

Beyond Wedges:

Achieving the Obama Administration's Goals for Reducing Greenhouse Gas Emissions



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Dear Reader:

To address climate change, the Obama Administration has set forth an ambitious goal for reducing CO₂ emissions, as well as a comprehensive set of Obama-Biden initiatives to reach this goal.

The question now being asked is -- *To what extent will the Obama-Biden initiatives, encompassing policy, technology, and price-driven actions, meet the goal?* Our report entitled, "Beyond Wedges: Achieving the Obama Administration's Goals for Reducing Greenhouse Gas Emissions" seeks to answer this important question.

Overall, we are optimistic and find that the Obama-Biden initiatives "get you 80% of the way there". However, an additional set of initiatives, not yet officially defined, would need to be formulated to achieve the remaining 20%. While the additional set of initiatives are numerous, we have provided in the report a few of our favorites.

We recognize that both the levels of reduction in CO₂ emissions and the accomplishment of these initiatives are challenging and possibly controversial. Moreover, each of you may have your own favorite initiatives and pathways for meeting the deep reductions in CO₂ and other greenhouse gases called for by the Obama Administration. We welcome your observations, feedback and critique.

Please note that this report -- "Beyond Wedges: Achieving the Obama Administration's Goals for Reducing Greenhouse Gas Emissions" -- reflects the judgments and reflections of the authors. While we gratefully acknowledge the U.S. Department of Energy/National Energy Technology Laboratory for their support, we are submitting this report as the product of our firm, Advanced Resources International, Inc.

Sincerely,

Vello A. Kuuskraa
President

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EXECUTIVE SUMMARY

The Obama Administration has proposed an ambitious national goal for managing CO₂ and other greenhouse gas (GHG) emissions, calling for these emissions to be reduced 80% by 2050¹. In addition, the Obama Administration, in the Obama-Biden comprehensive New Energy for America Plan, as well as in its other public statements, has set forth a set of initiatives that would place the nation on a pathway toward meeting this ambitious goal.

With annual U.S. greenhouse gas emissions projected to reach 9.5 billion metric tons (CO₂ equivalent) in 2050 in the Reference Case, achieving the Obama Administration's goal would limit annual GHG emissions in year 2050 to 1.2 billion metric tons, requiring an annual reduction of 8.3 billion metric tons.

This White Paper addresses the questions - - Is the ambitious CO₂/GHG emission reduction goal for year 2050 realistic?, To what extent will the "Obama-Biden Initiatives" achieve this goal?; and What would constitute the full set of initiatives and actions needed to reach this goal? We have drawn on our many years of analyzing alternative CO₂ emission reduction options, as well as our CarBen Model², to address these questions.

We find that the Obama-Biden initiatives go a long way toward meeting this CO₂/GHG emissions reduction goal. However, additional ideas, actions and pathways are required if the nation is to fully transition to the low-carbon economy envisioned by the Obama-Biden New Energy for America Plan.

¹ This CO₂ emissions reduction target is alternately defined as an 83% reduction from of 2005 levels, or an 80% reduction below 1990 levels. These two quantitative versions of the goal result in very similar CO₂ emission reduction targets for 2050.

² The CarBen Model is a transparent spreadsheet model of the U.S. economy that links domestic energy use (and other activities) to annual rates of CO₂ and other GHG emissions.

Our study assumes that a combination of policy initiatives and economic incentives (a price on carbon emissions of about \$40 to \$50 per metric ton of CO₂ equivalent) will compel industry to pursue major CO₂/GHG emission reductions. These initiatives include the development of more efficient, lower cost carbon capture and storage technology (CCS), the installation of advanced public transportation infrastructure (including high-speed rail connecting densely populated areas), and the transformation of the automobile industry with Plug-In Electric Hybrid (PHEV) vehicles and high mileage efficiency standards. Underlying these more visible actions would be steady progress in energy efficiency, both in end use and in various industrial practices.

A closer look at the specific Obama-Biden initiatives in the New Energy for American Plan shows that they would lead to 6.8 billion metric tons of annual CO₂/GHG emission reductions in year 2050 (Table EX-1):

- The “prescribed initiatives” in the Plan, such as increasing fuel economy standards, weatherizing one million homes annually, and “Putting 1 million plug-in hybrid cars on the road by 2015,” among others, would result in a 3.4 billion metric ton “wedge” of CO₂/GHG emission reductions.
- The “technology-driven initiatives”, from the Administration’s support of various research pathways such as developing and applying carbon capture and storage (CCS) technology in the Electricity Sector (as part of Clean Coal Technology) and the extension of CCS into the Industrial Sector, would provide a second 2 billion metric ton “wedge”.
- Market responses to a “price on carbon” from an economy-wide cap-and-trade program would provide a third, 1.4 billion metric ton “wedge” of reductions from non-CO₂ GHGs (such as methane) while providing incentives and economic rationale for pursuing the larger set of policy-driven Obama-Biden initiatives.

Table EX-2 and Table EX-3 provide additional sector level detail on the impacts of the GHG emission reductions pathways addressed by the Obama-Biden plan.

Table EX-1: Future CO₂ Emissions: Reference Case vs. Obama Administration Goal

U.S. Economic Sectors GHG Sources	Reference Case Year 2050 GHG Emissions*	Obama-Biden New Energy for America Plan, GHG Emission Reduction Initiatives (Tier I)				Supplemental Initiatives (Tier II)	Total GHG Emission Reductions	Achieving the Obama Administration's Year 2050 GHG Emission Goal
		Prescribed Initiatives	Technology- Driven Initiatives	Price- Driven Initiatives	Sub-Total			
1. Electricity	3.38	(1.58)	(1.52)	**	(3.10)	-	(3.10)	0.27
2. Transportation	2.49	(1.37)	-	**	(1.37)	(0.22)	(1.58)	0.91
3. Industrial Sector	1.05	(0.22)	(0.47)	**	(0.69)	-	(0.69)	0.35
4. Residential/Commercial	0.64	(0.26)	-	**	(0.26)	-	(0.26)	0.38
5. Non-CO ₂ GHGs	1.96	-	-	(0.63)	(0.63)	(0.68)	(1.31)	0.65
6. Terrestrial Offsets	-	-	-	(0.77)	(0.77)	-	(0.77)	(0.77)
7. International Offsets/Other	-	-	-	-		(0.56)	(0.56)	(0.56)
Total	9.5	-3.4	-2.0	-1.4	-6.8	-1.5	-8.3	1.2

