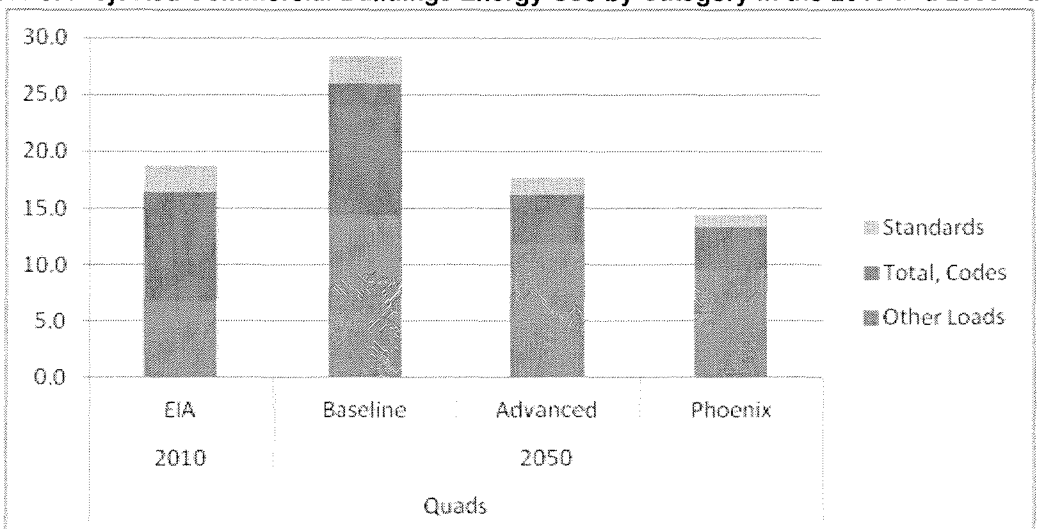
Figure 9 illustrates these changes as stacked bars. The first set, EIA 2010, is the set of initial conditions. The three other bars are 2050 cases. "Baseline" is ACEEE's extrapolation from the 2035 EIA projection. "Advanced" and "Phoenix" Cases depict our study case outcomes. On each bar, the uppermost (light green) segment or band represents "Standards" loads, those that are or can be regulated by standards for equipment and appliances, whether boilers or computers. These loads drop by 43% and 53% in the respective cases. Interestingly, because we change the size mix of commercial buildings in the Phoenix Scenario, the lighting results are virtually the same in both cases (1.7 v. 1.77 Quads): larger buildings use less daylighting, for example.

The middle band represents the loads regulated by building energy codes. It also accounts for much of the changes in energy consumption in our cases, with 39% and 58% reductions. These are the direct result of our assumptions about improved envelope quality, and large changes in space conditioning and hot water services (including delivery). These changes are large in comparison with those in current energy codes that are considered aggressive, such as the IECC 2012. However, our estimates are not constrained by current cost-effectiveness but reflect our judgment of technical and economic feasibility at a large scale, given enough time. In context, they are less stringent than the current Passivhaus specification, which requires 90% reductions in *total* building energy use (Klingenberg, Kernagis, James, 2008).

Finally, note that the lowest bar segment, "miscellaneous" loads, only show changes that are exogenously forced by our model inputs. As discussed above, these loads are very poorly understood and highly variable. Notable examples include Non-PC office equipment (printers, copiers, and faxes; servers and telecommunications equipment; elevators and escalators; and distribution transformers that convert mains to building supply voltages. Several other categories warrant mention: food services for restaurants; medical equipment (since hospitals, clinics, and medical/dental offices are commercial buildings), non-road electric vehicles (fork lifts, office robots), and process equipment for service stations, laundries, and similar commercial uses.

Thus, in both cases these miscellaneous loads are about 60% of commercial building energy consumption, which is astounding. Clearly, these areas require much further study, and the creation of mechanisms to assure that their energy use (active, standby, and off) is commensurate with their value to society.

Figure 9. Projected Commercial Buildings Energy Use by Category in the 2010 and 2050 Cases



Notes: Graphic representation of data from Table 11. Standards includes equipment and lighting), Codes refers to shell loads met by HVAC, and water heating. Other loads are numerous and include everything from elevators to service station equipment.

C. The Industrial Sector

The economic activity and resulting energy use within the industrial sector is largely driven by the demand for products from other sectors of the domestic economy and exports, much as the freight sub-sector of transportation is driven by demand for shipment of goods. This sector analysis will focus on domestic demand to simplify the analysis rather than attempt to address exports explicitly. From a global perspective, the exported products would be produced somewhere else so resources used and emissions produced would be similar, if not greater, whether they were manufactured here or overseas.

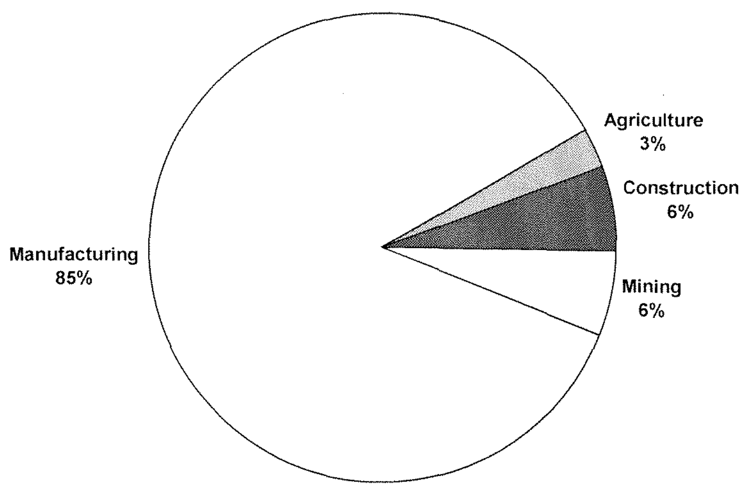
Since the other sectors of the economy drive the demand for industrial products, whether they are food, construction materials or consumer goods, our analysis of the industrial sector focuses on changes in energy intensity,[26] reflecting the amount of energy required to produce a unit of industrial output. For purposes of this analysis, we look at energy per value of shipments as the basis for our intensity calculations, because this is the unit of intensity that EIA has chosen for its analyses and data reporting. We use these intensities to estimate future industrial energy consumption based on the projected value of shipments from our extended AEO forecast (EIA 2010b).

1. Characterizing the Industrial Sector

The industrial sector comprises an array of complex and diverse activities which currently consume about 30% of U.S. total energy demands. It includes agriculture, construction, mining and manufacturing (Figure 10). As the figure notes, in 2010 manufacturing accounts about 85% of total energy consumption within the industrial sector and about 75% of value of shipments (EIA 2010b). Even within manufacturing, energy use is highly varied, ranging from diverse thermal and electrolytic processes to mechanical drive and chemical separation.

Because of this diversity in energy needs, it is more useful to think about process integration than it is to think about discrete technologies. This concept applies both within industrial plants and extends to the idea of entire supply chains. A focus on systems does not say that technologies—both process and product—are unimportant, but rather that it is the interaction and optimization of the application of these technologies that define to a greater extent the energy intensity of the industrial sector rather than the intrinsic efficiency of the technology alone.

Figure 10. 2010 Industrial Consumption by Subsector (30 Quads)



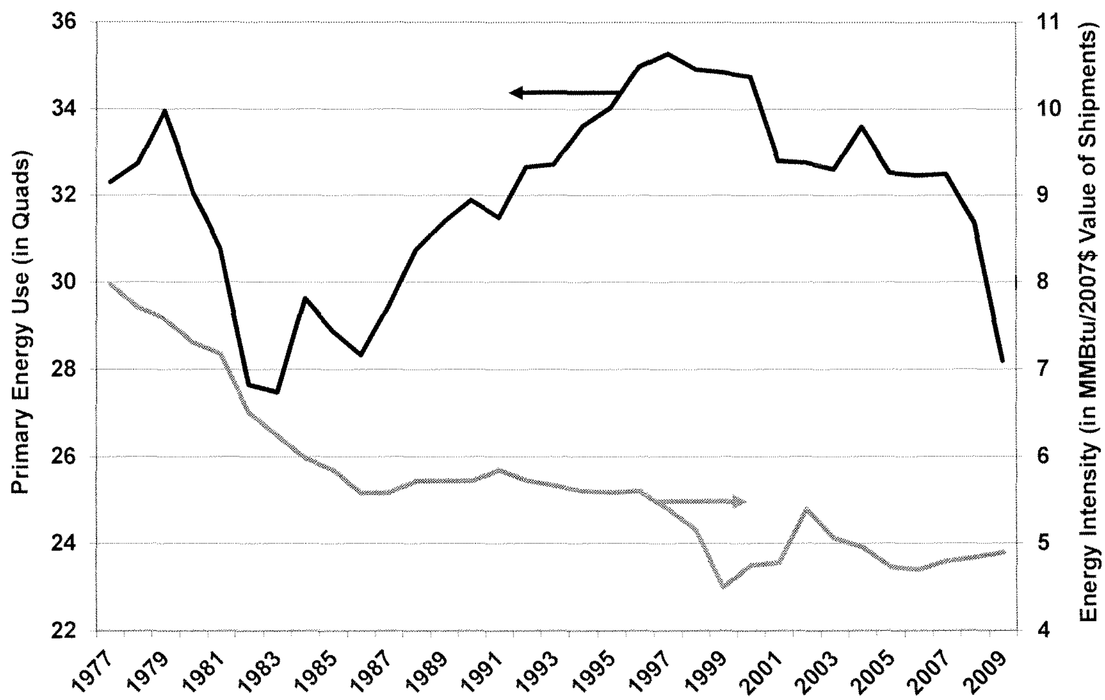
Source: EIA 2010

Investments and new processes in the industrial sector have driven declining energy intensity for as long as we have collected data. However, total industrial energy consumption has increased because growth in industrial sector output has exceeded that rate of declining energy intensity. Looking at the data over the past four decades, we can clearly see this trend (Figure 11), with periods of rapid

[26] While simple in concept, the term "energy intensity" embodies a rather complex set of interrelated metrics throughout the entire production chain within the industrial sector. It is anchored to the numerous steps within the production process, from the extraction of materials, chemical feedstocks, and energy resources themselves to the processing and fabrication of the final goods demanded by other sectors of the economy. An excellent discussion of this topic can be found in the 1995 EIA report *Measuring Energy Efficiency in the United States' Economy: A Beginning* http://tonto.eia.doe.gov/ftproot/consumption/0555952.pdf.

decline in intensity following energy price shocks and during periods of major capital investments. During the late 1970s and early 1980s the intensity declined at above 3% per year. During the late 1980s and early 1990s, the intensity improvements stalled as low energy prices and economic downturns slowed investment in manufacturing capacity. Since the mid-1990s we have seen industrial energy intensity resume its decline at a rate of about 1% per year.[27] EIA (2010) projects that this rate of intensity decline will continue into the future, once the economy recovers from its current slow-down.

Figure 11. Historical Industrial Energy Intensity and Consumption



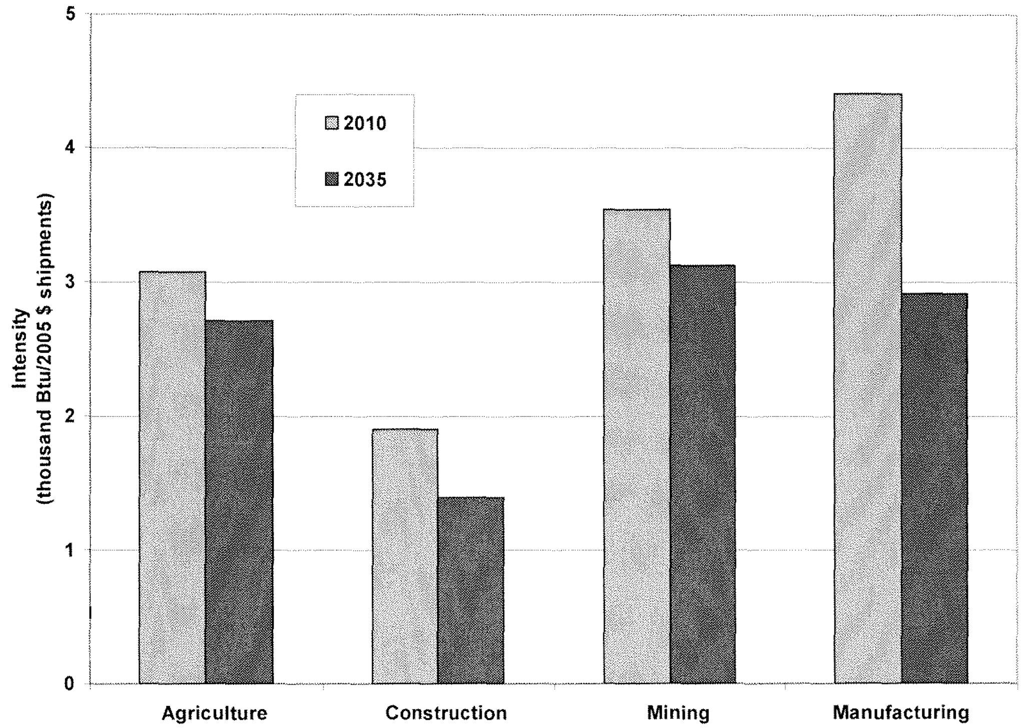
Source: ACEEE from EIA data

Because of the effects of the declining energy intensity, total industrial consumption remained about constant during the period shown in the graph. Manufacturing output expanded by 71% from 1997 to 2006, before the economy began to see the effects of the coming economic slowdown. Looking forward, EIA projects intensity will decline at an annual rate of 0.96% while manufacturing economic activity will grow at an average annual rate of 1.13% (from 2012-2035, after the economy is projected to recover), so overall manufacturing consumption is projected to increase as well since economic activity grows faster than intensity declines.

The energy intensity of the major industrial sub-sectors varies significantly, with manufacturing being the most energy intensive (see Figure 12).

[27] It is worth noting that the modest increase in the intensity seen is attributable to the recession that began in 2008, manifested both by the rapid drop in consumption and substantially reduced rates of investment in new technologies. During period of high manufacturing activity, intensity decreases because of increased capacity utilization of facilities allowing fixed energy use to be spread over more production.

Figure 12. Energy Intensity by Industrial Sub-Sector 2010 and Projected 2035



Source: EIA 2010

2. Relationship between Industrial Sector and other Economic Sectors

Industrial energy use is largely driven by the demands for goods and materials in other sectors of the economy and exports, including demand for energy resources. If we become more efficient in other sectors or use less material because of changes in the way we live, the demand for industrial goods will fall more or less proportionately. Since much of the fuels consumed in the U.S. come from our own industrial sector, reduction is fuels use from efficiency in other sectors will reduce the need for energy use by the industrial sector in their production. Fuel production in the U.S. includes both extraction (e.g., mining, oil and gas extraction) and transformation (e.g., refining).

This relationship between consumption and production however is not a one-way street, because innovation in the products and materials produced by the industrial sector is key to enabling energy efficiency in other sectors of the economy. For example, lightweight, high-strength materials developed by the manufacturing sub-sector have enabled significant energy efficiency improvements in the transportation sector by light-weighting cars, trucks and aircraft. In addition, other changes in the marketplace, such as a shift to more manufactured buildings systems may result in reductions in waste in the construction sub-sector thus requiring less construction materials production from mining, forestry and manufacturing.

The industrial sector thus plays a unique, dual role of both consuming technologies and products, but also producing products, materials and fuels for other sectors of the economy. As the structure of our overall economy shifts, we are likely to see shifts in the products that are produced by the industrial sector, such as renewable energy or efficiency products. Some of these products may be more energy intensive to produce, so there may be some net reduction in energy savings as savings in other sectors of the economy are offset by some increased industrial energy savings. This second order effect is not considered in this analysis, because the uncertainties in the first-order effects are so great as to mask any effects from the lesser effects.

3. Opportunities for Greater Energy Efficiency in the Industrial Sector

In contrast with other sectors of the economy, a bottom-up analysis has proven more difficult for the industrial sector because of the complexity and interconnectedness of the industrial sector (Cleetus et al. 2003). Most industrial energy is consumed in processes rather than by discrete systems making a technology focus challenging. In addition, because of changes in markets, product and technologies the opportunities for energy efficiency evolve in ways that cannot be clearly discerned—at least in the longer term. An ACEEE study (Shipley and Elliott 2006) found that the **identified** opportunities for industrial energy efficiency remained largely the same order of magnitude over the period from 1980 to 2000 in spite of significant realized energy savings in the sector. As known efficiency techniques were adopted, new energy savings opportunities were identified (e.g., the "fruit" grew back on the tree). Equally important, the study found that the nature of the identified savings changed because of new technologies, improved understanding of efficiency opportunities and better awareness. As the report concluded, the identified opportunities were as much about learning what energy efficiency "fruit" looked like as it was about re-growing the fruit with new technology.

While quantifying the magnitude of the technical and economic potential for energy efficiency in industry is challenging, what can be said is that the projected and realized opportunities for energy efficiency in the industrial sector are very large. A wide range of studies ASE, et al. 1997, Interlaboratory Working Group 1997, Plunket et al. 2003, McKinsey Global Institute 2009) have identified a large technical and economic efficiency opportunity at a very low cost. These findings are reinforced by experiences of companies in realizing significant and sustained energy efficiency savings (Prindle 2010). In addition, many of these companies have found that the non-energy benefits of energy efficiency investments exceeded the direct energy savings by a factor of greater than two (Elliott, Laitner & Pye 1997; Worrell et al. 2003; Lung 2005).

So with the complexities in industrial energy efficiency, where are the large savings opportunities likely to come from? Below we will give several examples of large systemic opportunities that are likely to contribute.

Recycled feedstocks and materials substitution. A major use of industrial energy is for materials transformation—the conversion of a raw material into a refined materials that can be used to produce goods. As we continue to extract raw materials from the earth, the quality of these raw materials decline so more energy is required to refine the materials into the building blocks of manufactured goods. If we shift from using virgin feedstocks, such as iron and aluminum ore and petroleum, to recycling existing materials, we can avoid a significant fraction of the energy required to transform a virgin feedstock (Elliott 1994; Elliott et al. 2006). We have seen recycling levels increase dramatically over the past two decades, particularly for metals to the extent that there are now robust global markets for scrape metals. However, significant opportunities remain to increase these levels further by designing products for recyclability.