* All figures in billions of metric tons of CO₂ equivalent annual emissions

** Technology driven initiatives depend on implementation of new technologies, but are supported by a carbon price

Table EX-2: GHG Emission Reductions from Obama-Biden Plan (Tier I) Initiatives

GHG Emission Reduction Pathways (MMmt)	2012	2020	2030	2050
1. Electricity Sector				
Energy Efficiency	0	81	284	753
Renewable Electricity Generation	124	325	550	826
Retrofit of Existing Plants with CCS	0	208	644	1,062
Deployment of New IGCC/NGCC Plants with CCS	25	251	484	461
Sub-Total	150	865	1,962	3,102
2. Transportation Sector				
Market Penetration of PHEVs	5	69	249	690
Increased Fuel Efficiency Standards	114	284	349	508
Low Carbon Fuels Standard	5	55	114	134
Public Transportation	106	52	49	33
Sub-Total	230	460	760	1,366
3. Industrial Sector				
Energy Efficiency				
Refining and Bulk Chemical Industries	25	53	68	92
Other Industries	28	70	93	128
Industrial Sector Carbon Capture and Storage				
Refining and Bulk Chemical Industries	0	17	84	208
Other Industries	2	38	118	265
Sub-Total	55	179	363	693
4. Commercial/Residential Sector				
Energy Efficiency				
Building Shell Efficiency Upgrades	3	15	30	58
Appliance/Equipment Efficiency Upgrades	38	103	156	207
Sub-Total	41	118	186	264
5. Non-CO2 & High GWP Gases				
Abatement of Non-Energy GHG Emissions				
Methane	10	41	122	253
Nitrous Oxide	1	6	28	66
High GWP Flourinated Gases	2	8	88	314
Sub-Total	13	56	238	633
6. Other				
Offsets from Forestry and Land Use Changes	0	191	383	765
Total GHG Emission Reductions (MMmt)	488	1,868	3,892	6,822

Table EX-3: CO₂/GHG Emission Reductions by Sectors of the U.S. Economy

1.	ELECTRICITY
	<i>Significant Efforts on Energy Efficiency, Increased Renewables and Carbon Capture and Storage in the Electricity Sector</i> , plus conversion of older power plants to biomass and modest increases in the use of natural gas, would provide <u>3.1 billion metric tons</u> of CO ₂ emission reductions.
2.	TRANSPORTATION
	<i>A Radically Transformed Transportation Sector</i> , involving increased public transportation, higher CAFE Standards, significant market penetration of (PHEVs) and a Low Carbon Fuels (LCF) standard would lead to <u>1.6 billion metric tons</u> of CO ₂ emission reductions.
3.	INDUSTRY
	<i>Incorporation of Energy Efficiency and Carbon Capture and Storage in the Industrial Sector</i> , particularly advances in manufacturing processes as well as capture (and productive use) of high CO ₂ concentration vents would stimulate <u>0.7 billion tons</u> of CO ₂ emission reductions.
4.	RESIDENTIAL AND COMMERCIAL
	<i>Improved End Use Energy Efficiency in the Residential and Commercial Sectors</i> through improved architectural designs, weatherization of homes and higher energy efficiency standards for appliances would support <u>0.3 billion metric tons</u> of CO ₂ emission reductions.
5.	NON-CO ₂ GASES
	<i>Significant Reductions in the Emissions of Non-CO₂ Gases (methane, nitrous oxide and fluorinated gases)</i> , including an eventual ban on the production and release of high global warming potential (HGWP) fluorinated gases would account for <u>1.3 billion metric tons</u> of CO ₂ equivalent emission reductions.

However, we will need to go beyond this initial set of CO₂ emission reduction “wedges” if the year 2050 greenhouse gas emission target is to be fully met. Our White Paper identifies a number of actions and initiatives that would help close the gap, providing the final, most challenging, 1.5 billion metric ton “wedge”. These supplemental actions could include banning the manufacturing and release of fluorinated (HGWP) gases, setting performance standards on methane emissions from oil and gas production, and further reducing CO₂ emissions in the Transportation Sector. Our analysis suggests that, in addition to the above, reaching the goal may require the purchase of GHG emission credits (offsets), equal to 0.6 billion metric tons of CO₂ from international sources. With diligent pursuit of advances in technology and other supplemental actions, we believe the purchase of CO₂ emission credits from international sources can and should be minimized.

We do not estimate what this energy and climate change transition will cost. However, we agree with Sir Nicolas Stern and other distinguished climate change investigators that the cost of inaction will be far greater. In a recent speech, president Obama aptly characterized the urgency of making this transition, saying, “The choice we face is not between saving our environment and saving our economy. The choice we face is between prosperity and decline³.”

This White Paper is our contribution to the grand effort the U.S. must now undertake to decarbonize our economy. In it, we have built upon the concept of “wedges,” introduced by previous climate change investigators (to whom we are greatly indebted^{4,5}), and used robust quantitative analysis to prioritize this set of climate change initiatives by their potential to mitigate GHG emissions. It is our hope that this analysis can help inform environmentally and economically sound decision-making that most efficiently uses society’s resources to solve the climate change problem. It is now time to go “beyond wedges” and take constructive action.

³ Remarks by the President on Clean Energy. April 22, 2009. Available at: http://www.whitehouse.gov/the_press_office/Remarks-by-the-President-in-Newton-IA/

⁴ Socolow, R.H., “Can We Bury Global Warming?”, *Scientific American*, July 2005.

⁵ P. Dipietro and V. Kuuskraa, “Armadillos in Oklahoma?”, presented at the Sustainable Energy Technologies Seminar: Carbon Sequestration, Nitze School of Advanced International Studies, The Johns Hopkins University, April 2007.

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I. INTRODUCTION

In policy documents and the 2010 Budget, the Obama Administration has set forth actions and initiatives to reduce annual CO₂ emissions by 80% in the year 2050. These initiatives and actions are many, and include putting one million plug-in hybrid cars on the road by 2015, ensuring that 25 percent of our electricity comes from renewable sources by 2025, and using cap-and-trade to place a “price on carbon”.

This White Paper addresses the question - - To what extent will these initiatives, and actions achieve the greenhouse gas reduction goal?

Table 1 summarizes the suite of policy initiatives and actions (emission reduction pathways) we analyze in this White Paper. We have divided these into two tiers, based on their conformance to the Obama-Biden Plan⁶.

- **Tier I Pathways** are those that are explicitly set forth as the Obama-Biden energy and climate change initiatives. Additionally, Tier I pathways include those that, while not explicitly mentioned, would follow naturally from the technological development and market-based incentives promoted by explicitly mentioned initiatives. Explicitly mentioned policies include increased market penetration of PHEVs and renewable electricity generation targets. An example of an initiative not explicitly mentioned, but that logically follows from technological development, is deploying Carbon Capture and Storage (CCS) in the Industrial Sector.
- **Tier II Pathways** include the remaining actions needed to meet the CO₂ emission reduction targets, such as the phase-out of high GWP gases and purchase of international CO₂ emission credits.

⁶ We investigate the initiatives with major emissions reduction potential as stated under the Obama Administration's Agenda on Energy and the Environment. This text is reproduced in Appendix B and available online at: http://www.whitehouse.gov/agenda/energy_and_environment/

The GHG emission reduction actions investigated in this report, while reflecting long-term marginal abatement costs, are fundamentally policy driven. We have not limited the application of certain technologies solely on the basis of their high cost. As such, we identify, using the CarBen model, the volume of emissions that could be realistically “squeezed out” of each sector of the U.S. economy, assuming that time and technology are the primary limiting factors.

We have chosen this approach based on our belief that near-term economic costs are not always appropriate constraints in long-term energy and climate change models. The costs of adopting GHG abatement actions and technologies, especially those that are newer and untested, will fall dramatically over time in response to appropriate incentives and “learning by doing”. As support for our approach is the policy decision to aggressively pursue wind and solar power, technologies with relatively high current costs of CO₂ emissions abatement, but whose price/kWh has fallen impressively over the past 10 years.

However, for the most part, the GHG emission reduction actions set forth are consistent with a long term CO₂ abatement cost of \$40 to \$50 per metric ton.

Table 1: Emission Reduction Pathways Investigated in This White Paper

Tier I – Emission Reduction Pathways Encouraged by the Obama Administration			
Electricity Sector	Transportation Sector	Industrial/Agricultural/ Terrestrial Sectors	Residential/ Commercial Sectors
Increased Energy (Fuel) Efficiency (Applied across all sectors)			
Renewable Electricity Generation (10% by 2012, 25% by 2025)	PHEV Market Penetration (1 Million PHEVs on-road by 2015)	Market Penetration of CCS Technology	New Appliance Efficiency Standards
Clean Coal Technology/ CCS & IGCC	Low Carbon Fuels Standard		Weatherize One Million Homes Annually
Increased Use of Natural Gas/NGCC with CCS	Expansion of Public Transportation Infrastructure	Abatement of High GWP GHG Gas Emissions	
Retirement of Existing, Fossil-Fuel Capacity		Carbon Storage with Forestry and Biomass	
Tier II – Remaining Pathways Essential for Achieving GHG Emission Reduction Goal			
International Offsets	Industrial/Agricultural Sector	Other	
Purchase of CO ₂ Emissions Credits	Restricting the Production and Release of Fluorinated GWP Gasses	Further Emission Reduction in the Transportation Sector	
	Performance Standards for Methane Emissions and Oil and Gas Production		

II. BACKGROUND

II.1 THE GOAL

In 2005, a common benchmark year, the US economy emitted approximately 7.3 billion metric tons of CO₂ equivalent greenhouse gases, consisting of 6 billion metric tons of CO₂ emissions and 1.3 billion CO₂ equivalent metric tons of other greenhouse gases such as methane.⁷ Notwithstanding significant advances in energy efficiency, annual U.S. CO₂ emissions are expected to reach nearly 9.5 billion metric tons in 2050, or approximately 23 tons per person. (For a detailed discussion of our year 2050 Reference Case projections, please see Appendix A.)

The Obama Administration intends to set the nation on a path that would decrease annual U.S. CO₂ equivalent emissions in 2050 to 1.2 billion metric tons, thereby reducing Reference Case CO₂ equivalent emissions by 8.3 billion metric tons. This reduction is equal to all current (year 2005) CO₂ emissions from the rapidly developing BRIC countries (Brazil, Russia, India and China) combined⁸.

The Carbon State of the U.S. Economy – 2050

This White Paper will discuss how and to what extent the ambitious Obama Administration goal for GHG emission reductions would be achieved. As background, we provide a brief description of the current and future sources of CO₂ and other GHG emissions by the main sectors of the U.S. economy for key years, Figure 1.