The manufacturing sector also uses hydrocarbon fuels as feedstocks to produce chemicals that are used to produce other products. Significant among these are plastics, which account for 4% of manufacturing energy use. Recycling of plastics to produce plastics represents another large energy savings opportunity. The U.S. recycles only a fraction of the plastics, in contrast to Europe, which is achieving much higher rates (Elliott et al. 2006).

In addition to increasing use of recycled feedstocks, there are opportunities for substitution of less energy intensive materials. Among the examples of materials substitutions are:

- rubberized asphalt that lasts twice as long and requires half the volume of conventional asphalt (Elliott et al. 2006)

- use of pozzolans[28] to displace Portland cement in structural concretes (Malhotra 1983)
- use of non-Portland cements in structural concretes
- use of waste products from manufacturing processes as feedstocks for other product production, such as has been seen in Kalundborg, Denmark where enterprises buy and sell waste products such as steam, dust, gases, heat, slurry or any other waste product in a closed loop (Kalundborg 2011).

In all these cases, the energy input for the materials use to produce goods and products is dramatically reduced by shifting to a less energy intensive feedstock.

Transformative processes. New processes might transform what we manufacture and how we manufacture these materials. For example, direct iron reduction[29] reduces the energy and carbon emissions that result from the reduction of iron from iron ore. Similar technologies are on the horizon for many other key materials such as organic chemicals and industrial gasses. In another example, the adoption of the submerged combustion melting process promises to reduce fuel use by 20% in the melting of glass and metals (ITP 2006).

In addition many of these new production processes allow the manufacture of materials that could not otherwise be produced. Examples of these new materials are some of the ultra-high-strength steels that are being produced that are already being used in the automotive industries (Ford Motor Company 2011). Research into glass offers the promise of producing materials with strength of more than 50% greater than current glass. This glass could be used to reduce the weight of products from containers to cars to buildings, while enabling applications of glass that can only be imagined today. In addition, high-strength glass fibers could enable lightweight composites at a favorable cost and energy of manufacture relative to carbon fiber (GMIC 2009; Spinosa 2009).

***Smart* manufacturing and supply chain integration**. Shipley and Elliott (2006) found that one of the major changes between 1980 and 2000 in the energy efficiency opportunity was the share of potential attributable to "sensors and controls." Advances in sensor, communication and computation have enabled levels of simulation and system optimization that were not envisioned three decades ago. The National Science Foundation (NSF) has supported research into this topic that suggests we are just starting to realize the transformative opportunities that this area may offer (SMLC 2011). We have seen automation and control progress from equipment level optimization to process line optimization. We are beginning to see systems deployed that optimize the operation of an entire plant, and are beginning to optimize across an entire company and even to an entire supply chain.

The energy efficiency improvements from smart manufacturing techniques result from optimization of multiple systems that eliminate energy waste, which allows for better process control that further reduces waste and improves product quality, and that better matches production levels and product mix to customer demands. ACEEE estimates that supply chain optimization could result in as much as 40-60% intensity reductions relative to current practice (Shipley and Elliott 2006).

Similarly, managing system processes can reduce waste throughout a supply chain. Food distribution is a prime example of the savings opportunity. It is estimated that about half of the food produced in the U.S. is wasted due to spoilage (Jones 2004). While some is lost in the supply chain, much is lost at the retail and consumer levels, with all of the energy embedded in the food wasted as well. By evaluating the food supply system from farm to table, there are opportunities to significantly reduce this waste by changing the processing, handling, packaging and delivery systems so that a fresher,

[28] A pozzolan is a material which, when combined with calcium hydroxide, exhibits cementitious properties. Pozzolans are commonly used as an addition (the technical term is "cement extender") to Portland cement concrete mixtures to increase the long-term strength and other material properties of Portland cement concrete, and in some cases reduce the material cost of concrete (Wikipedia 2011).
[29] A process where iron is produced from iron ore using a reducing gas without the need to produce coke.

better quality and more stable product is delivered to the consumer—with fewer energy requirements. We are already seeing such products emerge such as individually quick frozen fruits, vegetables and meats that preserve product quality for longer and convenience products such as individually packaged chicken parts that allow the consumer to prepare portions of the right size. While the embedded energy per unit may increase, if these changes reduce system waste then the net energy savings can be significant (Pollan 2006). These supply chain measures will likely need to be complemented with educational and communications outreach that further enhance adoption of new practices and recipes which offer variable ingredient portions for different number of servings.

4. Summary of Opportunities

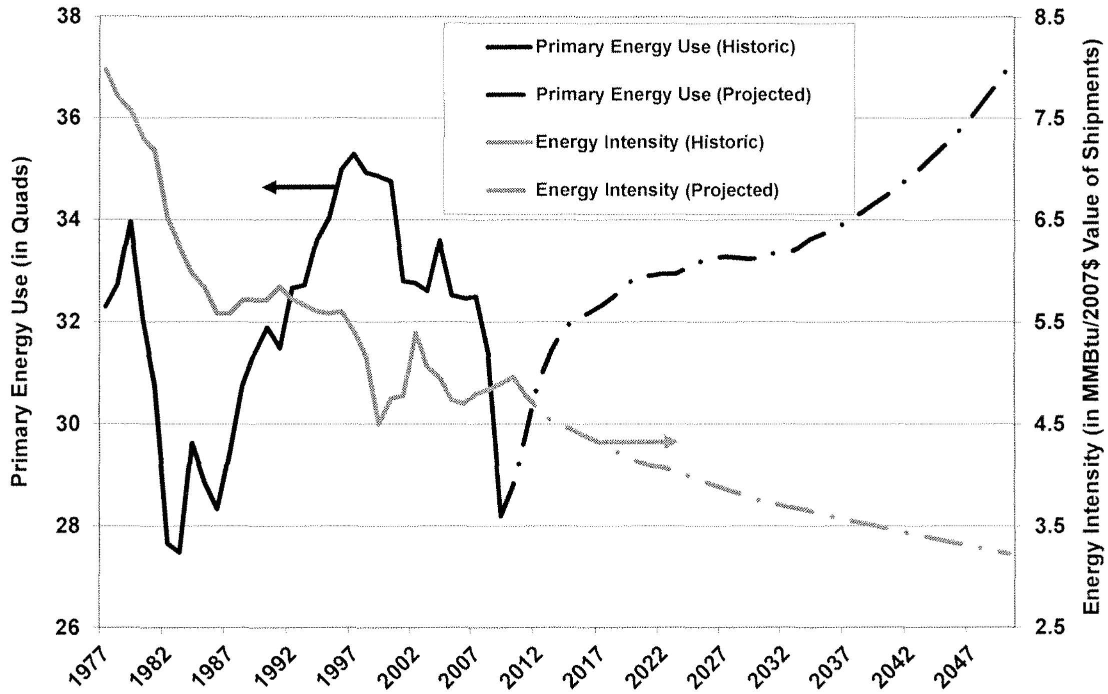
While we may not know how industrial processes and products will evolve over the next four decades, looking back we can see that changes will likely hold great promise for far greater efficiency. The more we look for opportunities, the more we find. Increasingly, the opportunities will come less from seeking out individual sources of waste and more from optimization of complex systems enabled by advances in information, communication and computational infrastructure.

5. Analytical Approach

As discussed above, we have seen two competing trends play out in industrial energy use: declining energy intensity and increasing economic activity in the sector. As a result, we have focused on the intensity of the industrial sector as the basis for our analysis, and then applied the intensity to the economic activity, in this case the value of shipments to project the level of energy consumption in the sector.

In the Reference Case, we project a declining intensity of 0.96% per year from 2010 to 2050, continuing the trend we have seen in this sector over the decades since data has been collected (see Figure 13). As noted above, the 0.96% rate is EIA's latest projection for the 2011-2035 period. This intensity decline results in a decrease in sector intensity of 27.2% in 2035 and 32.0% in 2050 relative to 2010. During this period, the value of shipments from the industrial sector increases 60.8% by 2035 and 88.9% by 2050, and as a result, the total industrial energy consumption increases by 17.0% in 2035 and 28.4% in 2050 relative to 2010.

Figure 13. Historic and Reference Case Industrial Consumption and Intensity



For our policy case we vary the rate of decline in industrial energy intensity reflect the changes in technology, products, and materials discussed above. More details are provided in the discussion that follows.

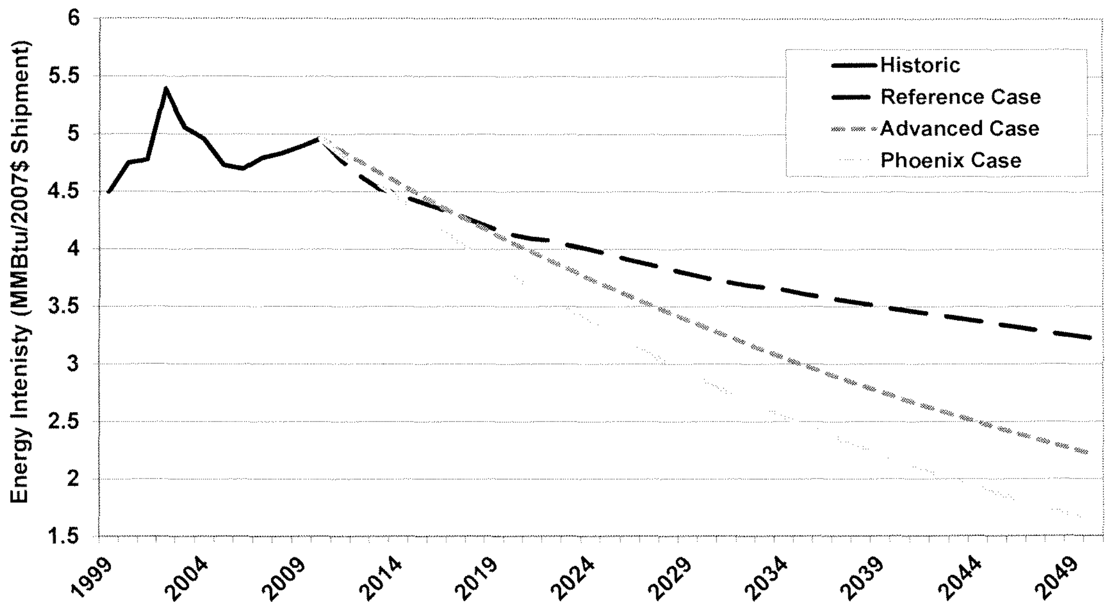
In addition to changes in industrial energy intensity, we will look separately in a later section at expanding opportunities for Combined Heat and Power (CHP) in the industrial sector.

6. Advanced Scenario

In this scenario, we assume that the overall energy intensity of the industrial sector declines at 2% per year, compared with 0.96% per year in the Reference Case. The 2% per year rate represents a rate of decline that McKinsey (2009) identified as a rate of intensity that could be sustained in the industrial sector. This rate of decline is lower than was experienced during the late 1970s and well into the 1980s. A number of the leading firms, such as 3M, Dow, UTC and Alcoa have been achieving reductions in intensity well above this level for over a decade (Prindle 2010). While some, more technically mature industries such as steel may not be able to achieve this rate at least in the near term, many others will be able to achieve even more aggressive results.

In this scenario, we do not consider any major structural changes such as major substitutions of new materials for current materials choices, or shifts in products that are produced in response to changes in consumer demands. Rather, we see continued improvements in product and process technologies, as well as continued improvements from the system optimization trend we have seen emerge over the past two decades. We also hold the ration of electricity to fuel constant at the level in the Reference Case. While our analysis estimates that the improvements in intensity are smooth and continuous (see Figure 14), in reality the changes will likely be more lumpy, much as has been seen in the historic data (see Figure 8) due to the periodicity of economic cycles, investments and technology introductions.

Figure 14. Projected Industrial Energy Intensities for Reference and Policy Cases



While it may appear that these efficiency improvements would likely occur under business-as-usual conditions, in reality a number of barriers to investment in efficiency have been identified (Elliott, Shipley & McKenney 2008):

1. Need for new technologies, products, and processes
2. Access to industry-specific technical expertise, assessments, and training for workers
3. Availability of a trained and capable workforce
4. Access to capital required to implement process investments needed to realize energy productivity opportunities

In the United States, both the public and private sectors have under-invested in all of these categories over the past 30 years. We also need to address these four general barriers is required if we are to achieve the savings suggested in this scenario.

7. Phoenix Scenario

In this scenario, we increase the annual rate of decline in intensity to 2.75% from the Reference Case. This rate of intensity reduction is consistent with the reductions that were seen during the 1980s and with the changes we have seen in the steel industrial during the peak of their reinvestment period from the mid-1990s until the mid-2000s.

In this scenario we assume that we see more aggressive modernization and technology advances than are envisioned in Advanced Scenario. These advances result from more concentrated and expanded R&D by government and industry, and more favorable tax treatment of process investments that encourage greater investments in production capacity. In this scenario we see transformative process technologies such as submerged combustion melting, which can reduce energy use for melting by a quarter,[30] coming to market sooner than in the Advanced Scenario. In

[30] See http://www.osti.gov/glass/Glass%20R&D%20Project%20Factsheets/Energy%20eff%20glass%20melter%20next%20gen.pdf.

addition we see more dramatic shifts in materials available for production of consumer goods, such as high strength glass that can reduce the amount of material used in consumer containers by a quarter, while enabling products that cannot not be envisioned with existing materials. We also see shifts to alternative materials and feedstocks, such as biologically produced plastic monomers or non-Portland cement concretes that are far less energy intensive and may have performance characteristics beyond the conventional materials. We have seen such a transformation over the past 20 years in the steel industry that is now producing new, high-strength steels, many largely from recycled feedstocks, that are able to compete with aluminum and fiber reinforced composites on a weight and performance basis. These new materials enable new products, such as lightweight cars that in turn use less energy in their application.

These changes will not come easily, but will require a major commitment to research and education to insure that manufacturing has the knowledge, workforce and infrastructure needed to realize this transformed sector. These changes will also require a significantly higher level of investment in productive capacity by the industrial sector than we have seen over the past 30 years.

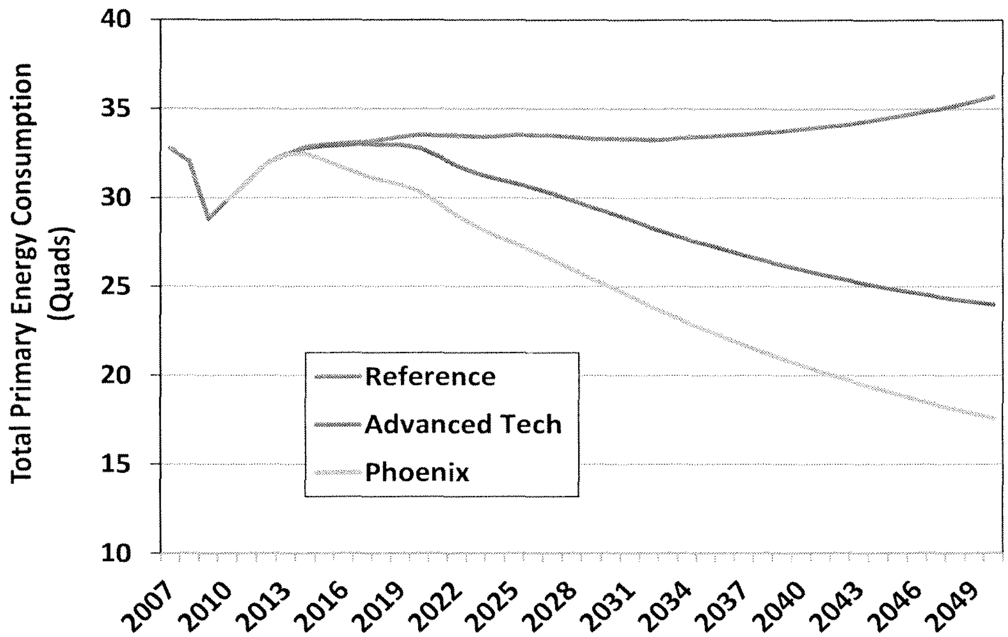
8. Sector Impact Results

We project that value of shipments in the Reference Scenario for the industrial sector is $10,850 billion for the U.S. in 2050, an increase of almost 90% over the 2010 value of shipments. In our Reference Scenario we project that the total primary energy in the industrial sector would increase 19% from the estimated 2010 level (see Table 12 and Figure 15).

Table 12. End-Use and Primary Industrial Energy Consumption in Quads for Reference and Energy Efficiency Scenarios

	2010 Actual Data	2050			Change from 2050 Reference Case	
		Reference Case	Advanced Case	Phoenix Case	Advanced Case	Phoenix Case
Industrial Sector						
Delivered Energy						
Electricity	3.2	3.4	2.3	2.3	-33%	-33%
Other Fuels	20.6	25.9	17.4	12.3	-33%	-53%
Subtotal Delivered	23.8	29.2	19.6	14.5	-33%	-50%
Electricity Losses	6.1	4.0	1.6	1.7	-60%	-59%
Total Primary Energy	29.9	33.2	21.3	16.2	-36%	-51%

Figure 15. Industrial Energy Consumption in the Reference Case and for the Advanced and Phoenix Scenarios



In the Advanced Scenario, primary energy use actually decreases 29% relative to 2010 energy while the value of shipments is held constant. This represents a 36% reduction in primary energy consumption relative to the 2050 Reference Scenario estimates. The ratio between end use electricity and other fuels was maintained across these two , with the Advanced Scenario focusing on improvements in efficiency of the technologies alone.

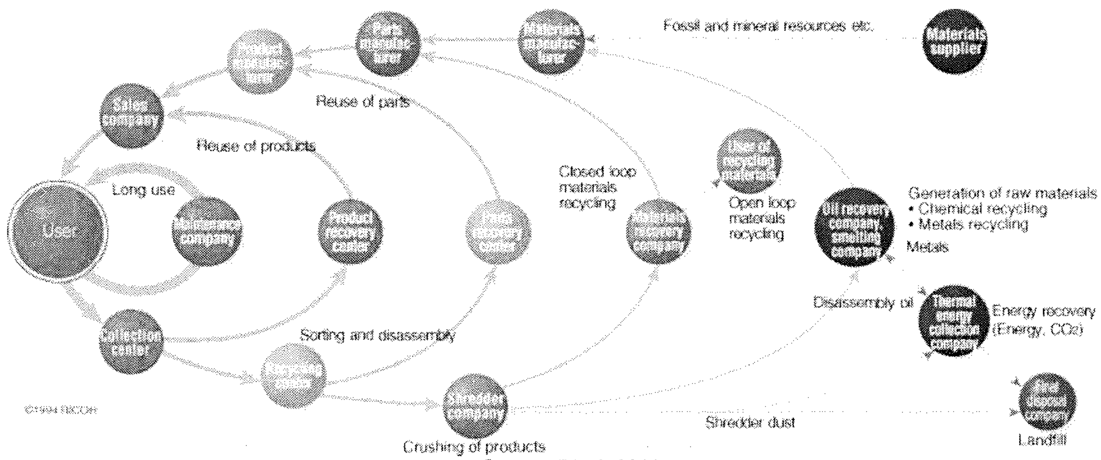
In the Phoenix Scenario, total primary energy falls to 46% below the 2010 level for the same level of value of shipments, representing a 51% reduction of energy use relative to the 2050 Reference projections. In this case, we see electricity use remaining at about the same level as in the Advanced Scenario, with other fuels decreasing by over half relative to the Reference case. This distribution in savings results from a shift to more electric technologies as has been suggested in several analyses, such as Seryak et al. (2011).