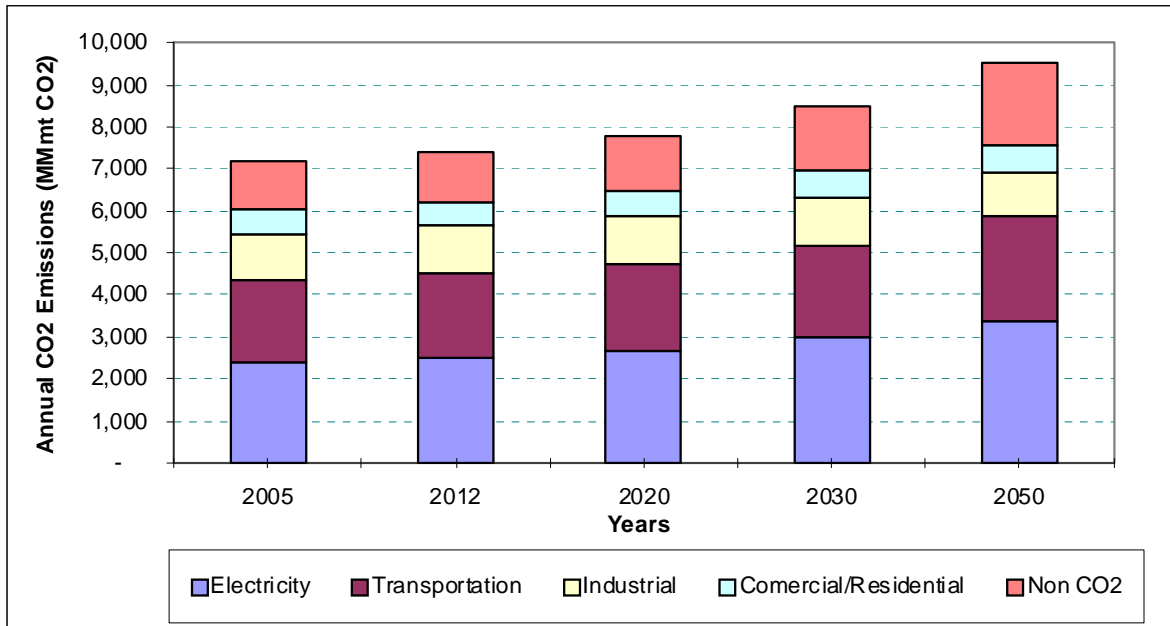
The largest source of CO₂ emissions in the U.S. economy is from the generation of electricity, which accounts for 35% of total CO₂ emissions*. The CO₂ emissions in this sector are mainly from the large fleet of coal fired power plants, which account for over 82% of CO₂ emissions from the Electricity Sector (year 2005).

⁷ Emissions of Greenhouse Gases Report, EPA 2008. <http://www.eia.doe.gov/oiaf/1605/ggrpt/index.html>

⁸ EIA International Energy Outlook. Only includes emissions from the consumption and flaring of fossil fuels

* Emissions from the Residential, Commercial and Industrial sectors are from the use and combustion of fossil fuel to meet process energy demands. The Electricity Sector emissions account for the CO₂ emitted to provide electricity to these sectors. Emissions from non-energy related CO₂ emissions are included in the Industrial Sector

Figure 1: Reference Case CO₂ Emissions by Sector



The next key sector is Transportation which accounts for 26% of total CO₂ emissions. The majority of emissions are from the use of petroleum by the Light Duty Vehicle (LDV) fleet. Much of the emissions from this sector are due to the low average fuel efficiency of the LDV fleet. In 2005, the average LDV achieved 19.5 miles per gallon (MPG).

The Industrial Sector emits approximately 11% of all CO₂ emissions, the largest share of which originate from the Bulk Chemicals industry, which emitted 228 MMmt CO₂ in 2005. The Commercial and Residential Sectors together are responsible for 7% of total CO₂ emissions, equal to 644 MMmt CO₂ (year 2005), largely from the combustion of natural gas for space heating.

Non-CO₂ greenhouse gases (methane, nitrous oxide and fluorinated compounds), with 1,957 MMmt of CO₂ equivalent emissions, are responsible for 21% of total GHG emissions (year 2005). The fastest growing of these are the fluorinated gases used in and released from refrigerants and electric power transformers.

II.2 ACHIEVABLE GHG EMISSION REDUCTION WEDGES

The results of our analysis suggest that the Obama-Biden initiatives (Tier I Pathways) would reduce annual CO₂ emissions in year 2050 by 6.8 billion metric tons, thus achieving the great bulk of the reductions needed to meet the national CO₂ emission reduction goal.

However, to fully reach the CO₂ emission reduction goal by 2050, a second set of pathways (Tier II) is required, targeting an additional 1.5 billion metric tons of annual CO₂ emission reductions, Figure 2. Tier II pathways include the phasing out of high GWP gases, placing performance standards on methane emission from oil and gas production, pursuing new, low carbon fuels for transportation, and purchasing CO₂ emission credits from other countries.