9. Discussion

The industrial sector is projected to continue on a path of decreasing energy intensity that dates back as to before the second World War. Rather than a dramatic change in direction for energy use in this sector, we see the potential for incrementally increasing the rate of intensity reductions, which promise to result in significant reductions in primary energy use in 2050. Total energy use in the industrial sector is not driven internally to the sector, but rather results from the combination of the energy intensity of the sector and the overall demand for industrial goods, as is the demand for freight transport as discussed in the transportation section. To the extent that changes in the structure of the economy reduce demand for goods due to changes in consumption behavior, the reductions in industrial primary energy offer even greater opportunities to reduce energy use in the sector.

Increased use of CHP in the industrial sector represents an important efficiency opportunity, primarily to reduce wasted energy in the electric power sector. Our analysis focuses on meeting electricity needs within the industrial sector, due to fact that most manufacturing is not co-located with energy demands in other sectors of the economy. If we were to see a shift toward distributed manufacturing, creating symbiosis opportunities allowing for sharing of energy infrastructures and waste streams among various industrial and the community, as have been accomplished over the past three decades in Kalundborg Denmark (Kalundborg 2011). Fully implemented, the producers and consumers are integrated allowing for reuse, recycling and waste minimization not possible without integration of consumption with production of goods. This concept is embodied in the Ricoh "Comet Circle" (Ricoh 2011), shown in Figure 16. A number of technology changes such as a shift to flexible manufacturing, a concept of a plant that can produce multiple products on demand, are needed to realize this shift (see Ford Motor Company 2011).

Figure 16. Ricoh Comet Circles Reflecting Waste Reduction



Source: Ricoh 2011

A shift to local manufacturing does result in some important interactions with the freight transportation sector, some resulting in reductions in energy use while others potentially increasing energy use. By increasing the level of local resource utilization, we can reduce both the tons of products shipped and the distance they are shipped. However, the shift to local, short-haul freight reduces the opportunity for modality shifts from less efficient trucks to more efficient long-haul trucks and to even more efficient rail transport. The exploration of this topic is beyond the scope of this report, but represents an area of future research.

D. The Transportation Sector

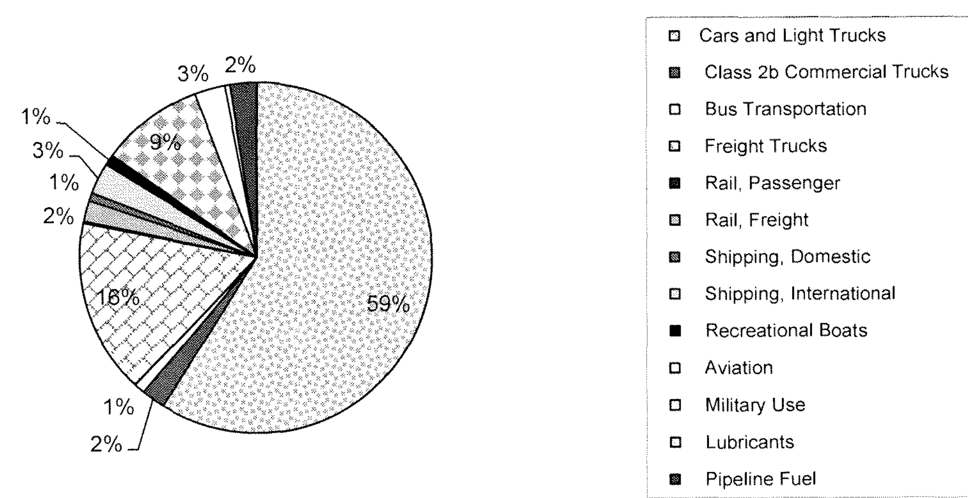
1. Introduction

The transportation system in the U.S. provides vital support to the U.S. economy and public life but is responsible for 66% of U.S. oil consumption (EIA 2011c). The transportation sector is almost entirely dependent on petroleum based fuels. It also contributes more than a quarter of U.S. annual greenhouse gas emissions (GHG). This sector in 2009 generated 31% of the total carbon dioxide (CO_2), which was second to electricity generation that contributed 39% of the total CO_2 (EPA 2011, EIA 2011c). Energy consumption in transportation has followed an increasing trend over the last three decades (Greene and Plotkin 2011), although it experienced a rare decline in 2008-2009 due to the recession and high gas prices during that period. Recently-adopted fuel economy standards will cause fuel consumption to flatten for the next 15 years, but Increasing travel activity, as projected by the Energy Information Administration (EIA), will cause fuel use to rise again thereafter absent new initiatives. Reducing transportation energy use will require a comprehensive approach encompassing increased vehicle efficiency, reduced personal and freight vehicle miles, and attractive alternative modes of transport.

Sector Description

According to the EIA, total energy consumption in the transportation sector in 2010 was 27.47 quadrillion Btu (Quads) (EIA 2011b). Transportation energy use in EIA's Reference Case will increase to almost 32 Quads in 2035, an annual increase of 0.6%. It will rise to almost 36 Quads in 2050 if this trend continues. The transportation sector is dominated by light- and heavy-duty on-road vehicles, followed by aviation and shipping. Light-duty vehicles including cars and light trucks consumed 16.2 Quads or 60% of the total transportation energy, while heavy-duty vehicles including tractor-trailers, vocational trucks, and buses consumed 5.3 Quads or 20% of the total transportation energy in 2010. Sub-sector energy consumption in 2010 is illustrated in Figure 17.

Figure 17. U.S. Transportation Energy Use in 2010



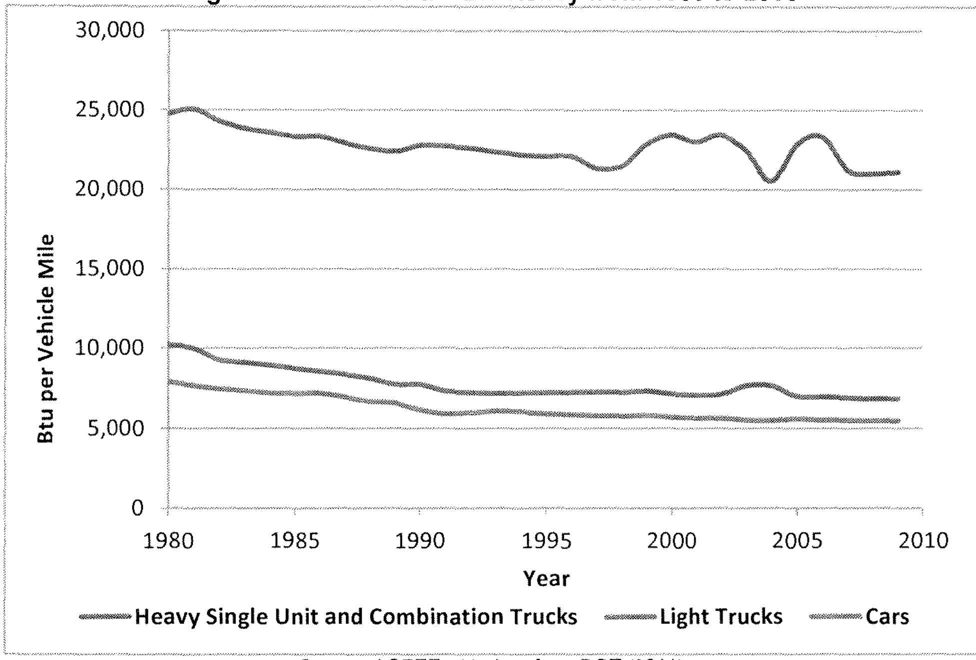
Source: EIA (2011b)

2. Reducing Energy Use in Transportation

Reducing transportation sector energy consumption will reduce GHG emissions and enhance energy security by reducing oil dependence, and could contribute to economic growth as well. However, the task will require major technology advances as well as changes to travel and development patterns.. The International Energy Agency identified in a 2010 report modal shift, efficiency improvement, and use of alternative fuels as the primary means to reduce transportation GHG emissions and fuel consumption in Organization for Economic Cooperation and Development (OECD) countries including the U.S. (IEA/ETP 2010). Accordingly, this analysis will examine the scope and range of improvements that are technically feasible in those areas and how they can best contribute to reducing energy use in transportation. We examine highway vehicles, rail, shipping and aviation. We did not consider energy used by the military, in lubricants, or in pipelines.

Fuel efficiency improvement. With the advent of the Corporate Average Fuel Economy (CAFE) program in 1975, passenger vehicle fuel efficiency increased dramatically into the late 1980s. Fuel economy improved very little over the succeeding two decades, however, as fuel economy standards were essentially unchanged during this period. Historical on-road fuel efficiency in Btu per vehicle mile is shown in Figure 18. Car and light truck energy consumption per mile declined by almost 32% on average from 1980 to 2009 while freight truck fuel consumption decreased by 15% during the same time (DOE 2011).

Figure 18. Vehicle Fuel Efficiency from 1980 to 2009



Source: ACEEE with data from DOT (2011)

There have been several major changes in fuel efficiency standards in recent years. The Energy Independence and Security Act of 2007 mandated light-duty CAFÉ levels of at least 35 miles per gallon by 2020 and set a timetable for the first fuel efficiency requirements for medium- and heavy-duty vehicles. In 2010, the Environmental Protection Agency (EPA) and National Highway Traffic Safety Administration (NHTSA) adopted fuel economy and GHG standards for light-duty vehicles that will increase the average CAFE value for new light-duty vehicles to 34.1 miles per gallon in 2016 (EPA and NHTSA 2010). The agencies recently proposed a rule that would further increase light-duty fuel economy to 49.6 miles per gallon by 2025 (EPA and NHTSA 2011a).

Heavy-duty vehicles will soon be regulated for fuel efficiency and GHG emissions for the first time. A fuel efficiency and GHG emissions rule adopted in 2011 by EPA and NHTSA for model years 2014 to 2019 will require tractor-trailers to reduce fuel consumption per ton-mile by 10-24% in 2017 from 2010 levels, depending on their configurations (EPA and NHTSA 2011b). Vocational vehicles, such as refuse, delivery, dump and utility trucks and transit buses will reduce fuel use by 6-9% during the same time frame. Fuel consumption of gasoline and diesel work trucks (heavy pickups) will decrease by 11% and 16%, respectively, by 2018. These initial standards do not reflect the full range of efficiency technology available today. The National Academy of Science (NAS) Committee to Assess Fuel Economy Technologies from Medium and Heavy-Duty Vehicles found that fuel consumption for all heavy-duty vehicles, including tractor trailers, transit buses and other vocational vehicles, and work trucks, could be reduced by 33-46% by 2020, compared to 2010 levels (NAS 2010). These gains were based on vehicle technologies including aerodynamic features, reduced rolling resistance, reduced idling and accessory loading; powertrain technologies, including engine improvements, hybrid technology, and efficient transmissions; and intelligent driving. The NAS analysis relied upon technologies that were either already available or under development. Some of the technologies considered may not yet be cost-effective, especially for vocational vehicles and work trucks, which have relatively low annual mileage. However, hybridization in particular has large potential for several important vocational vehicle segments in the medium term.

Fuel efficiency improvement in aviation will combine engine advances, including geared turbofans and compressor optimization at low speed, drag reduction, and increased operational efficiency (EPA

2010). Material substitution and design changes to reduce aircraft weight will also reduce fuel consumption (Greene and Plotkin 2011). The National Aeronautics Research and Development Plan (NARDP) of the White House's National Science and Technology Council, envisions "N+2" aircraft in the next 5-10 years that will reduce fuel consumption by at least 40% compared to a 1997 Boeing 777 aircraft with GE-90 engines. These aircraft will use revolutionary configurations such as hybrid wing body, small supersonic jets, cruise-efficient short takeoff and landing, and advanced rotorcraft (NSTC 2010). Research from other agencies also projected 40-50% reduction by 2030 in aviation fuel consumption with improvements in engines, ground operation and air traffic management, and reductions in airframe weight and drag (EPA 2010; NSTC 2007). The NARDP also set a goal of developing "N+3" aircraft and engines in the next 25 years that will reduce fuel consumption by up to 70% compared with a 1998 B737 aircraft with CFM 56 engines. This goal assumes significant advances in aerodynamics, engine performance, propulsion/airframe integration, and material (NSTC 2010).

Passenger and freight rail fuel efficiency has improved steadily over the past two decades, Rail freight energy intensity (Btu per ton-mile) declined by 17% in the decade from 2000 to 2009 (Davis et al. 2011, Table 9.8). Additional opportunities for improvement exist in this sector, through increased load factor, improved engine and locomotive efficiency, reduced frictional and braking energy, aerodynamic improvement, and increased operational efficiency (EPA 2010). Adoption of electric or hydraulic hybrid locomotives in line-haul operation can have fuel savings of 15% in the next 15 years (EPA 2010). Other researchers have estimated that rail energy consumption could be reduced by 40% in 2050 utilizing technological and operational potential in full (Greene and Plotkin 2011).

Shipping and recreational boating energy consumption could also be reduced by almost 40% by 2030, according to an EPA estimate the agency describes as "very aggressive" (EPA 2010). This reduction would be accomplished by technology retrofits including engine optimization, reduced ballast, reduced hull friction, and propeller design optimization on existing ships, improved technology or design concept including increased capacity, hull and superstructure design, and hybridization of new ships, and operational improvements for all ships. The IEA's 2009 analysis estimated that shipping energy consumption could be reduced by as much as 60% in OECD countries by taking full advantage of available and potential opportunities in vessel design, propulsion system, and operation management (IEA/SPT 2009).

Advanced technology. Hybrid technologies, both electric and hydraulic, will be important to improving fuel efficiency in several transportation subsectors. Full hybridization of light-duty vehicles has the potential to reduce per-mile fuel consumption by 50% (IEA/ETP 2010). Hybrid systems will also contribute to reducing energy consumption in the rail and shipping sectors. EPA estimates 15% improvement in fuel economy from grid-capable hybrid locomotives by 2030 if they are introduced in 2015-16 and a similar improvement from shipping with the introduction of hybrid propulsion systems (EPA 2010). According to other estimates, hybrid locomotives can achieve a 50% gain in fuel efficiency (Greene and Plotkin 2011).

Battery electric vehicles are typically far more fuel efficient in use than even the most efficient internal combustion engine vehicle. Given the large energy losses in the production and transmission of electricity, however, the energy efficiency competition between an electric vehicle and a hybrid, for example, is much closer on a "well-to-wheels" basis. Hence, while vehicle electrification will clearly reduce oil consumption, net energy savings will depend heavily on the particulars of the vehicles being compared. However, increases in power generation efficiency are expected in all scenarios considered in this report, as discussed below. Especially in the Advanced and Phoenix Scenarios, these increases are sufficient to ensure that vehicle electrification will result in substantial net energy savings, even given the further improvements expected in the efficiency of hybrid vehicles.

These advanced technologies are not suited to meet all transportation needs. Hybrid systems provide most benefit in urban driving, where idle-off and regenerative braking provide the most benefit. They do not offer large benefits for long-haul freight truck operation, for example. Plug-in vehicles are also best suited to city and local operation, at least until a network of fast charge and battery swap stations has been established in extensive areas. Battery capacity and cost also will slow the market penetration of these vehicles. Fuel cells will have to overcome high upfront costs and infrastructure challenges to ensure access to hydrogen (H_2).

The 2009 NAS study, *Transition to Alternative Transportation Technologies—Plug-in Hybrid Electric Vehicles,* projected approximately 106 million PHEVs by 2050 in a "probable penetration" scenario. However, this number could sharply rise to approximately 240 million by 2030 in a "maximum possible scenario"—over 70% of the light-duty fleet—with strong policy intervention, including mandates to manufacturers, subsidies, and increased taxes on fuel (NAS 2009). The IEA 2009 report envisioned plug-ins, electric vehicles, and fuel cell vehicles capturing nearly 80% of the light-duty market in 2050. For heavy-duty vehicles, the report estimates 30% penetration for fuel cells and plug-ins plus 20% penetration for natural gas technology in 2050 (IEA/ETP 2010). Natural gas and biofuels may play an important role in the transportation sector in the future, but they do not bring an intrinsic energy efficiency gain and will not be further discussed explicitly here.

Reduced travel activity and modal shift. The dominant surface transportation modes, cars and trucks, are among the least efficient transportation modes. They have achieved their high shares of passenger and freight trips by virtue of the provision of infrastructure for them—roads and highways and parking—as well as taxation and land use policies that made them the preferred choice for most families, not their energy efficiency. They are well-suited to the dispersed development patterns that have emerged since the 1950s as the result of federal state, local, and private-sector policies and regulations that have resulted in enormous growth in vehicle miles traveled, as well as the more recent just-in-time delivery demands on freight carriers. Yet congested roadways and high fuel prices and the high cost of personal transportation, approaching 20% of household expenditures, among other concerns, have given rise to many efforts to reinvest in alternative transportation modes and to better integrate land use and transportation planning.

Modal shifts in urban travel to public transit and non-motorized modes and in long distance travel to high speed trains can deliver energy savings, since these alternative modes are typically much more efficient than personal vehicles or short-distance air travel. However, mass transit now serves less than 1% of the total passenger miles. While more flexible transit systems, including IT-enabled paratransit and bus rapid transit, may increasingly attract suburban users, major reductions in vehicle miles traveled will require that new development occur in compact, mixed use, transit-oriented communities and that existing suburbs be retrofitted to greater walkability and higher density. Such development and redevelopment patterns not only facilitate higher usage of alternative travel modes but, even more importantly, reduce the distances that people and goods must travel to reach their destinations. Compact communities would be consistent with, though by no means assured by, the residential sector Phoenix Scenario trend toward smaller homes. A substantial reduction in vehicle miles traveled can be promoted through pricing policies as well. These often can be designed to be revenue-neutral, as in the case of pay-as-you-drive insurance, although net revenues from a pricing measure might be needed to fund alternatives to driving.