Figure 2: US GHG Emissions: Reference Case and Obama Administration Energy Plan

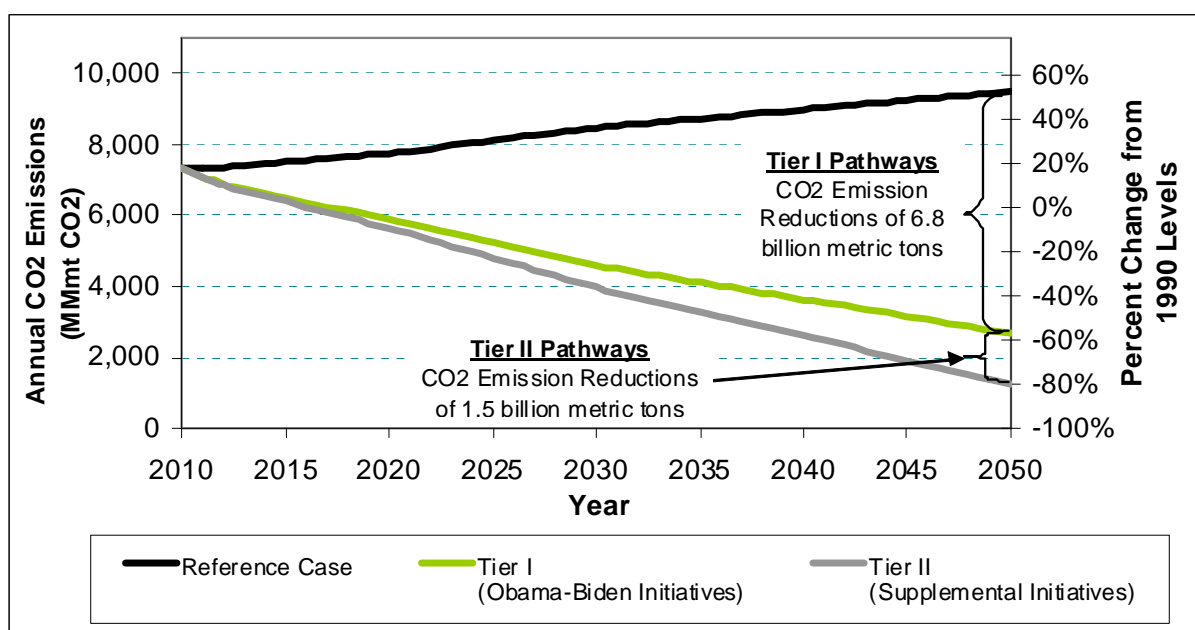
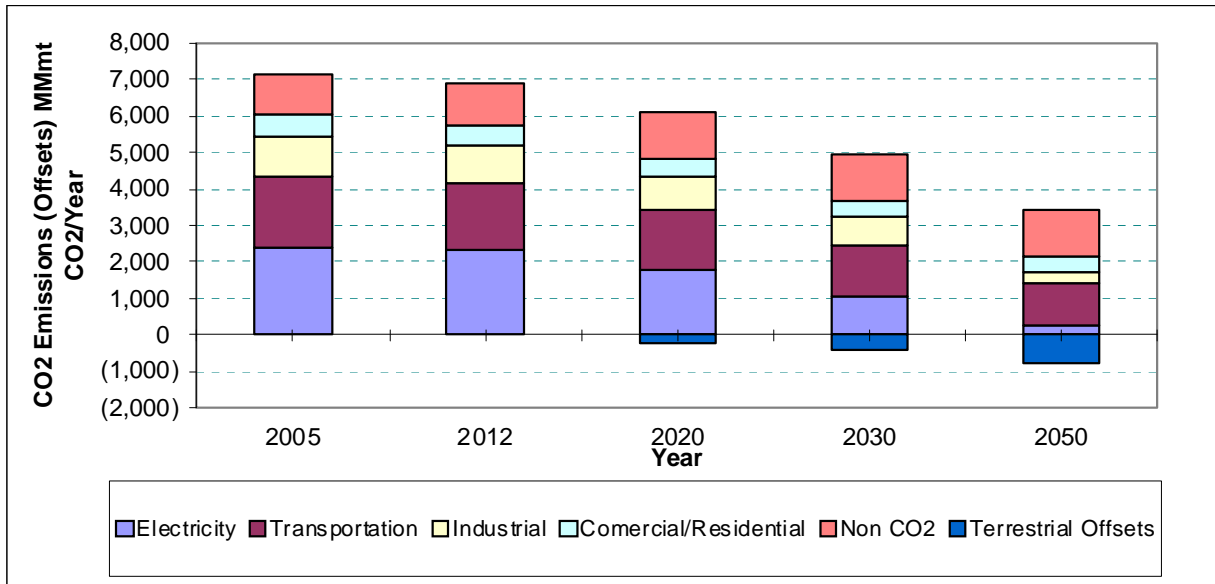


Figure 3 shows how the CO₂ emission profile of the economy would appear if the Tier I initiatives were fully implemented. The offset emissions from forestry and land use change are subtracted from total U.S. GHG emissions to reach net annual emissions of 2.7 billion metric tons by 2050.

Figure 3: Obama Plan Scenario CO₂ Emissions by Source (Tier I Initiatives Only)



Tier I Pathways

The Obama-Biden initiatives, which we term Tier I pathways, would achieve 6.8 billion metric tons of GHG emission reductions by year 2050. Table 2 tabulates the CO₂ reductions available by the Industrial Sector. Table 3 distributes the year 2050 GHG emission reductions by the nature of the initiative used to achieve the reductions - - policy prescription, technology or carbon price.

The large CO₂ emission reduction potential of the Tier I pathways is due to their focus on the most CO₂ intensive areas of the economy, such as today's coal-fired power plants, the existing fleet of light duty vehicles (LDVs) and energy use in the industrial, residential and commercial sectors. Figure 4 shows the relative contribution of each pathway.

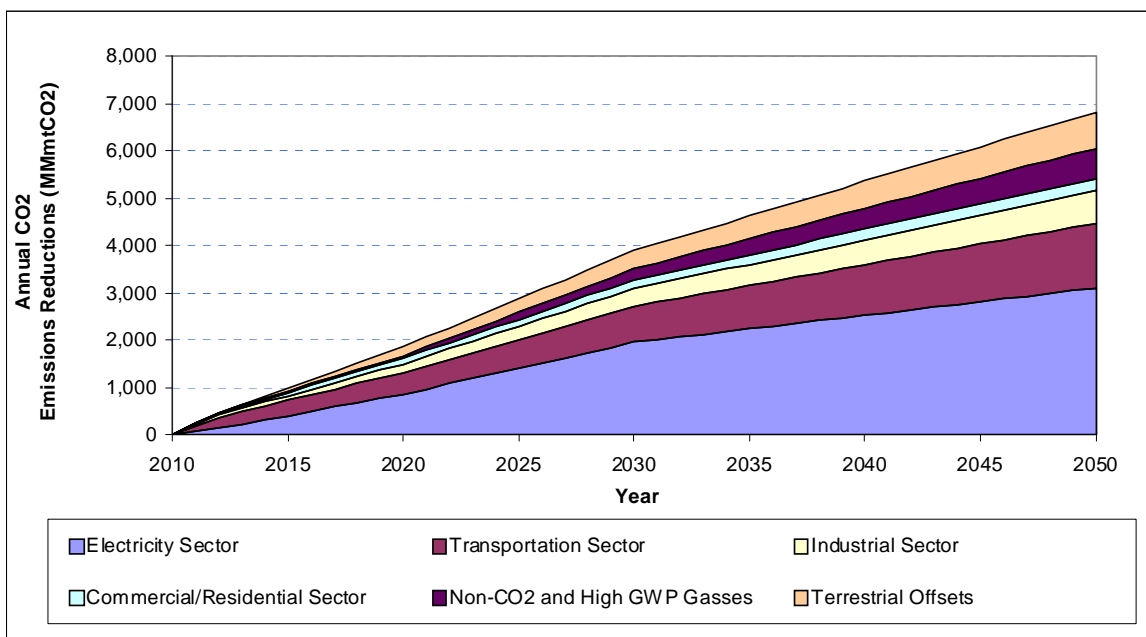
Table 2: GHG Emission Reductions from Tier I Pathways