The 2009 study *Moving Cooler* found that it would be possible to achieve reductions in on-road GHG emissions of up to 24% relative to expected levels in 2050 through land use changes, investments in alternative modes, and local and regional pricing measures, along with operational improvements and freight strategies (Cambridge Systematics 2009a). All measures employed would yield proportional reductions in fuel use. Additional reductions could be brought about through economy-wide pricing measures. The Moving Cooler results form the basis for the transportation system efficiency component of the Phoenix Scenario below.

Trucks are at present the preferred mode for nearly all short-haul and much long-haul freight transport, since roads are everywhere and shipping by truck is faster than other surface modes. Air freight's share also has grown steadily in recent decades. However, shifting from less fuel-efficient truck and aviation freight to more fuel-efficient rail or waterborne freight can save money and generate significant fuel savings. Such a shift would face numerous challenges, including infrastructure, flexibility, time constraints, and time and resources involved in transferring freight between modes. Investment in intermodal facilities could yield greater use of less energy-intensive freight modes, however, especially in the face of increasing in fuel prices and traffic congestion.

Integration of transportation and land use planning can reduce freight as well as passenger energy use by increasing the feasibility of alternatives to trucking. Establishment of "freight villages" at intermodal nodes, where value-added activity and IT-enabled logistics systems would be based, could provide system efficiency gains for multiple shippers and carriers. On the other hand, the Industry section above contemplates a rise in distributed manufacturing, which could limit the viability of rail and water freight modes by dispersing origins and destinations and encourage the use of smaller, less-efficient freight trucks. At the same time, this trend could dramatically reduce the distances that certain goods would travel. The net transportation energy impacts of distributed manufacturing are unclear and will depend upon the design of, and motivations for, such operations.

3. Scenario Analysis

Reference Case. The Reference Case for transportation, as for the other sectors, is based on an extrapolation of AEO 2010 projections through 2035 out to 2050. For highway vehicles, an extrapolation of AEO 2010 is already implemented in Argonne National Laboratory's VISION model (ANL 2010), and we adopt the VISION Base Case for our Reference Case for these vehicles. VISION projections to 2050 are based on growth rates derived from AEO 2010, together with other sources for population and GDP growth (ANL 2010).

Because our Reference Case is based on AEO 2010 (via VISION), it is somewhat outdated. It reflects the CAFE goal of 35 miles per gallon in 2020 established in EISA 2007, rather than the subsequent fuel economy rules. Fleet average fuel economy of light-duty vehicles in the Reference Case increases from 27.8 miles per gallon in 2010 to 40.9 miles per gallon in 2050. The Reference Case also does not include the heavy-duty fuel efficiency standards adopted in August 2011. Finally, our Reference Case reflects the growth in vehicle miles traveled projected in AEO 2010, which averages 1.75% per year between 2010 and 2035, and the VISION extrapolation to 2050. While these projections show a declining growth rate, reaching 0.7% per year by 2050, they may nonetheless overstate future VMT growth. Changing trends in household income, congestion, exurban housing construction, and workforce participation, for example, could lead to slower growth than reflected in our Reference Case.

Advanced Scenario. The Advanced Scenario, by definition, relies entirely on technological progress in vehicles. For light-duty vehicles, this scenario reflects both the CAFE rule for model years 2012 through 2016, resulting in average fuel economy of 34.1 miles per gallon in 2016, and the rule proposed in 2011 by EPA and NHTSA for model years 2017 to 2025, which is projected to increase fuel economy to 49.6 miles per gallon in 2025 (EPA and NHTSA 2011a). Fuel economy values for light-duty vehicles are stated throughout this discussion in terms of regulatory CAFE values, rather than in terms of the adjusted values shown on vehicle labels, which are substantially lower. Major, further improvements to conventional vehicles, considerable weight reduction, high penetration of advanced hybrids, and modest penetration of plug-in hybrids and battery electric vehicles are the principal elements of the likely pathways to reach that CAFE target.

After 2025, we assume modest further increases in the fuel economy of conventional gasoline vehicles, rising to 65 miles per gallon for cars and 47.7 miles per gallon for trucks, or 57.9 miles per gallon combined, by 2050. Penetration of plug-in vehicles will increase and fuel cell vehicles will begin to appear in the market. We assume that 44% of new cars in 2050 will be EVs, plug-in hybrids, or fuel cell vehicles. We also assume 30% penetration for hybrid vehicles in 2050 compared to 11% penetration for them in the Reference Case. For trucks, we assume a lower penetration of EVs, plug-in hybrids, or fuel cell vehicles, about 22% in 2050. Using VISION assumptions regarding the in-use fuel efficiencies of plug-in hybrid, electric, and fuel cell vehicles relative to conventional vehicle fuel efficiency leads to an average new light-duty vehicle fuel economy of 77 miles per gallon. This value falls between the Mid and High Mitigation case new light-duty fuel economy values for 2050 in Greene and Plotkin (Greene and Plotkin 2011). We note also that other analysis suggests that considerably higher levels are achievable by that time. For example, DeCicco projected that an average light-duty fuel economy for gasoline-powered vehicles of 74.4 miles per gallon could be reached by 2035 (DeCicco 2010).

For heavy-duty on-road vehicles, the Advanced Scenario includes both the fuel efficiency gains of EPA and NHTSA's standards for model years 2014 to 2019 and additional improvements from technologies evaluated by the National Academy of Sciences panel (NAS 2010). Based on largely on the panel's report, we estimate that the fuel efficiency of tractor-trailers could double in 2050 from 2010 levels with improvements from engines, transmissions, aerodynamics, and other vehicle technologies. As a result, fuel efficiency of a tractor-trailer would reach 13.3 mpg in 2050, compared to 6.2 mpg in 2010. We estimate that fuel efficiency of medium-duty vocational vehicles could rise from 7.7 miles per gallon in 2010 to 20 miles per gallon in 2050 with advanced engines, transmissions, and aerodynamics. They will also benefit from hybrid technologies, including hydraulic hybrids.

The Advanced Scenario assumes that shipping, aviation, and rail will also experience moderate to high efficiency gains in this timeframe. We estimate that rail, shipping, and aviation, using technology and system efficiency improvements, can reduce fuel consumption by 50%, 49%, and 43%, respectively, from the 2050 extended Reference Case. This range of improvement is reasonable considering estimates by EPA and other researchers (Stodolsky 2002; EPA 2010; IEA/ETP 2010).

This scenario assumes no changes in development patterns or modes of transportation relative to the Reference Case. This by no means reflects a view that changing development patterns or mode split is beyond the realm of an Advanced Scenario; it simply follows from defining the Advanced Scenario throughout this report as an advanced technology scenario. Transportation energy consumption under the Advanced Scenario is presented in Table 13. Energy consumption in 2050 under this scenario is 25% lower than the 2010 AEO level and 43% lower than 2050 Reference Case consumption.[31]

Table 13: Energy Consumption in Quads from Transportation in Advanced Scenario

	2010 AEO	2050 Reference Case	2050 Adv Scenario
Light-Duty Vehicles (below 10,000 lbs. Gross Vehicle Weight)	16.75	19.47	11.64
Heavy-Duty Vehicles	4.68	8.22	4.45
Rail	0.58	0.84	0.42
Shipping	1.26	1.62	0.82
Aviation	2.58	3.76	2.14
Total	**25.85**	**33.91**	**19.47**

Note: The total energy consumption shown in this table does not include energy use associated with military use, lubricants and pipeline fuel.

Phoenix Scenario. The Phoenix Scenario is based on a substantial reduction in on-road vehicle travel, both passenger and freight, relative to the other , as well as some operational improvements. It also includes greater penetration of hybrids, plug-ins, and fuel cells than in the Advanced Scenario in both the light- and heavy-duty sectors. For on-road passenger and freight travel, we adopt the Moving Cooler study's Long Term/Maximum Results bundle of measures, assuming Aggressive Deployment (stopping short of Maximum Effort Deployment), together with pay-as-you-drive insurance and a per-mile travel fee (Cambridge Systematics 2009a). The study finds savings of 22% by 2050 from these measures. The reductions are achieved through land use strategies, enhancement of alternative modes, parking policies, transportation systems operations strategies, and multimodal freight

[31] These percentages are slightly different from those shown later in Table 17 as the Table 17 values also include changes in the efficiency of electricity generation and distribution.

improvements, as well as pricing measures. The land use strategies are characterized by the assumption that, between now and 2050, at least 64% of new development is "in compact, pedestrian- and bicycle-friendly neighborhoods with high-quality transit." (Cambridge Systematics 2009b).

In this scenario, we also assume that there will be no market share for conventional gasoline or diesel technologies in light-duty vehicles in 2050. Instead, we take IEA's projection of 30% hybrid-electric vehicles, 50% plug-ins vehicles, and 20% fuel cell vehicles in the Blue Map scenario (IEA/SPT 2009). Using the same advanced technology fuel economies assumed in the Advanced Scenario results in average fuel economy of 97.8 miles per gasoline gallon equivalent for light-duty vehicles. These technology shifts in combination with fewer vehicle miles traveled will reduce light-duty vehicle energy consumption by 60% from the Reference Case, to 8.15 Quads.

The heavy-duty sector will also experience higher penetration of hybrids and fuel cells compared to Advanced Scenario. This is in line with IEA's estimate of 20% fuel cell and 5-10% penetration of plug-ins in heavy trucks for its Blue Map scenario (IEA/SPT 2009). VMT from these vehicles would also decline as a result of increased development of compact neighborhoods, which will also promote local production and consumption. Use of mass transit will increase relative to the other due to mode shift, but we assume this will be offset by higher efficiency of mass transit, including operating at higher passenger loads. Combining these factors results in about 60% savings for heavy-duty vehicles relative to the Reference Case level to 3.08 Quads in 2050, where VMT reduction contributed 0.8 Quads in savings. The light and heavy-duty vehicle analysis was performed using the VISION Model, with modification to the heavy-duty template in order to accommodate advanced technology trucks including fuel cells and plug-ins in the heavy-duty fleet.

We assume that energy consumption in aviation could be reduced by 70% from the Reference Case level in 2050, combining technological and operational efficiency improvement and reduced travel (NSTC 2007; Greene and Plotkin 2011). This falls between Greene and Plotkin's Mid and High Mitigation , based on engine and airframe improvements, operational efficiency improvements, and a modest reduction in vehicle travel. They point out that past improvements in the first category alone have delivered a two-thirds reduction in energy per passenger mile since 1970. This reduction occurred without substantial improvements to aircraft operating procedures, including air traffic control, over the last 30 years (NSTC 2007). Fundamental changes to aircraft operation and system improvement including expanding individual aircraft capacity, maximizing arrivals and departures at airports, and mitigating adverse impacts of weather would be required to achieve the 70% reduction assumed in this scenario (NSTC 2007).

For freight rail and shipping, we assume the same energy usage as in the Advanced Scenario. Some goods transported by truck or by air would shift to rail or water in this scenario. However, the use of coal, which accounted for 43% of rail tonnage in the U.S. in 2004 (CBO 2006), will be greatly reduced in the Phoenix Scenario (see Electricity Supply Sector, below). We assume this factor, together with operational improvements, will be sufficient at least to keep energy use for these alternative modes from rising. Table 14 presents energy consumption under the Phoenix Scenario. Energy consumption from transportation declines by 60% from the Reference Case and by 47% from the 2010 AEO level.

Table 14: Energy Consumption in Quads from Transportation in Phoenix Scenario

	2010 AEO	2050 Reference Case	2050 Phoenix Scenario
Light-Duty Vehicles (below 10,000 lbs. Gross Vehicle Weight)	16.75	19.47	8.15
Heavy-duty Vehicles	4.68	8.22	3.08
Rail	0.58	0.84	0.42
Shipping	1.26	1.62	0.82
Aviation	2.58	3.76	1.13
Total	**25.85**	**33.91**	**13.6**

E. Combined Heat and Power (CHP) and Clean Distributed Energy

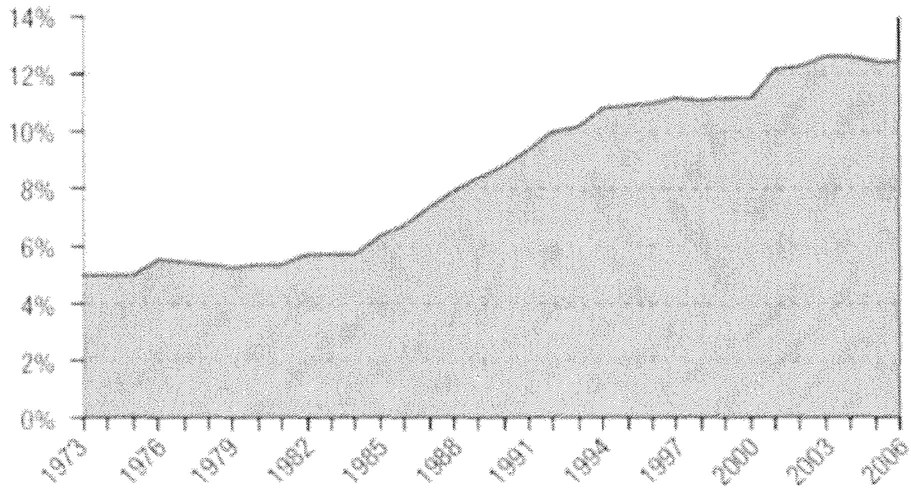
In addition to changes in industrial energy intensity, expanding CHP in the industrial sector represents a further opportunity for greater efficiency. CHP systems, also known as cogeneration, generate both electricity and useful thermal energy in a single, integrated system. In some existing generation systems, additional equipment can be installed to recover energy that would otherwise be wasted (this is known as "recycled energy"). CHP is more energy efficient than separate generation of power and thermal energy because heat that is normally wasted in conventional power generation is recovered as useful energy (Shipley et al. 2008). This recovered energy is used to satisfy an existing thermal demand of an industrial plant or even the heating and cooling of nearby buildings or water supply facilities. CHP and district energy factor heavily into the concepts of industrial symbiosis discussed earlier (Kalundborg 2011). CHP systems can save customers money and reduce net overall emissions by displacing utility fuel use and emissions.

CHP is not restricted to the industrial sector, though industrial CHP does constitute the majority of the installed capacity in the U.S. A number of larger commercial and institutional consumers represent good markets for CHP including universities, hospitals, government campuses, military bases, and large hotels. These non-industrial systems account for approximately one-sixth of installed capacity (Shipley et al. 2008).

EIA (2010b) reports that the U.S. has 75,672 MW of CHP capacity representing about 7% of total electricity capacity in the country. CHP has represented an increasing share of total U.S. generation (as is shown in Figure 19) since the mid-1980s, as the impact of the Public Utilities Regulatory Policy Act of 1978 (PURPA) has enabled CHP in the marketplace.[32] The current level of CHP generation represents a fraction of the share of generation seen in many other industrialized countries. CHP provides 30% or more of the electricity in countries such as the Netherlands, Russia, Finland, and Denmark. The U.S. Department of Energy has projected that CHP could provide 20% or more of U.S. electricity by 2030 (Shipley et al. 2008).

[32] For a discussion of the impacts of PURPA on CHP, see Elliott and Spurr (1999).

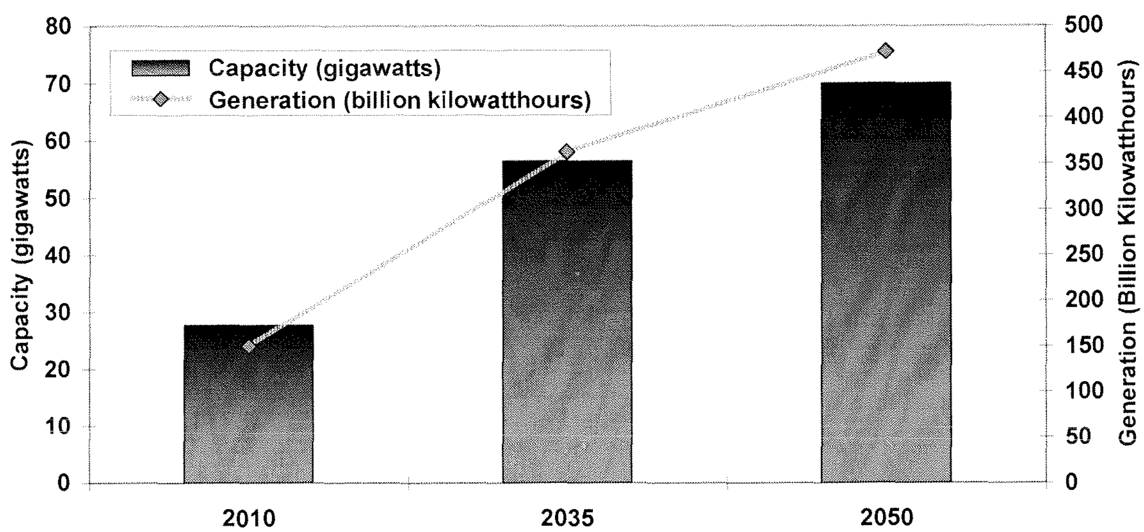
Figure 19. CHP as a Percentage of U.S. Annual Electricity Generation



Source: Shipley et al. (2008)

EIA (2010a) projects that the generation from CHP is likely to continue to increase (see Figure 20). By 2025, installed capacity is projected to double with electricity generation from CHP increasing by 142%. ACEEE has extended the EIA forecast to 2050 by applying the growth rate for 2030-2035 to growth beyond 2035. In this extended projection, the CHP capacity would increase 152% and generation from CHP would increase 214%, representing an important energy efficiency resource to the economy in the Reference Case.

Figure 20. Projections of CHP Capacity and Generation to 2035 (Extended to 2050 by ACEEE)



Source: EIA 2010 extended to 2050 by ACEEE

1. Industrial Combined Heat and Power (CHP)

Many people focus on the power output from the CHP system. However, for efficiency benefits to be realized from CHP there must be a thermal load that can be displaced by the output from the system as well. As the overall intensity of industry decreases, the thermal load that is available to be displaced by CHP systems decreases, limiting the amount of CHP than can be supported by the thermal load. Because of the diverse nature of the industrial sector it is not reasonable to assume that all thermal loads could be met through CHP, so we constrain the available thermal load to 20% of total thermal load.[33] We thus assess the available thermal load to support CHP, and limit the CHP installed if it exceeds the available thermal load.

Since EIA projects significant additions to capacity in its Reference Case, it is not clear that it is reasonable to increase the capacity beyond our Reference Case, because this represents a larger share of the total electricity consumed in the industrial sector. In reality, a significant fraction of the electric output from many CHP facilities will be sold into the wholesale electricity marketplace. For simplicity of accounting and analysis, we assume that the output from industrial CHP is netted against electricity consumption in the industrial sector. The share of industrial electricity increases significantly in the two efficiency scenarios (see Table 15). The available thermal load in the industrial sector in the Advanced Scenario is sufficient to support the projected CHP capacity in the Base Case. However, in the Phoenix Scenario, there is insufficient thermal load as a result of the reduced energy use and shift to electricity in manufacturing to fully support the CHP capacity in 2050 in the Reference Case, so the capacity is reduced by about 30% relative to the Advanced Case.

Table 15. Net Electric Output and Capacity from CHP

	2010		**2035**		**2050**	
	Generation (BKWh)	**% Industrial Electricity**	**Generation (BKWh)**	**% Industrial Electricity**	**Generation (BKWh**	**% Industrial Electricity**
Industrial CHP						
Reference	150	16%	363	36%	472	48%
Advanced	150	NA	363	52%	472	71%
Phoenix	150	NA	363	56%	333	50%
Capacity (GW)						
Reference & Advanced	27.7 GW		56.5GW		70.0 GW	
Phoenix	27.7 GW		56.5 GW		49.7 GW	
Non-Industrial CHP						
Reference	20		30		50	
Advanced & Phoenix	20		50		100	
Capacity (GW)						
Reference	3.7 GW		4.7 GW		7.4 GW	
Advanced & Phoenix	3.7 GW		7.8 GW		14.8 GW	

[33] The total thermal load is estimated by using EIA (2010b) estimates for fuels available for heat and power, summing estimates for LPG for heat and power, residual fuel oil, petroleum coke, natural gas for heat and power, industrial coal, and biofuels for heat. Based on its experience analyzing CHP system opportunities, ACEEE estimates only a fifth of that total thermal load is assumed to be available for displacement by CHP. The balance of the thermal load is assumed to be technically or economically infeasible for displacement by CHP because the loads are too small, a mismatch on temperature not readily collocated with a CHP facility.

2. CHP Outside of Industrial Sector

In the Reference Case, we project that CHP outside of the industrial sector will contribute 50 Billion kWh to meeting electricity demand, up from 20 Billion kWh in 2010 (see Table 15). In the Advanced and Phoenix Scenarios, we assume that electricity from non-industrial CHP is doubled. Electric generation from non-industrial CHP was not increased further in absolute terms in the Phoenix Scenario because as energy use efficiencies reduce electric and thermal demand in this scenario, we are concerned that capacity would exceed demand for both the thermal and electric output, similarly to our bounding of industrial CHP.

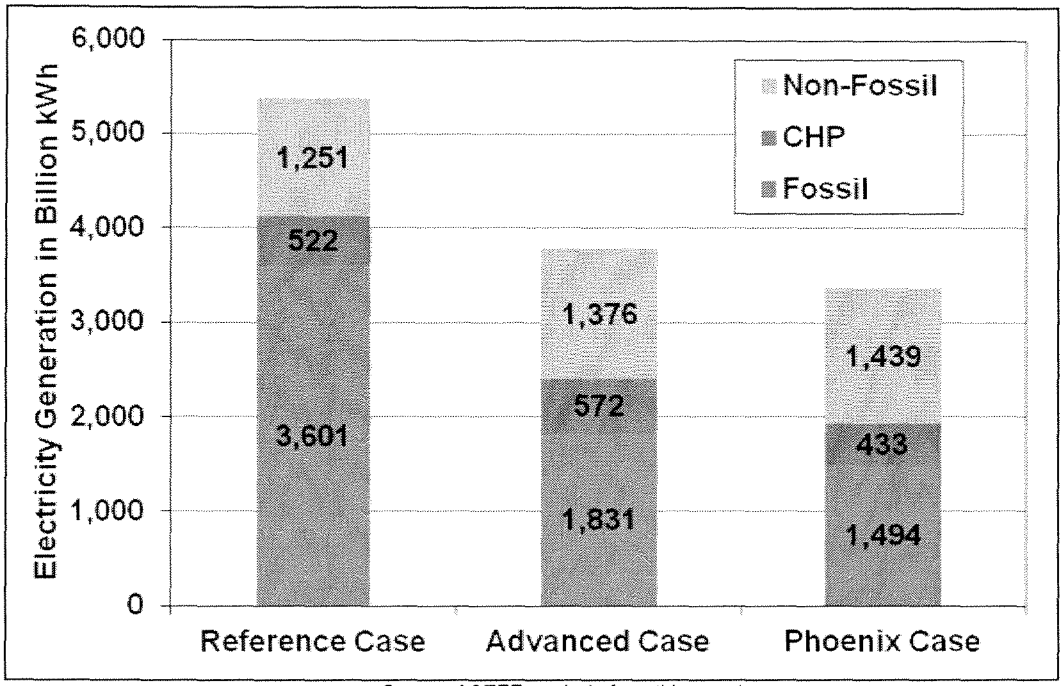
F. The Electricity Supply Sector

The production and distribution of electricity requires a number of steps starting with the actual generation of electricity at a power plant. From the power plant, electricity is sent out through a series of high-voltage transmission lines to the load centers where it is actually needed and then finally to the many distribution systems that serve individual facilities, commercial buildings, homes, industrial plants, and transportation vehicles. Over the last several decades, the efficiency with which electricity has been generated and distributed has hovered at about 31% efficiency (EIA 2011a). That is to say, for every one unit of energy that is transformed into electricity that is used in a home or business, about two units of energy are lost as waste heat. In 2010, for example, total demand for electricity—whether supplied by the utilities or generated onsite by the customers themselves—was estimated at 3,699 billion kWh. On a heat equivalent basis this represents 12.6 quads of energy, but 39.3 quads of energy inputs were required in generate this electricity. With a typical efficiency conversion at the power plant of about 34%, an additional 6% may be either used to support the operation of the power plant or lost in the transmission and distribution (T&D) of electricity to the ultimate customers. The overall system efficiency would be estimated at about 32%. The implication is that a full accounting of energy that is delivered as electricity must also include the energy in both generation and T&D, as well as the energy as it actually reaches the end-user.

For purposes of this analysis, we have divided electricity generation into utility fossil fuel (i.e., coal, natural gas, and petroleum), non-fossil (i.e., renewables and nuclear) sources, and CHP from industrial and non-industrial sources (as discussed in the previous section). Currently fossil fuels account for about two-thirds of electric generation. In 2050, in the Reference Case, total reliance on fossil fuels for electric generation is projected to increase modestly.

As the demand for electricity falls significantly in the Advanced Technology and Phoenix Cases, we anticipate that the generation mix will shift from a fossil fuel dominated mix to a more balanced mix in the Phoenix Case, as can be seen in Figure 21. As demand for electricity is reduced, we assume that this will result in substantial retirements of old coal units, thereby avoiding substantial environmental compliance costs for some of these units and also reducing emissions of greenhouse gases. We assume a significant decline in fossil generation as coal plants retire, resulting in natural gas assuming a dominate role in fossil generation, as has been suggested by several recent analyses such as the recent MIT (MITEI 2011) study. The share of non-fossil utility generation increases from about 23% in the 2050 Reference Case to 32% and 40% in the Advanced and Phoenix Cases, respectively. Great uncertainty exists as to the relative mix of non-utility generation, as renewable technologies compete with nuclear generation. Because of the uncertainty, we assume that all non-fossil resources—nuclear or otherwise—have the same heat rate as the typical fossil resource in the same period. This assumption is consistent with the treatment of non-fossil assets in EIA's *Annual Energy Review 2010* (EIA 2011a)

Figure 21. Electricity Generation in 2050 by Source



Source: ACEEE analysis from this report

The share of electricity generated from CHP will also increase as the overall electricity demand falls in the enhanced efficiency cases, though in the Phoenix Case the CHP generation declines in absolute terms and in overall share from the Advanced Case because the available thermal load declines with improved efficiency in the industrial sector combined with an increase in electrification of industrial processes, as is discussed in the prior section.

We also anticipate increases in the efficiency of generation technologies. We project modest improvements in delivered electricity efficiency will occur in the Reference Case, with efficiency levels rising from slightly above 32% in 2010 to about 36% in 2050. We suggest that even greater efficiencies could be obtained with the best individual power plants expected to push design efficiency levels to 55-60% by 2050 (Harvey 2010). For example, new combined cycle generation systems offer efficiencies above 60%, while maintaining efficiency over a wider range of operating loads than were practical before (GE Energy 2011). CHP systems can achieve even higher incremental electric efficiencies, approaching 80% (Elliott et al. 2009).

We also anticipate modest decreases in T&D losses as a result of improved transmission system equipment through the deployment of technologies such as super conductors and high-efficiency transformers. In addition, the greater use of distributed resources, in this case represented by CHP and some renewable sources, will reduce T&D losses as the distance between generation and use is decreased.

Combining improvements in equipment and T&D efficiencies with the shift in the generation mix described above, we project that the delivered electric system efficiency in 2050 would increase from about 36% in the Reference Case to about 40% in the Advanced Case and approaching 48% in the Phoenix Case (see Table 16). We caution that these are rough estimates and are subject to substantial uncertainty with respect to generation mix and technology development.

Table 16. Electric Generation and Delivered Efficiency by Resource

Metrics	2010 Actual Data	2050 Reference Case	Advanced Case	Phoenix Case
Total Delivered Electricity (Billion kWh)	3,749	5,375	3,779	3,366
Utility Fossil Generation	2,437	3,601	1,831	1,494
Utility non-Fossil Generation	1,142	1,251	1,376	1,439
CHP	170	522	572	433
Delivered Electricity System Efficiency				
Utility Generation	31.3%	34.1%	37.1%	45.0%
CHP	71.6%	71.6%	75.2%	79.2%
Overall Electric System Efficiency	**32.1%**	**35.9%**	**40.2%**	**47.7%**

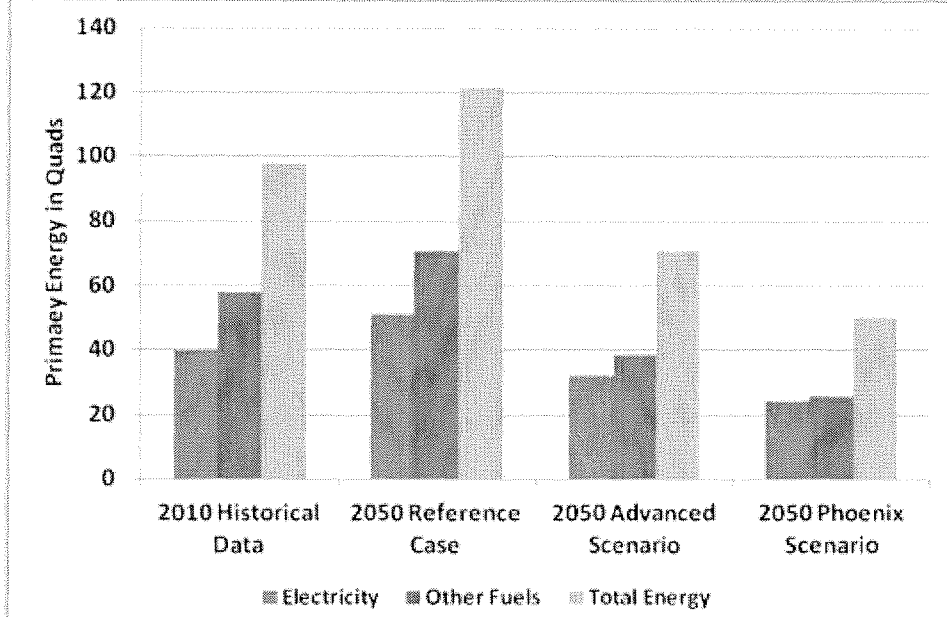
G. Adding It All Up

With the detail now provided for each of the separate end-use sectors, we now have a complete profile of how the nation's energy demands might look in the year 2050—assuming the right policies and investments decision drive these energy productivity improvements. Figure 22 and Table 17 on the following pages summarize this detail for the benchmark or historical data for 2010, and across each of the three cases that we examine for the year 2050 in this analysis: (i) the extended AEO Reference Case, (ii) the Advanced Case, and (iii) the Phoenix Case, as they have all been described in the earlier sections of this report. The data are reported for each of these four cases by end-use sector, including their anticipated electricity and other energy needs, and also including the anticipated losses in the production of electricity for the entire United States.

The very last row of Table 15 gives us the first summary of the four cases. In 2010 the U.S. economy consumed a total of 98 quads (rounded) to support the production of goods and services. Under standard assumptions and economic projections this will rise to about 122 quads of total energy.[34] Under both the Advanced Case and the Phoenix Case, the energy efficiency of the economy would improve significantly. For comparable levels of economic activity as in the Reference Case, consumers and businesses would require a total of only 70 and 50 quads of energy in 2050 for the Advanced Case and the Phoenix Case, respectively. As shown in the last two columns of Table 17, this reflects a 42% and a 59% savings in 2050 for these same two cases as a result of the increased energy efficiency investments. Again, as we discuss more fully later in this report, the good news is that the economy will continue to maintain the same level of goods and services in these two policy cases as in the 2050 Reference Case. Indeed, as we discuss in the next section, the larger economy may, in fact, turn out to be even more robust as a result of the efficiency investments implied within each of the policy cases. The reason is that energy efficiency investments provide a much lower cost of energy services that increases the larger productivity of the American economy.

[34] As a historical footnote, the most recent projections for energy use both in the 2010 benchmark data and the 2050 projections (as we've extended them here) have changed dramatically from even just a few years ago. As an example, the AEO 2005 forecast for the year 2010 (EIA 2005a) suggested that we might consume closer to 111 quads compared to the estimated 98 quads that we actually used in that year. More intriguing, extending the EIA (2005a) forecast to 2050 in the same way as done for this analysis would have suggested that we would be using more like 180 quads of energy rather than the 122 quads shown in Table 17. The weaker and a slightly more energy-efficient economy accounts for this very big difference in the EIA (2005a) and the EIA (2011a) extended Reference Cases. Looking out to the year 2050, the extended AEO 2011 Reference Case shows a 3% higher population, with a 22% lower per capita income and a 14% lower energy intensity. These three factors translate into a 31% lower energy requirement for the 2050 Reference Case energy that sets the stage for the two policy cases discussed in this report.

Figure 22. Energy Productivity and Impact on Future Energy Needs



Note: Electricity includes total energy needed to generate and distribute electricity to homes and businesses.

Moving from the summary chart shown in Figure 22, Table 17 provides a number of other interesting perspectives that emerge from this assessment.[35] Perhaps the most immediate observation is the huge variability in the range of savings among sectors and end-uses. People may be surprised to see that industry already tends to be more energy efficient than imagined. So while there are significant improvements still to be tapped within the variety of industrial sectors, industry generally has smallest scale of improvement. On the other hand, buildings have significant potential to cost-effectively reduce overall energy use while still providing the desired level of amenities and services as in the Reference Case projections. The 2050 industrial sector savings, for example, range between 36 and 51% for the two policy cases while residential and commercial buildings might realize overall energy savings from 45 to 69% savings. Transportation savings, moving closer to buildings in the scale of efficiency improvements, fall in between with suggested savings of 38 to 56%, respectively. Interestingly, the transportation sector actually increases some electricity use as a means of reducing larger sector energy consumption. In other words, increasing electricity consumption for the nation's vehicle fleet can actually reduce total transportation energy use. Finally, and especially in the case of the electricity sector, moving toward much more efficient generation technologies, such as combined heat and power, greatly increases the thermal efficiency of electricity production (see the discussion on this point in the write-up of the efficiency gains in the industrial sector). Again, the result is that any savings in end-use demand for electricity is amplified by further savings driven by increased performance in the production and distribution of electricity throughout the economy.

[35] Readers might note that the data for sector totals in Table 17 might differ slightly from totals reported in the building sector analysis. The reason is an assumption of reference case system electricity efficiencies in driving the buildings assessment. Table 17 incorporates the revised Advanced Case and Phoenix Case electric system efficiencies as they might otherwise impact the primary energy data in the buildings data. See Appendix A for a further discussion of reconciling the differences.

Table 17. Energy Use by Scenario and by Sector (with all values in Quads)

	2010 Historical Data	2050			Change from 2050 Reference Case	
		Reference Case	Advanced Case	Phoenix Case	Advanced Case	Phoenix Case
Residential Sector						
Delivered Energy						
Electricity	4.97	6.66	3.95	3.23	-40.7%	-51.5%
Other Fuels	6.47	6.20	1.80	0.80	-71.0%	-87.1%
Subtotal Delivered	11.44	12.86	5.75	4.03	-55.3%	-68.7%
Electricity Losses	10.59	12.88	6.70	3.94	-48.0%	-69.4%
Total Primary Energy	22.03	25.74	12.45	7.97	-51.6%	-69.0%
Commercial Sector						
Delivered Energy						
Electricity	4.60	7.96	5.60	4.66	-29.7%	-41.5%
Other Fuels	3.90	4.97	0.79	0.52	-84.1%	-89.5%
Subtotal Delivered	8.50	12.93	6.39	5.18	-50.6%	-59.9%
Electricity Losses	9.82	15.14	9.04	5.36	-40.3%	-64.6%
Total Primary Energy	18.32	28.07	15.43	10.54	-45.0%	-62.4%
Industrial Sector						
Delivered Energy						
Electricity	3.20	3.36	2.25	2.25	-32.8%	-32.8%
Other Fuels	19.89	25.86	17.38	12.25	-32.8%	-52.6%
Subtotal Delivered	23.09	29.21	19.63	14.50	-32.8%	-50.4%
Electricity Losses	6.82	4.01	1.62	1.66	-59.6%	-58.5%
Total Primary Energy	29.91	33.23	21.25	16.17	-36.0%	-51.3%
Transportation Sector						
Delivered Energy						
Electricity	0.02	0.36	1.09	1.34	202.8%	272.2%
Other Fuels	27.42	33.55	18.38	12.26	-45.2%	-63.5%
Subtotal Delivered	27.44	33.91	19.47	13.60	-42.6%	-59.9%
Electricity Losses	0.05	0.70	1.85	1.64	165.6%	135.0%
Total Primary Energy	27.49	34.61	21.32	15.24	-38.4%	-56.0%
Economy-Wide Totals						
Delivered Energy						
Electricity	12.79	18.34	12.89	11.48	-29.7%	-37.4%
Other Fuels	57.68	70.58	38.35	25.83	-45.7%	-63.4%
Subtotal Delivered	70.47	88.92	51.24	37.31	-42.4%	-58.0%
Electricity Losses	27.28	32.73	19.21	12.61	-41.3%	-61.5%
Total Primary Energy	97.75	121.65	70.45	49.92	-42.1%	-59.0%

IV. Macroeconomic Impacts of Energy Efficiency Investments

At this point we have established that the U.S. economy can go a very long way to improve its overall energy efficiency. That is, the nation has the wherewithal to provide an expanded set of goods and services, and to do so using considerably less energy. What lessons might we draw from the larger perspective of the macroeconomy? To generate some meaningful insights in that regard we now turn to an analysis of the macroeconomic impacts of these scenarios. To do this, we mapped the suggested 2050 energy savings into ACEEE's proprietary Dynamic Energy Efficiency Policy Evaluation Routine, or DEEPER modeling system.