Emission Reduction Pathways (MMmt)	2012	2020	2030	2050
Tier I				
1. Electricity Sector				
Energy Efficiency	0	81	284	753
Renewable Electricity Generation Target	124	325	550	826
Retrofit of Existing Plants with CCS	0	208	644	1,062
Deployment of New IGCC/NGCC Plants with CCS	25	251	484	461
Sub-Total	150	865	1,962	3,102
2. Transportation Sector				
Market Penetration of PHEVs	5	69	249	690
Increased Fuel Efficiency	114	284	349	508
Low Carbon Fuels Standard	5	55	114	134
Public Transportation	106	52	49	33
Sub-Total	230	460	760	1,366
3. Industrial Sector				
Energy Efficiency				
Refining and Bulk Chemical Industries	25	53	68	92
Other Industries	28	70	93	128
Sub Total	52	124	161	220
Industrial Sector Carbon Capture				
Refining and Bulk Chemical Industries	0	17	84	208
Other Industries	2	38	118	265
Sub Total	2	55	202	473
Sub-Total	55	179	363	693
4. Commercial/Residential				
Energy Efficiency				
Building Shell Efficiency Upgrades	3	15	30	58
Appliance/Equipment Efficiency Upgrades	38	103	156	207
Sub-Total	41	118	186	264
5. Non-CO2 & High GWP Gases				
Abatement of Non-Energy GHG Emissions				
Methane	10	41	122	253
Nitrous Oxide	1	6	28	66
High GWP Flourinated Gases	2	8	88	314
Sub-Total	13	56	238	633
6. Other				
CO2 Emission Offsets from Forestry and Land Use Changes	0	191	383	765
Total GHG Emission Reductions	488	1,868	3,892	6,822

Table 3: GHG Emission Reductions from Tier I Pathways: Year 2050

U.S. Economic Sectors GHG Sources	Obama-Biden New Energy for America Plan, GHG Emissions Reduction Initiatives (Tier I)			
	Prescribed Initiatives	Technology- Driven Initiatives	Price- Driven Initiatives	Sub-Total
1. Electricity				
Energy Efficiency	(0.75)			(0.75)
Renewable Generation Target	(0.83)			(0.83)
Retrofit Existing Plants with CCS		(1.06)		(1.06)
Deployment of IGCC/NGCC with CCS		(0.46)		(0.46)
Sub-Total	(1.58)	(1.52)	-	(3.10)
2. Transportation				
Market Penetration of PHEVs	(0.69)			(0.69)
Increased Fuel Efficiency	(0.51)			(0.51)
Low-Carbon Fuels Standard	(0.13)			(0.13)
Public Transportation	(0.03)			(0.03)
Sub-Total	(1.37)	-	-	(1.37)
3. Industrial Sector	(1.46)	-	-	(1.46)
Energy Efficiency	(0.22)			(0.22)
Carbon Capture and Storage		(0.47)		(0.47)
Sub-Total	(0.22)	(0.47)	-	(0.69)
4. Residential/Commercial	-	-	-	-
Energy Efficiency	(0.26)			(0.26)
5. Non-CO2 GHGs	-	-	(0.78)	(0.78)
Abatement of Non-Energy GHG Emissions			(0.63)	(0.63)
6. Terrestrial Offsets	-	-	(0.77)	(0.77)
Total	-3.4	-2.0	-1.4	-6.8

Figure 4: CO₂ Emission Reductions from Tier I Pathways



Much of this report examines the potential for GHG emission reductions by sector. However, some of the initiatives or pathways cut across the economic sectors. When viewed from this perspective, we find that energy efficiency, carbon capture and storage, and renewables provide the “big three” GHG emission reduction pathways:

- **Energy Efficiency.** Energy efficiency, in all of its forms, would provide 2.5 billion metric tons of annual CO₂ emission reductions in year 2050, Table 4. Most of these efficiency gains are captured in the Electricity Sector, from lower use due to construction of more energy efficient buildings and use of higher energy efficiency light bulbs and appliances. Efficiency gains also accrue from introduction of higher fuel efficiency vehicles, more energy efficient industrial processes and expansion of public transportation.

- **Carbon Capture and Storage.** The application of carbon capture and storage (CCS) technology in the Electricity and Industrial Sectors has the second greatest impact on reducing CO₂ emissions, providing 2 billion metric tons of annual reductions in year 2050.
- **Renewables.** Increased use of renewables for generating electricity, including hydro, biomass, wind and solar, would provide 0.8 billion metric tons of annual CO₂ emission reductions in year 2050.

Also important are the non-CO₂ gases, such as methane, nitrous oxide and high GWP fluorinated gases. The reduction in emissions of these gases, in response to a price on carbon, would provide 0.6 billion metric tons of annual CO₂ emission reductions in year 2050.

Tier II Pathways

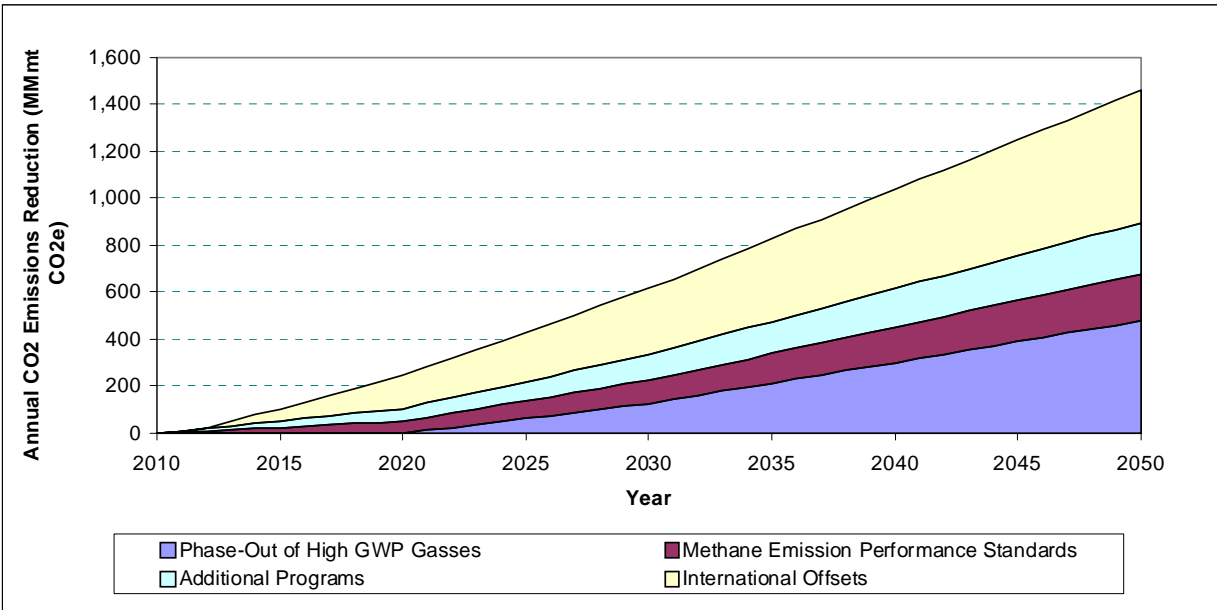
A series of “Tier II” pathways are needed to make up the 1.5 billion metric ton difference between the GHG emission reductions required by the Obama Administration’s goal and the 6.8 billion metric tons of CO₂ emission reductions achievable from Tier I pathways.