Although we have not evaluated the individual cost of the efficiency upgrades characterized in the earlier part of this report, the model contains a number of algorithms that can provide working computations to generate such information. In particular, we build on work of Cleetus et al. (2003) and Dahl (2006) to generate a set of capital costs associated with different levels of energy savings in the different end-use sectors of the economy. As explained in Appendix B, for example, a 10% savings might generate a cost that requires three or four years for the investment to pay for itself through the energy bill savings. On the other hand, a 50% savings might require nine or ten years before the investment is paid back. These results are broadly consistent with results summarized in Laitner et al. (2006) and Hanson and Laitner (2004).

Once we know both the costs and the likely energy bill savings, DEEPER can then transform the data to match changes in consumer and business spending with the appropriate sector labor and income coefficients. This, in turn, allows us to generate information on the net employment benefits associated with energy efficiency improvements. This also allows us to assess the contributions to household income and the nation's Gross Domestic Product. Again, Appendix B provides more detail on the DEEPER modeling system.

Following this analysis, we briefly discuss the potential for a macroeconomic rebound effect that could modify our results somewhat.

A. Providing Jobs and Income

Earlier in this report, reflecting on the historical record for energy efficiency improvements (see Section II), we noted that the economy would likely benefit from any improvement that was cost-effective. Indeed, the evidence pointed to a large number of studies suggesting net savings from accelerated investments in the more productive use of energy. Yet, few assessments of policy have been completed that reflect as deep of a penetration of efficiency improvements as suggested by the findings in Section III—a 42% energy savings for the Advanced Case and a 59% energy savings for the Phoenix Case, all by 2050. Hence, there is the need to map those savings into the DEEPER model to provide us with a sense of likely outcomes.

At this point we offer a note of caution as we first describe the mapping of a large-scale energy savings into any macroeconomic model, and as we then characterize the net impacts. Recall that the point of the exercise in Section III of the report was to evaluate the potential for energy efficiency improvements for a single year in time. In this case we examined the outcomes in the year 2050 so that we might determine how changes in the nation's infrastructure might accommodate significant productivity gains. But the very large improvements that might be possible for the year 2050 will be the result of decisions, behaviors, and investments that will have to be made beginning next year and continuing right on through 2050. As it turns out, mapping the kind of changes that have to be made over time can take any number of paths. In this case, we assume a slow ramp up of activity so that more than half of the program effort and investment occurs in the last ten years of the time horizon. In other words, while the activity begins very slowly in 2012, it doesn't reach full stride until the period 2040 through 2050. Table 18 provides the highlights of impacts given that trajectory.

Table 18. Indicative Macroeconomic Impacts

Financial and Economic Indicators	Advanced Case	Phoenix Case
Energy Savings from 2050 Reference Case	42%	59%
Implied Cost of Technology		
Simple Average Payback 2012	3.5	3.6
Simple Average Payback 2050	5.6	9.9
Cumulative Financial Impacts 2012-2050 (Billion 2009 Dollars)		
Program Cost	$500	$1,200
Total Investments	$2,400	$5,300
Annual Payments on Investments	$2,900	$6,400
Energy Bill Savings	$15,000	$23,700
Net Savings	$11,600	$16,200
Net Present Value at 5% Discount Rate	$3,000	$3,900
Total Resource Cost Ratio at 5% Discount Rate	2.8	2.1
Net Macroeconomic Impacts in the Year 2050		
Employment (millions of jobs)	1.3	1.9
Percent from Reference Case	0.4%	0.6%
GDP (billion 2009 dollars)	100	200
Percent from Reference Case	0.3%	0.4%

The first critical assumption reflected in Table 18 is the assumed cost of the energy efficiency improvements. Here we simplify that idea by using the payback metric. In other words, if an efficiency measure is installed, how many years will it require for the energy bill savings to pay for the installed cost of that improvement? From the DEEPER algorithms it generally appears that in the very first year of activity (that is, year 2012), the first technologies on average will pay for themselves in just over three years. Some very simple efficiency upgrades may pay for themselves in less than a year while others might take many more years than that. With most technologies having a life of well over a decade, and in many cases more than 20 or 30 years, this implies a very positive return. At the same time, as the easier upgrades are completed it become more costly to implement efficiency improvements. In the Advanced Case the payback rises closer to a 6-year average—with some measures perhaps exceeding 7 or 8 years while others perhaps only 3 or 4 years. In the Phoenix Scenario, however, the economy is being pushed harder and the new efficiency enhancements in 2050 might rise to an average 9.9-year payback. While still roughly the equivalent of a 10% average annual return, it becomes less cost-effective compared to the easier installations.

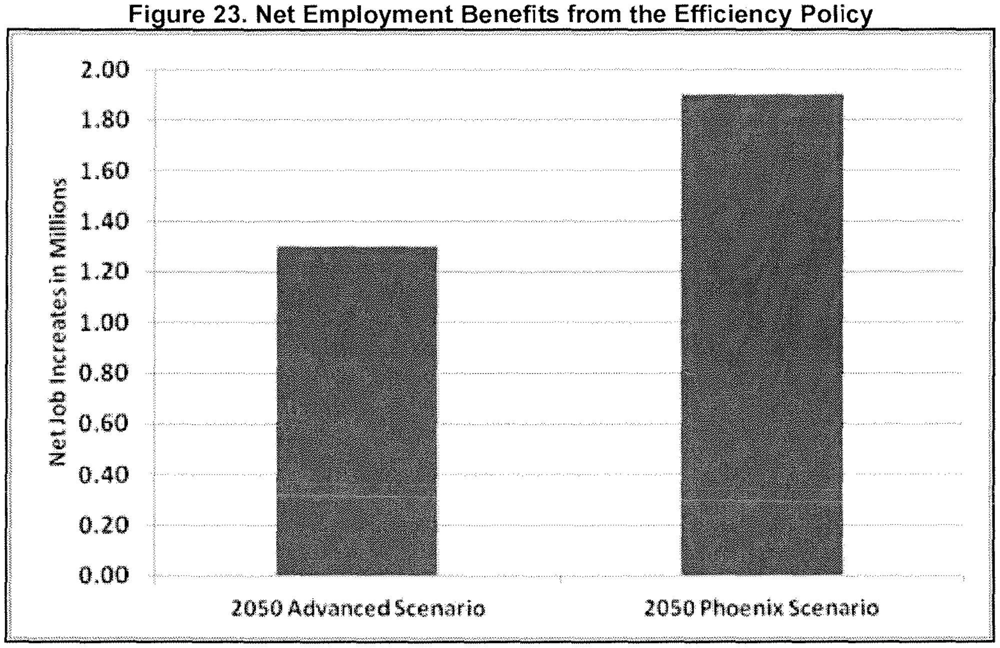
A second observation from Table 18 is the assumption that policies cost money to implement. This is true whether we are talking about private sector activities or government-initiated efforts. Such expenditures include efforts to train key personnel, to market and promote the critical ideas, to inform consumers and businesses about the opportunities, and to evaluate overall success so that appropriate adjustments can be made in overall program design and outreach. In DEEPER the working assumption—based on the evaluation of other policy initiatives—is that program costs will start at about 25% of the first efficiency investments. As more and more marketing experience builds and as the market itself is slowly transformed, the program costs are assumed to drop to about 15% of the total investment by 2050.

As one might expect, lower payback means lower upfront or capital costs. Table 18 suggests the cumulative investments in the efficiency upgrades for the Advanced Case will about $2.4 trillion over the 39-year period 2012 through 2050 (with all financial values reported in constant 2009 dollars). The significantly greater magnitude of efficiency changes in the Phoenix Case, together with the higher costs per unit of improvement, increases the cumulative investments to $5.3 trillion in that same period of time. This seems like a lot of money until we realize that the economy will likely invest something like an average of $4.6 trillion per year each year over the 2012 through 2050 time horizon. In other words, while energy efficiency appears to be significantly more costly in the Phoenix Scenario, it is still roughly the equivalent just one year's routine investment spread out over a 39-year period.

DEEPER also assumes that most of the upgrades will be financed over time rather than paid for directly by businesses and consumers. Here we implement the conservative assumption of a 7% nominal interest rate that is paid for on average for a five-year period. Because the improvements are paid for over time, this results in annual payments that are less in a given year than the new investments that are made. Cumulatively, the total payments are shown to be $2.9 and $6.4 trillion over the entire 39-year period for the Advanced Case and the Phoenix Case, respectively. But the good news is that these investments generate a cumulative energy bill savings of $15 trillion in the Advanced Case, which increases dramatically to $23.7 trillion in the Phoenix Case. This larger cumulative savings in the latter scenario is the result of both a deeper level of savings that also occurs earlier in time.

The net consumer and business savings—reflecting energy bill savings less both the program costs and the annual payments for the upgrades—run to a total of $11.6 and $16.2 trillion for the two cases, respectively. When discounted at 5% over the entire 39-year period, the net present value falls to $3.0 and $3.9 trillion for the Advance Case and the Phoenix Case, respectively. The benefit-cost ratio shows a net positive 2.8 and 2.1 for the Advanced Case and the Phoenix Case, in that order.

Figure 23. Net Employment Benefits from the Efficiency Policy



The big news is the significant and sizeable impact of these investments—and especially as those efficiency upgrades pay for themselves over time and drive a significant increase in net employment (see Figure 23 above). The Advanced Case shows about 1.3 million net jobs in the year 2050. Surprisingly, the Phoenix Case, benefiting from a larger investment and net energy bill savings, grows to 1.9 million net jobs (rounded) in 2050. The triple bottom line, including a significant net energy bill savings, a sizeable boost in the job market, and (although not shown here) a substantial reduction in air pollution and greenhouse gas emissions, confirms that the U.S. economy would be greatly revitalized under either of these two investment-led productivity .

B. The Impact of Rebound on Overall Energy Consumption

A number of policy analysts have recently written about the "rebound effect." Traditionally this term has been used to refer to potential increases in demand for energy services, as a result of efficiency improvements. For example, consumers may drive longer distances because they know their cars are more efficient and cost less to operate. Our analysis of energy savings in the transportation sector includes these impacts. In the buildings sector, a variety of field studies have shown such a rebound effect to be minimal (see, for example, Nadel 1993 and Ehrhardt-Martinez and Laitner 2010a). More recently, growing attention has been paid to a "macroeconomic rebound effect," meaning that as costs of energy services decline, resources are freed up that enable both people and equipment to amplify their level of effort and economic activity. This allows the economy to expand, which, in turn, will tend to pull energy use back up to a slightly higher level to support that added output.

If the economy is more productive as the result of the very large net energy bill savings, as suggested by the DEEPER modeling runs discussed above, the logical question is how might this affect the nation's overall energy use. Unfortunately, DEEPER is not presently set up to answer this question, but we are exploring ways to incorporate such feedback into DEEPER and hope to write a paper on this subject once we do. We note that DEEPER estimates a 0.3% and 0.4% higher GDP in the Advanced and Phoenix Cases. As a rough approximation, if the economy is 0.4% larger, than energy use might also be on the order of 0.4% higher, raising energy use by about a fourth of a quad relative to the values shown in Table 17.

V. Comparison to Other Studies: Further Discussion and Review

Ours is not the first study to look at energy efficiency opportunities out to 2050. In this section we compare our results to five other studies—Lovins et al. (2011), the California Council for Science and Technology (CCST 2011), Harvey (2010), IEA/ETP (2010), Goldstein (2009), and Laitner (2009a).

First, physicist and noted author Amory Lovins and his team at the Rocky Mountain Institute (RMI) released a book in September 2011, *Reinventing Fire: Bold Business Solutions for the New Energy Era*. In that extensive review, the RMI investigation suggested that a business-as-usual energy scenario might increase the nation's demands for primary energy to about 117 quads by 2050. This compares to our Reference Case assumption of 122 quads, which is a larger number that is likely affected by growth assumptions for the U.S. economy. While the Lovins team assumed a 158% expansion of the American economy by 2050, our assumption—based on the data extrapolated from the AEO 2011—was that the expansion of GDP might be closer to 180% by 2050.

By unleashing smart business investments at all levels of the economy, RMI found that systematic energy efficiency improvements could bring the energy consumption down to 71 quads by 2050. This is on the same order of the Advanced Case 70 quads suggested by our report, but significantly higher than the 50 quads found in the Phoenix Case. At the same time, Lovins and RMI found a very large number of system upgrades that, although not formally quantified into their main scenario, are likely to reflect a savings that would reduce total energy use much closer to 50-quad estimate reflected in our Phoenix Case. More important, they concluded "we can run the same 2050 economy . . . but with half the delivered energy, with less risk, and for $5 trillion less" (expressed in 2010 net present value dollars). When that net savings of $5 trillion is adjusted for the differences among the several scenarios and key assumptions, this compares favorably with the findings in our assessment in which we find a net present value savings that range from $3.0 to $3.9 trillion (in 2009 dollars) that are cumulative over the period 2012 through 2050 (shown in Table 18 above).

Although from a slightly different perspective, the International Energy Agency released an analysis in 2010 that also explored alternative energy futures in the year 2050. The emphasis was on reducing energy-related carbon dioxide emissions globally (IEA/ETP 2010). At the same time, however, the global scenario integrated many of the same technology perspectives reflected in the main body of this report, and it contained a separate analysis that was done for the United States in a way that makes it possible to compare those results with both this evaluation and the Reinventing Fire assessment. In short, the IEA analysis suggested that a mix of carbon abatement options might enable the U.S. to cost-effectively reduce energy-related carbon dioxide emissions by 82% compared to standard projections for the year 2050. According to the IEA report, clean energy options like nuclear and renewable energy technologies might account for 45% of the potential reductions but that various forms of energy efficiency might provide 55% of the total reductions. To better underscore the cost-effective opportunities to increase our nation's energy productivity, we can compare both the IEA/ETP and the Reinventing Fire analyses with the ACEEE Advanced and Phoenix Cases—all over the period 2010 through 2050. Table 19 below highlights the key metrics from this comparison.

Table 19. Key Metrics from Year 2050 Alternative Future Studies

Metric	Year 2050 Impacts			
	ACEEE-Advanced	ACEEE-Phoenix	IEA ETP	Reinventing Fire
BAU GDP Index (2010 = 1.00)	2.79	2.79	1.95	2.58
BAU Energy Use (2010 = 1.00)	1.24	1.24	1.05	1.27
Efficiency Scenario Energy Use (2010 = 1.00)	0.72	0.51	0.47	0.69
Investment (Trillion 2009 Dollars)	2.9	6.4	5.9	4.5
Savings (Trillion 2009 Dollars)	15	23.7	15.1	9.5

Note: Both the investments and savings data in the last two rows of the table reflect cumulative values in constant dollars over the period 2010 through 2050.

A number of insights begin to emerge with even a cursory review of the table above. First, despite wide variations in expected performance of the U.S. economy—building on the forecasts published by the Energy Information Administration (EIA 2011b), the ACEEE scenarios anticipate a "business-as-usual" (BAU) 2050 economy that is nearly three times as large as it is in 2010. The IEA suggests a much smaller growth trajectory while Reinventing Fire falls between ACEEE and the IEA. But all three suggest the potential for large gains in energy efficiency. ACEEE, for example, suggests that improvements by 2050 could see energy use that is somewhere between 51% and 72% of the 2010 consumption levels. IEA and Reinventing Fire suggest improvements that are 47% and 69% of 2010 levels. All four scenarios indicate the need for significant upfront cumulative investments that range from about \$3 to \$6 trillion (rounded) over the period 2010 through 2050. At the same time, all four also suggest the potential for a very large future energy bill savings as the size of the nation's energy bills shrink.[36]

Other assessments generally confirm these magnitudes and opportunities for efficiency improvements show in the table above. University of Toronto professor L. D. Danny Harvey (2010), for example, published an extensive 600-page volume, *Energy Efficiency and the Demand for Energy Services*, which provided a highly detailed assessment of the energy efficiency resource both in North America and globally. While focusing on stabilizing atmospheric concentrations of carbon dioxide emissions at lower levels, Harvey explored a range of economically feasible rates of reduction in the global primary energy intensities over the next 40-100 years. Depending on the assumptions affecting population growth and per capita incomes, his scenario assessments suggested that a wide variety of

[36] This larger energy bill savings suggested by ACEEE is, in significant part, because the EIA/ACEEE estimate of the Base Case GDP is higher, providing larger nominal energy and energy bill savings, especially in the ACEEE Phoenix Case. In the Phoenix Case, for example, ACEEE suggests a 70 quad energy savings by 2050. The IEA and Reinventing Fire suggest an average 55 quad savings. As this larger savings accumulates over time, the energy bill savings would be proportionately larger as well.

efficiency improvements could reduce carbon dioxide emissions by more than 40% by 2050 and as much as 80% by 2100. As he acknowledges, however, the deeper efficiency gains would require an aggressive set of behaviors and policies implemented in a persistent way over a long period of time.