Within Tier II, the phase-out of fluorinated (HGWP) gases has the largest potential for CO₂ emission reductions, due to their very high radiative forcing. The establishment of methane emission performance standards for oil and gas production provides another large Tier II “wedge”. The remaining CO₂ emission reductions would accrue from additional initiatives, such as greater use of bio-diesel in the Transportation Sector, discussed in a separate section in the White Paper, and the purchase of international CO₂ emission credits, Table 4 and Figure 5.

Table 4: GHG Emission Reductions from Tier II Pathways

Emission Reduction Pathways (MMmt)	2012	2020	2030	2050
Tier II				
Phase-Out of High GWP Gas Production	0	0	126	478
Performance Standards on Oil and Gas Industry Methane Emissions	10	50	100	200
Additional Emission Reductions from the Transportation Sector	11	55	109	218
Purchase of International CO2 Emission Credits	0	141	281	562
Total GHG Emission Reductions	21	245	616	1,458

Figure 5: GHG Emission Reductions from Tier II Pathways



II.3 METHODOLOGY

Our study uses the CarBen model, an Excel-based model that combines data from the Energy Information Administration's (EIA) National Energy Modeling System (NEMS) and other sources, to track GHG emissions from all sectors of the U.S. economy. The model contains a wide and flexible array of policy levers (initiatives) that allow the user to modify the Electricity, Transportation, Industrial and end use sectors of the economy to achieve reductions in economy-wide GHG emissions. The model outputs are GHG emission reduction "wedges" which quantify the effect each initiative has on reducing total emissions.

To assess the numerous GHG emission reduction pathways discussed above, we draw on the specific GHG emission reduction calculations imbedded in our CarBen model which provide a logical quantitative linkage between a specific initiative and its expected volume of CO₂/GHG emission reductions.

The GHG emission reductions are measured against the Reference Case, as set forth in the EIA's Annual Energy Outlook (AEO) 2008 through 2030. To extend the Reference Case projections to 2050, we extrapolate forward the trends in place from 2012-2050 (please see Appendix A).

Our analysis assumes a set of policy initiatives and actions, and is not solely based on economics. However, the great bulk of the initiatives and actions set forth are consistent with a CO₂ price of \$40 to \$50 per metric ton.

III. DETAILED DISCUSSION OF EMISSION REDUCTION PATHWAYS

III.1 CREATING A LOW CARBON ELECTRICITY SECTOR

In the Reference Case, annual CO₂ emissions from the Electricity Sector in 2050 equal 3.4 billion metric tons, or 35% of economy-wide CO₂ emissions. Approximately 87% of the sector's CO₂ emissions in 2050, equal to 2.9 billion metric tons, are from coal-fired power plants (without CO₂ capture and storage). Most of year 2050 Reference Case CO₂ emissions from these coal fired plants, approximately 2 billion tons, are from plants in service today.

From a CO₂ emission reduction standpoint, the existing 314 GW stock of coal fired power plants are at the heart of the challenge in the Electricity Sector. In addition, the Electricity Sector also needs to address CO₂ emissions from future additions of coal-fired power and other fossil fuel-fired capacity, such as natural gas-fired plants and combustion turbines. Figure 6, illustrates the Reference Case CO₂ emissions from these sources to year 2050.

Figure 6: Electricity Sector CO₂ Emissions from Coal-Fired Power Plants: Reference Case