Moving from a global to a state perspective, the California Council for Science and Technology (CCST) released a May 2011 report entitled *California's Energy Future: The View to 2050*. The study was motivated by both legislation and an executive order that were designed to push California total greenhouse gas emissions to 80% below their 1990 levels by the year 2050. The approach was two-fold. First, the Council wanted to establish an "existence proof." In effect, it was asking the question, can it be done? And what needs to change to allow California to get there? Second, its focus was on "technology, GHG emissions and other impacts, not economics." The conclusion was that, yes, California can achieve 80% cuts in total GHG emissions and still meet its energy needs. But the Council noted that the state might get only ~60% of the reduction cuts with technology that we largely know about today. The remaining 20% will have to come from new technologies and revised behaviors. This is not an especially daunting conclusion, since in 1970 we were arguing about whether even a 5% savings in national energy use was feasible by 2010 and we now see the very large savings that have unfolded since that time. Imagine what a forecast of computer technology 40 years ago would have failed to predict. Based on the 60% interim target, CCST identified efficiency opportunities that might help the state achieve more than half of the needed reductions.

In 2009 Physicist David Goldstein released a book entitled *Invisible Energy: Strategies to Rescue the Economy and Save the Planet* (Goldstein 2009). Following an extensive review of the efficiency potential in a full array of technologies, he concluded that "energy efficiency can produce savings of 35 to 50% in the next 20 to 40 years." At the same time, however, he suggested that savings of 80 to 90% are possible in the major uses of energy. Of most interest, Goldstein estimates that "implementing the opportunities already available with current technologies could save more than $10 trillion [for the American economy] over the next 40 years." This amount includes $4 trillion through energy savings measures plus $5 trillion in reduced energy prices. He also suggests there would likely be additional trillions in secondary non-energy benefits that result from efficiency measures.

Finally, in an investigative comparison of many typical policy models as they might assess the economic impacts of climate legislation, Laitner (2009a) set up an independent diagnostic model in a report entitled *The Positive Economics of Climate Change Policies: What the Historical Evidence Can Tell Us*. In that assessment he examined the impact of an 86% reduction in energy and non-energy greenhouse gas emissions by the year 2050. Many of the typical models, he noted, might achieve only a 72% reduction of total emissions with energy efficiency providing just 15% of those reductions, and clean energy supply (e.g., some combination of nuclear, renewable, and coal-fired electricity with carbon capture and sequestration) providing another 29%. Domestic and international offsets were expected to provide more than half of the needed reductions. All of this was at a very high cost with a negative impact on the economy. On the other hand, when energy efficiency was properly mapped into the policy solution, the diagnostic modeling exercise found that a much larger 86% emissions reduction is not only possible, but also cheaper by comparison. Energy consumption declined from 129 quads in the Reference Case to as little as 64 quads in the Policy Case. That 65-quad savings falls roughly halfway between the 50-quad savings identified in the Advanced Case and the 70-quad savings in the Phoenix Case.

VI. Conclusions and Moving Forward

Based on our nation's previous track record and the available evidence, two critical details emerge from this assessment. The first is that the larger well-being of the economy has been powered in good measure by historical gains in our nation's overall level of energy efficiency. The second is that the prospect for future improvements is very large. Perhaps more critically, our nation's larger prosperity will depend on our ability to secure those large-scale efficiency improvements. At the same time, the capacity for such improvements is larger than the public and most policymakers understand or believe.

In 1970 our economy required 15,900 Btus of energy to support a dollar of economic activity. By 2010 this ratio had fallen by more than half—to 7,300 Btus per dollar (where economic activity in measured in constant 2005 dollars). The annual rate of decline in the nation's energy intensity was about 1.9% even as our economy grew by 2.9% per year. The better part of those annual growth rates occurred in the years through 2006. Since 2006 and right on through this year, however, it appears the annual rate of energy efficiency improvement dropped to 0.7% per year, even as the nation's economy expanded by just 0.5% per year. In a working paper prepared for this assessment, the data underscores the vital link between efficiency improvements and a robust economy. Simply stated, it actually does require energy to power the economy but the energy that is at work within the economic process must be cost-effective relative to the cost of labor and other investments needed within the economy. And the cheapest form of energy has actually been the steady increase in our nation's energy efficiency (Laitner forthcoming).

In the Reference Case benchmarked to the *Annual Energy Outlook 2011* (EIA 2011b) and extended out to the year 2050, the annual rate of efficiency improvement is projected to be just under 2.0% per year over the period 2012 through 2050. In the Advanced and Phoenix Cases, that rate of improvement grows to 3.3% and 4.3%, respectively. If we choose to invest in the large-scale energy efficiency resource, the data in Table 17 imply a net energy bill savings that ranges from $2.6 to 4.0 trillion cumulative over the same time horizon of 2012 to 2050. Lovins et al. (2011) suggest that same scale of net savings, noting a $5 trillion net savings through 2050 (with all three estimates of net energy bill savings based on a net present value assessment). In other words, as Lovins notes and our own study suggests, we can run the same 2050 economy, but with 40% to 60% less energy, with less cost and less risk, and with a substantial net boost to employment—from 1.3 to 1.9 million jobs (about 0.5% above Reference Case). And as Lovins et al. (2011), the California Council of Science and Technology (CCST 2011), and other studies have all underscored, we have the technical and behavioral capacity to move in this direction, but it will require a set of policies and choices, all made possible by more productive investments.

Jacobson and Delucchi (2009) have noted that "society has achieved massive transformations before." They cite the World War II transition when "the U.S. retooled automobile factories to produce 300,000 aircraft, and other countries produced 486,000 more." Or as Laitner (2004) previously noted, rather than practical limits on further efficiency gains, it might be more the limits of public policy to encourage the needed innovations and investments (see also CCST 2011). In effect, the ACEEE energy efficiency scenarios highlighted in this study merely represent a different recipe of technology investments compared to the standard Reference Case, but it is one that emphasizes a more productive investment pattern that can enable the U.S. economy to substantially reduce overall energy expenditures—should we choose to invest in and develop that larger opportunity. The question is will we choose to make those more productive investments?

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APPENDIX A: OVERVIEW OF THE ASSESSMENT METHODOLOGY

This assessment was generally carried out in various stages over a two-year period beginning in late 2009. Our intent was to compare a 2050 reference case for each of the end-use sectors with what we might anticipate as cost-effective energy efficiency improvements, also by the year 2050. Hence, the focus was on changes, or what we might call the 2050 deltas, from a suggested business-as-usual (BAU) energy consumption for residential buildings, commercial buildings, industrial processes, and transportation services. We also included the potential energy savings from improvements in the supply-side operations of electricity generation, transmission and distribution.

Staff Leads for Sector Analysis

Harvey Sachs provided the lead on residential and commercial buildings in collaboration with Steve Nadel. Neal Elliott was the lead analyst for industry while Siddiq Khan provided the transportation sector analysis with active support from Therese Langer. Both Skip Laitner and Neal Elliot developed the set of assumptions on the potential for supply-side efficiency improvements in the electric utility sector. Laitner was the lead analyst for the macroeconomic assessment, and working with Steve Nadel, he provided the overall integration of the individual sectors as all of the individual analyses converged into the main report.

An Overview of End-Use Assessments

While we generally benchmarked to the Energy Information Administration's *Annual Energy Outlook* 2010, we also made an effort to update some key benchmarks to the AEO 2011. At the same time, each group of analysts used specific techniques appropriate to their end-use sectors which generated minor differences from the Annual Energy Outlook. In the building sectors, for example, we used an equivalent stock model that reflected different assumptions about the typical square footage of a building, its level of occupancy, and the mix of end use services which included everything from space heating and cooling, lighting, and a full array of equipment and appliances.

Industry, on the other hand, is an incredibly diverse group of agricultural, mining, construction, and manufacturing services that produces everything from aspirin tablets and pounds of fruit and vegetables to tons of copper and millions of new homes and cars. The Bureau of Labor Statistics, for example, tracks more than 9,000 producer price indexes for individual products and group of products each month (see, generally, www.bls.gov/ppi). With that enormous diversity as a backdrop, we chose to model the efficiency improvements as sector-wide changes in energy intensities over time per million constant dollars of shipments.

For transportation services we relied on the Argonne National Laboratory's VISION model (ANL 2010). This allowed us to reflect the level of energy services (for example, the number of miles traveled or ton-miles of freight that might be hauled) together with the mix and fuel economy with an evolving stock of both new and existing vehicles that might be needed to meet given demands for transportation services.

In the case of evaluating the efficiency gains in electricity generation we took the anticipated or projected demands for electricity services and produced a working estimate of how much of the electricity demands might be met through distributed generation, and at what overall system efficiencies might be anticipated with best practices associated with reasonably known generation, transmission, and distribution technologies. We also provide estimates (as suggested in Figure 21) of what the more energy-efficient, supply-side technologies might imply for the use of fossil fuels, non-fossil fuel resources (as nuclear energy and renewable energy technologies), and combined heat and power technologies, and what they, in turn, might also imply about the larger "system efficiency" of generating and distributing the electricity that might be demanded.

Against this back drop one might quickly imagine the differences which materialize when compared, for example, to the integrated National Energy Modeling System (NEMS) used by the Energy

Information Administration. As but one example of potential differences, the Annual Energy Outlook indicates a total primary energy use that is just under 98 quadrillion Btus of energy in 2010. More significantly, under the standard or BAU assumptions of normal efficiency improvements and economic growth, extending the NEMS forecast to 2050 might indicate a growth to perhaps 126 quads of energy in that same year. On the other hand, adding up the different sector assessments, we find that the total energy use might grow to only 122 quads of energy by 2050. Much of that four-quad difference appears to be the result of a divergence of assumed system efficiencies in the economy-wide production of electricity. Extending the AEO assumptions in the reference case seems to indicate an improvement of overall system efficiency from about 32% in 2010 to only 34% in 2050. Our own judgment suggests a reference case that might be closer to 36% by 2050. That small difference translates into a roughly three-quad difference. Differences in rounding and other small assumptions account for the remaining quad of BAU energy consumption.

As we have integrated the individual sector assessments for both the Advanced Case and the Phoenix Case (as defined in the main report), we find that working from an assumed 122 quad Reference Case in 2050, the individual sector savings results in an aggregate total savings of 51 and 72 quads, respectively. These integrated results are summarized in Table 17.

Future Areas of Research

While the prospects for large-scale enhancements in energy efficiency are very real, both time and resource constraints prevented us from undertaking a fully integrated macroeconomic assessment of that economic potential. This is particularly true as we evaluate the long-term economics of the suggested efficiency measures and system improvements, and as we might examine the positive environmental and climate benefits that are likely to follow from greater levels of energy productivity. For example, one specific area that we think would be useful to explore is the so-called macroeconomic rebound effect. As we've noted in the main body of the report, that impact is likely to be minimal but the issue merits further and a more systematic review.

In a related set of topics, we also believe that additional insights might be gained about the energy efficiency resource potential by integrating the human and social elements of technology development and deployment—especially as they might enable a more positive economic outcome to emerge. Here we might extend our previous work on what we call "people-centered initiatives" (Ehrhardt-Martinez and Laitner 2010b) to explore more cost-effective ways that increase energy savings. Finally, the evidence suggests that if we do not boost our nation's energy productivity well-above the historical rates of improvement, the economy may follow a less robust growth trajectory. It may turn out, for example, that a weakened energy and economic productivity may support fewer jobs than we now anticipate. In that case, rather than simply a net gain 1.3 or 1.9 million more jobs compared to the reference case, we might find that accelerating the deployment of the full energy efficiency potential might also preserve millions of existing jobs.

APPENDIX B: KEY ECONOMIC AND TECHNOLOGY ASSUMPTIONS

As implied in the main part of this report, the impact assessment described here is really an examination of how changed behaviors and investment flows might reasonably characterize an alternative and perhaps a more productive energy and economic future. As business leaders and policymakers first think about the policy implications of suggested climate change legislation, they may conclude that the implied transition to a less carbon-intensive economy will end up costing more. On the other hand, when all system costs are properly included and balanced, it can be shown—on a net basis—that the alternative future or the enacted policy may actually cost less.

In a format consistent with a number of other past studies that inform this debate (see, for example, McKinsey 2009; CCS 2008; Laitner and McKinney 2008; Barrett et al. 2005; Laitner et al. 2006; Lovins et al. 2004; Interlaboratory Working Group 2000), this appendix highlights the major analytical assumptions that underpin the assessment described in the main part of the report.

The assumptions generally fall into four major categories: prices, quantities, investment flows, and input-output modeling. Each of these categories is subscripted by sector and by end-use energy or fuels. The analytical tool used to evaluate the energy and climate policy impacts is the DEEPER Model, which is described next. This is then followed by the major price, cost, income, and demand assumptions that underpin the results summarized in the main body of the report.

The DEEPER Modeling System

The Dynamic Energy Efficiency Policy Evaluation Routine—the DEEPER Modeling System—is a 15-sector quasi-dynamic input-output model of the U.S. economy.[37] Figure A-1 on the following page contains a block diagram of the model that highlights many of the key features discussed in this appendix. Although updated model with a new name, the DEEPER model has a 19-year history of use and development. See Laitner, Bernow, and DeCicco (1998) for an example of an earlier set of modeling results.[38] Laitner and McKinney (2008) also review past modeling efforts using this modeling framework. The model is used to evaluate the macroeconomic impacts of a variety of energy efficiency, renewable energy, and climate policies at both the state and national level. The timeframe of the model for evaluating policies at the national level is 2010 through 2050, or in the case of evaluating the Long-Term Energy Efficiency Outlook characterized in this report, for the single year impact for 2050. In its current implementation, the model iterates for the net impacts across the sectors of the economy to evaluate gains and losses in jobs, income and contribution to GDP compared to a previously defined Reference Case.

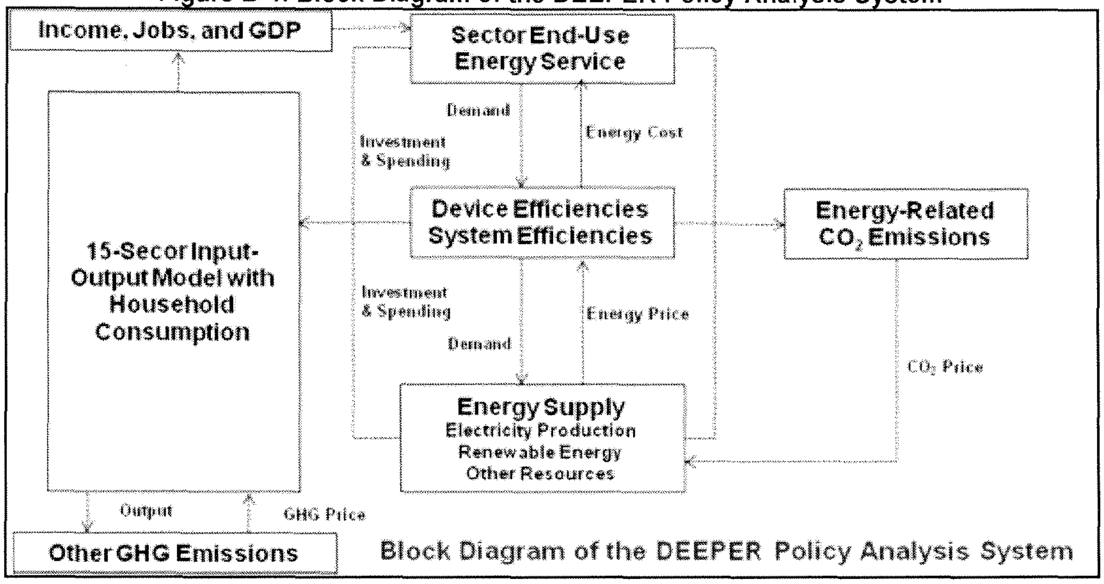
Although not used in this particular assessment, the model includes a representation of both energy-related CO_2 emissions and all other greenhouse gas emissions as well as emissions reduction opportunities. The DEEPER Model focuses, in particular, on the use of energy in all sectors of the economy, electricity production, and energy-related CO_2 emissions as well as on the prices, policies, and programs necessary to achieve the desired emissions reductions. The DEEPER Model is an Excel-based analytical tool with three linked modules combining approximately two dozen interdependent worksheets. The primary analytic modules are: (i) the Energy and Emissions Module,

[37] There are two points that might be worth noting here. First, the model solves recursively. That is, the current year set of prices and quantities is dependent on the previous years' results. As the model moves through time, there are both secular and price-quantity adjustments to key elasticities and coefficients within the model. Second, there is nothing particularly special about this number of sectors. The problem is to provide sufficient detail to show key negative and positive impacts while maintaining a model of manageable size. If the analyst chooses to reflect a different mix of sectors and stay within the 15 x 15 matrix, that can be easily accomplished. Expanding the number of sectors will require some minor programming changes and adjustments to handle the larger matrix.

[38] When both equilibrium and dynamic input-output models use the same technology assumptions, both models should generate reasonably comparable set of outcomes. See Hanson and Laitner (2004) for a diagnostic assessment that reached that conclusion.

(ii) the Electricity Production Module, and (iii) the Macroeconomic Module. The block diagram of the DEEPER Modeling System on the following page lays out the analytical framework of the model.

Figure B-1. Block Diagram of the DEEPER Policy Analysis System



The model outcomes are driven primarily by the demands for energy services and alternative investment patterns as they are shaped by changes in policies and prices. A key feature of the model is one that also allows consumer behaviors to also adjust to changing preferences. This follows the logic outlined in Laitner, DeCanio, and Peters (2000), and fits within the framework outlined by Ehrhardt-Martinez (2008). The changes are implemented in what we call a price-preference ratio following Laitner (2009b) and Laitner and Hanson (2006). The functional form of the price-preference ratio is computed as an index of price divided by the consumer's implicit discount rate. This is a rate that reflects a desired return on investment. For example, if a consumer chooses not to adopt a technology, for whatever reason, unless it pays for itself over a 2-year period, that suggests a 50% discount rate; or said differently, a desire to earn at least a 50% return on his or her investment in an energy-efficient technology. All else being equal, either a doubling of prices or a 50% reduction in the implicit discount rate (or some equivalent combination of the two) will have the same impact on the various elasticities within the model.[39]

Although the DEEPER Model is not a general equilibrium model, it does provide sufficient accounting detail to match import-adjusted changes in investments and expenditures within one sector of the economy and balance them against changes in other sectors. As shown in the block diagram above, the demand for energy-related services is the starting point for policy-induced changes. Both price and non-price policies—including standards, technical assistance, financial incentives, research and development (R&D), or general information and labeling programs (e.g., the EPA and DOE ENERGY STAR programs)—can shift consumer preferences and the availability of technologies. Implementation of these policies stimulates an array of changes in prices, investments, and expenditures. These changes include program costs and incentives that might be needed to shift behaviors and investments so that the energy and emissions targets are satisfied. As changing demands confront a changing mix of energy resources, GHG prices (in constant dollars per metric ton of avoided CO_2-equivalent emissions) and energy prices (in constant dollars per million Btus of energy) are likely to change in response. The combination of new policies and induced changes in

[39] One nice feature of this functional form is that it is less important to determine the "right" starting implicit discount rate as it is to show what a shift in the size of that rate might matter.

prices stimulates changes in investments and other consumer behaviors. These changes in investments and consumer behaviors drive the final results that emerge from application of the DEEPER Model.[40] With this preliminary characterization of the model, the sections that follow describe the three major modules within DEEPER.

Energy and Emissions Module: The DEEPER Model is benchmarked to the most current version of the *Annual Energy Outlook* (EIA 2011b), which now extends out through 2035. Based on data available from other sources like Economy.com (2010), which now goes out to 2041, we must make a reasoned estimate of how the economy might grow through the year 2050 in a "Business-as-Usual" or Reference Case scenario, and how that will, in turn, affect energy use, fuel and electricity prices, and greenhouse gas emissions. The key benchmark data for the Reference Case are highlighted in Table A-1, below.

Table B-1. Key Reference Case Data for Benchmark Years

Indicator	2010	2025	2050	Annual Growth Rate 2010-2050
Population (millions)	310.8	358.1	442.0	0.88%
Total Energy Use (Quads)	97.7	107.8	124.6	0.61%
Per capita Income (2005 dollars)	42,535	55,899	83,796	1.71%
US GDP (billion 2005 dollars)	13,221	20,015	37,042	2.61%
Energy Intensity (kBtu / 2005 $GDP)	7.39	5.38	3.36	-1.95%
Average End Use Energy Price (2009 $/MBtu)	16.58	19.08	21.42	0.64%
Total Energy Expenditures (Bln 2009 dollars)	1,168	1,503	1,949	1.29%

The main Reference Case assumptions shown in the above table are for the key benchmark years of 2010, 2025 and 2050. In general the economy is expected to grow at a rate of about 2.6% annually; total end-use energy consumption will grow 0.6% per year. Rising average annual end-use energy prices (with all values in 2009 dollars) will increase at a rate of about 0.6% annually. Because of the expected growth in overall energy use, the nation's total energy bill (across all sectors and all fuels) will grow about 1.3% per year—escalating from an estimated $1.2 trillion dollars in 2010 to about $1.9 trillion by 2050.

Some of the important inputs derived from this module that feed into the macroeconomic model described below include:

- The policies and measures that are phased in over time;
- The stringency of the emissions reduction target;
- The rates of growth in energy-related prices;
- The pattern of consumer and investor decisions concerning the adoption of new technologies; and
- The resulting innovations that lead to new technologies and/or changes in demands for services.

[40] As noted in Hanson and Laitner (2004), a combination of price and non-price policies can generally produce a much more cost-effective policy resolution than either type of policies would induce by itself. The resulting deployment of new technologies depends on the assumed effectiveness of programs that might be implemented and the incentives being offered. Implementation of these policies—along with the resulting deployment of new technologies—strengthens the ability of the market to respond to the price signal. In this context, prices act as a signal for necessary changes, rather than as a punishment for consumers and producers.

Table B-2. Employment, Compensation, Value-Added, and Total Output by Sector 2009

		Millions of Dollars		
Economic Sector	**Employment (Million Jobs)**	**Employee Compensation**	**Value-Added**	**Output**
Agriculture	3.39	40,503	130,286	346,793
Oil & Gas Extraction	0.78	46,901	176,602	341,321
Coal Mining	0.10	7,454	16,339	32,410
Other Mining	0.17	9,696	30,974	60,026
Electric Utilities	0.51	58,070	205,868	327,468
Natural Gas Utilities	0.11	13,206	63,725	182,788
Transportation, Other Utilities	3.46	150,949	263,638	576,688
Construction	9.87	378,245	573,984	1,216,251
Manufacturing	11.96	820,545	1,498,632	5,191,447
Refining	0.08	12,619	122,653	699,919
Trade	23.57	886,527	1,653,055	2,216,415
Services	100.73	4,621,345	7,322,787	10,768,655
Finance	15.81	630,575	1,962,162	3,090,895
Government	1.85	136,505	98,395	310,579

Macroeconomic Module: This set of spreadsheets contains the "production recipe" for the U.S. economy for a given "base year." For this study, the base year used was 2009. The input-output data, or sometimes referred to as the I-O data, currently purchased from the Minnesota IMPLAN Group (IMPLAN 2011), is essentially a set of economic accounts that specifies how different sectors of the economy buy (purchase inputs) from and sell (deliver outputs) to each other. Further details on this set of linkages can be found in Hanson and Laitner (2009). For this study, the model was run to evaluate impacts of the selected policies upon 15 different sectors, including: Agriculture, Oil and Gas Extraction, Coal Mining, Other Mining, Electric Utilities, Natural Gas Distribution, Construction, Manufacturing, Wholesale Trade, Transportation and Other Public Utilities (including water and sewage), Retail Trade, Services, Finance, Government, and Households.[41] To provide the reader with a sense of scale for these major sectors, Table A-2, above, provides sector employment (in millions of jobs and the individual sector wages and value-added contributions to the nation's gross domestic product (GDP) as well as the total economic output of the U.S. economy (with all of the dollar values in millions of 2009 dollars). As described below, examining the job and value-added intensities of the different sectors in this table provides early insights of likely scenario outcomes.

The principal energy-related sectors of the U.S. economy are not especially job-intensive. For example, taking total employment for electric utilities and dividing it by the total number of revenues received by those that sector, it turns out that the nation's electric utility industry in 2009 supported only 1.6 direct jobs for every one million dollars of revenue received in the form of annual utility bill payments. The rest of the economy, on the other hand, supports about 6.8 direct jobs per million dollars of receipts. *Thus, any productive investment in energy efficiency that pays for itself over a short period of time will generate a net energy bill savings that can be spent for the purchase of goods and services other than energy.* The impact of a one million dollar energy bill savings suggests there may be a net gain of about 5.4 jobs (that is, 6.8 jobs supported by a more typical set of consumer purchase compared to the 1.6 jobs supported by the electric utilities). Depending on the sectoral interactions, however, this difference may widen or close as the changed pattern of spending works its way through the model, and as changes in labor productivity changes the number of jobs needed in each sector over a period of time.[42]

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[41] While there are only 14 sectors shown in the table above, household spending is allocated to each of the sectors using the personal consumption expenditure data provided with the IMPLAN data set.
[42] As we will see later in this appendix, DEEPER does capture sector trends in labor productivity. That means the

Based on the mapped into the Energy and Emissions module, the set of worksheets in the Macroeconomic Module translates the selected energy policies into an annual array of physical energy impacts, investment flows, and energy expenditures over the desired period of analysis. Using appropriate technology cost and performance characterization as it fits into the investment stream algorithm discussed below, DEEPER estimates the needed investment path for an alternative mix of energy efficiency and other technologies (including efficiency gains on both the end-use and the supply side). It also evaluates the impacts of avoided or reduced investments and expenditures otherwise required by the electric generation sector. These quantities and expenditures feed directly into the final demand worksheet of the module. The final demand worksheet provides the detailed accounting that is needed to generate the implied net changes in sector spending. Once the mix of positive and negative changes in spending and investments have been established and adjusted to reflect changes in prices within the other modules of DEEPER, the net spending changes in each year of the model are converted into sector-specific changes in final demand. This then drives the input-output model according to the following predictive model:

$$X = (I-A)^{-1} * Y$$

where:

X = total industry output by sector
I = an identity matrix consisting of a series of 0's and 1's in a row and column format for each sector (with the 1's organized along the diagonal of the matrix)
A = the matrix of production coefficients for each row and column within the matrix (in effect, how each column buys products from other sectors and how each row sells products to all other sectors)
Y = final demand, which is a column of net changes in spending by each sector as that spending pattern is affected by the policy case assumptions (changes in energy prices, energy consumption, investments, etc.)

This set of relationships can also be interpreted as

$$\Delta X = (I-A)^{-1} * \Delta Y$$

which reads, a change in total sector output equals the expression $(I-A)^{-1}$ times a change in final demand for each sector.[43] Employment quantities are adjusted annually according to exogenous assumptions about labor productivity in each of the sectors within the DEEPER Modeling System (based on Bureau of Labor Statistics forecasts; see BLS 2009). From a more operational standpoint, the macroeconomic module of the DEEPER Model traces how each set of changes in spending will work or ripple its way through the U.S. economy in each year of the assessment period. The end result is a net change in jobs, income, and GDP (or value-added).

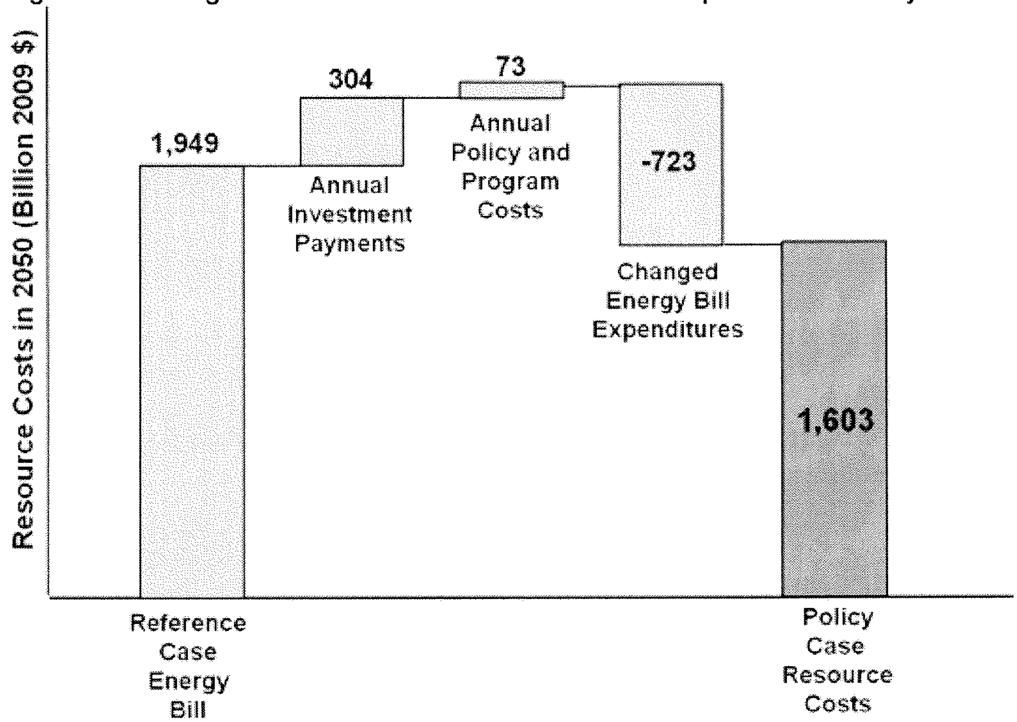
For each year of the analytical time horizon (i.e., 2012 to 2050 for the climate policy assessment in this report), the model copies each set of results into this module in a way that can also be exported to a separate report. For purposes of this separate report, and absent any anomalous outcomes in the intervening years, we highlight the decadal results in order to focus attention on the differences in results emerging from various alternative policy assumptions. For a review of how an I-O framework might be integrated into other kinds of modeling activities, see Hanson and Laitner (2009). While the DEEPER Model is not an equilibrium model, we borrow some key concepts of mapping technology representation for DEEPER, and use the general scheme outlined in Laitner and Hanson (2006). Among other things, this includes an economic accounting to ensure resources are sufficiently available to meet the expected consumer and other final demands reflected in different policies.

number of jobs needed per million dollars of revenue will decline over time.

[43] Perhaps one way to understand the notation $(I-A)^{-1}$ is to think of this as the positive or negative impact multiplier depending on whether the change in spending is positive or negative for a given sector within a given year.

Figure B-2 on the following page offers a diagram that illustrates the way DEEPER tracks changes in expenditures to evaluate the macroeconomic impacts of policy. In this case the example is drawn a typical diagnostic run of the Advanced Case Policy Scenario for the year 2050. The Base Case energy expenditures are estimated to be $1,949 billion (in 2009 dollars) for 2050. The enhanced energy efficiency provisions require an outlay of $304 billion in combined energy efficiency investments together with payments to the market for borrowing the necessary funds. The entire case is driven by an estimated $73 billion in various public and private program spending to catalyze the investments and more energy-efficient behaviors. The economy-wide energy bill savings are estimated to be $723 billion in 2050. The bottom line is a net reduction from the Reference Case energy bill so that businesses and consumers are paying only $1,603 billion for energy as a result of the improved efficiency gains.

Figure B-2. Changes in the 2050 Resource Costs from Adoption of Efficiency Policies



Source: DEEPER Diagnostic Run for Advanced Policy Case Impacts

Energy Prices

The sector prices for electricity and fuels are typically shaped by the change in demand for energy and any potential cost of CO_2 emissions as a function of their carbon intensities. In this analysis, however, we follow the Reference Case prices for energy by fuel and by sector through the year 2050. Table B-1 highlights the kinds of pricing changes that might be expected within the economy.

Technology Investment Streams

As previously noted, the investment costs are estimated for three different categories of emissions reductions: energy efficiency investments, low-carbon energy supply technologies, and non-CO_2 emissions reductions. The key set of assumptions for each of the major sources of investment flows is summarized below.

Energy Efficiency

One critical piece of information needed to evaluate the impact of these is the cost of investment in energy efficiency technologies. To derive this information, we adapt the structure of the Long-Term Industrial Energy Forecast or LIEF model (Cleetus et al. 2003). The key relationship in this model is the current gap between average and best energy efficiency technology or the best efficiency practice.

The assumption in the LIEF model is that as a sector moves closer and closer to best practice or best technology (sometimes referred to as the production frontier), the cost of efficiency investment per unit of energy saved will increase. The rate of that potential cost increase depends on the energy prices, the elasticity of the efficiency supply curve, and the discount rate. It also depends on how innovations and R&D policies might shift the best technology or best practice frontier. As used in this exercise, the investment cost is shown as:

$$\text{Investment per Unit Energy Savings} = \left[\frac{1-G_0}{1-S}\right]^{(1/A)} * \left[\frac{P}{C}\right]$$

where:

P = price of energy in the base year
C = capital recovery factor (CRF) or sector implicit discount rate for the given year
A = an elasticity that reflects the magnitude of the investment response to changes in price levels or the capital recovery factor
S = percent of sector energy savings in current year compared to base year consumption
G_0 = the energy intensity gap, or the difference between best and average practice

In many ways this can be thought of as the energy savings that should be economically viable in the base year, but have not been realized.

By way of example, the data might suggest that today there is a current energy intensity gap of 25% based on the potential for long-term efficiency gains through the year 2050, a long run efficiency substitution elasticity of 0.6, and an implicit discount rate of 20%.[44] If energy prices of a given sector are, say, $12.19 per million Btu in 2010, these assumptions suggest an average payback of about 3.7 years for a 10% efficiency gain based on prices in 2010. This rises to a 10-year payback for a 50% efficiency gain by 2050. Based on the much higher Reference Case prices in 2050, these paybacks would decline over time to 1.4 and 3.7 years. These results are broadly consistent with results summarized in Laitner et al. (2006) and Hanson and Laitner (2004).[45]

At the same time, the DEEPER Model uses a modified accounting function for each of the end-use sectors and fuels as they are impacted by the American Power Act provisions, out to 2030. Using estimates from McKinsey & Company (2009), Committee on America's Energy Future (2010), Gold et

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[44] This adaptation of the LIEF equation ignores the autonomous time trend component. In other words, as used here, the assumption of an efficiency gap remains static and there is only movement toward best practice or best technology rather than improvement in the base year representation of best practice or best technology. As the historical record suggests, the gap may actually grow to 50%—if the U.S. chooses to invest in greater innovation and energy productivity improvements. Hence, the use of a fixed 25% gap for purposes of estimating investment costs will tend to overstate the cost of the new efficiency gains.

[45] Although this is not emphasized in either the report or appendix, DEEPER also can explore changes in costs needed to drive a final result. For example, as it is now configured, if investments cost 20% less than now projected for the year 2050, the net gain in jobs shown in the main report increase by about 3.5%. On the other hand, if the investments run about 50% more than now suggested, the net increase in jobs might decline by about 9%. But this would continue to be a highly positive net gain in 2050. The significance of this finding is that the framework of the American Power Act framework—especially if it includes a greater emphasis on energy productivity benefits—is likely to generate a robust outcome for the American economy for all the reasons described earlier in the report.

al. (2009), and Eldridge et al. (2009), among others, each of the cost curve functions was adjusted by sector to reflect both the current and anticipated technology costs and performance reflected in those various studies. In the modeling characterized in this report, the payback periods typically begin at about 2.5 to 3 years in 2013, and depending on policy assumptions, R&D, changes in implicit discount rates, and how quickly efficiency is "used up," the payback periods in 2050 might range from 5 to 9 years. On the other hand, to the extent that that are innovations and economies of scale and scope that tend to lower technology costs, we might expect to see paybacks that remain closer to 5 years. For this working assessment, however, we generally allow DEEPER to move toward the higher technology costs since we are more interested in highlight the potential of energy efficiency rather than evaluating a specific set of policy over time. In this regard we are then maintaining a conservative (i.e., higher cost) focus in completing this particular assessment for 2050.

Policy and Program Costs

One of the working assumptions in this review is that that policies and programs are needed to drive the requisite investments. In generating an estimate of what these incremental costs might look like, we borrow from a study by Amy Wolfe and Marilyn Brown, *Estimates of Administrative Costs for Energy Efficiency Policies and Programs* (Interlaboratory Working Group 2000, Appendix E-1). In that study the average administrative cost is assumed to be \$0.60 per million Btu of efficiency gains. In Eldridge et al. (2009) and McKinsey & Company (2009), these program costs were generally assumed to run about 15-20% of the annual investments in efficiency gains. In Table 4 of this main report, comparing the program cost totals with the annual payments for investments, the range is shown to be approximately 24% in the early years as program activity and R&D investments scale up early in the scenario. Under the current assumptions this declines to about 18% by 2050.