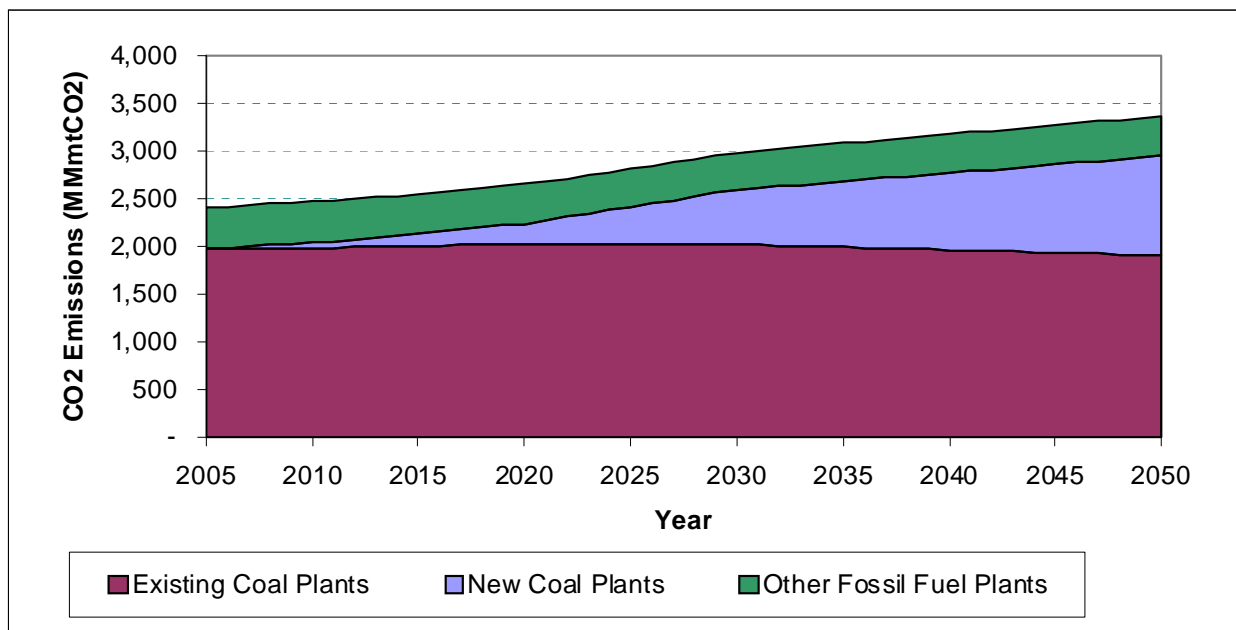


Table 5, below, describes how four pathways - - Energy Efficiency, Renewable Energy Generation, Carbon Capture and Storage (CCS) on existing plants, and Carbon Capture and Storage (CCS) on new IGCC and NGCC plants - - would reduce CO₂ emissions from the Electricity Sector.

Our analysis suggests that the pathways outlined in the Obama Administration's Energy Plan could reduce annual CO₂ emissions from the Electricity Sector by over 3 billion metric tons in 2050, decreasing the emissions footprint of the electricity sector by 92%, Table 6 and Figure 7.

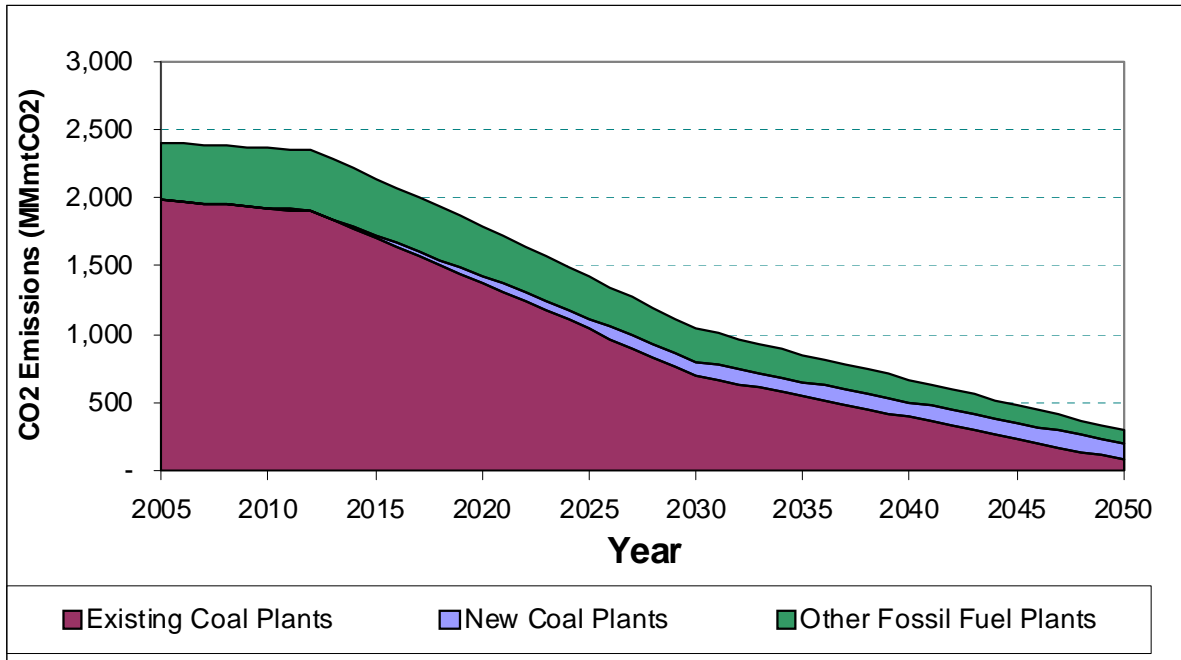
Table 5: Relationship Between Emission Reductions Pathways and Major CO₂ Sources in the Electricity Sector

Tier I CO ₂ Emission Reduction Pathways	Existing Coal Fired Power Plants	Coal Additions	Other Fossil Fuel Plants
Energy Efficiency	By reducing the demand for electricity, especially in an electricity supply environment that will be somewhat constrained by renewable generation targets, energy efficiency initiatives can encourage the retirement of existing coal fired power plants.	In addition to retirements of existing coal fired assets, reductions in energy demand will cause fewer new plant builds, reducing the emissions from both additions of coal and other generating assets relative to the reference case.	
Renewable Energy	Some parts of the country do not have much potential for wind or solar generation. The renewable electricity standard proposed by the Obama administration will encourage operators to convert their coal fired power plants to biomass.	In an electricity supply market that is constrained by a renewable electricity generation target, operators will build more renewable generating capacity relative to the reference case, at the expense of coal and other types of generating capacity.	
CCS Technology on New and Existing Plants	CCS technology will allow for the retrofit of existing coal fired power plants. This is likely to be a favorable option, because it allows these plants to continue to run, forgoing the capital costs of new plant construction.	If Integrated Gasification Combined Cycle (IGCC) plants with CCS can be implemented on a commercial scale, the emissions from additions of coal capacity will be greatly reduced.	The development of CCS for coal-fired plants is also relevant to natural gas fired plants.

Table 6: CO₂ Emission Reductions: Electricity Sector (MMmt of CO₂)

Year	2012	2020	2030	2050
Electricity Sector Emissions: Reference Case	2,501	2,653	2,988	3,375
CO₂ Emission Reduction Potential				
• Energy Efficiency	-	81	284	753
• Renewable Electricity	124	325	550	826
• Carbon Capture and Storage				
Application to Existing Plants	-	208	644	1,062
Application to New Plants	25	251	484	461
Total CO₂ Emission Reductions	150	865	1,962	3,102
Electricity Sector Emissions: Obama Plan	2,351	1,788	1,026	274

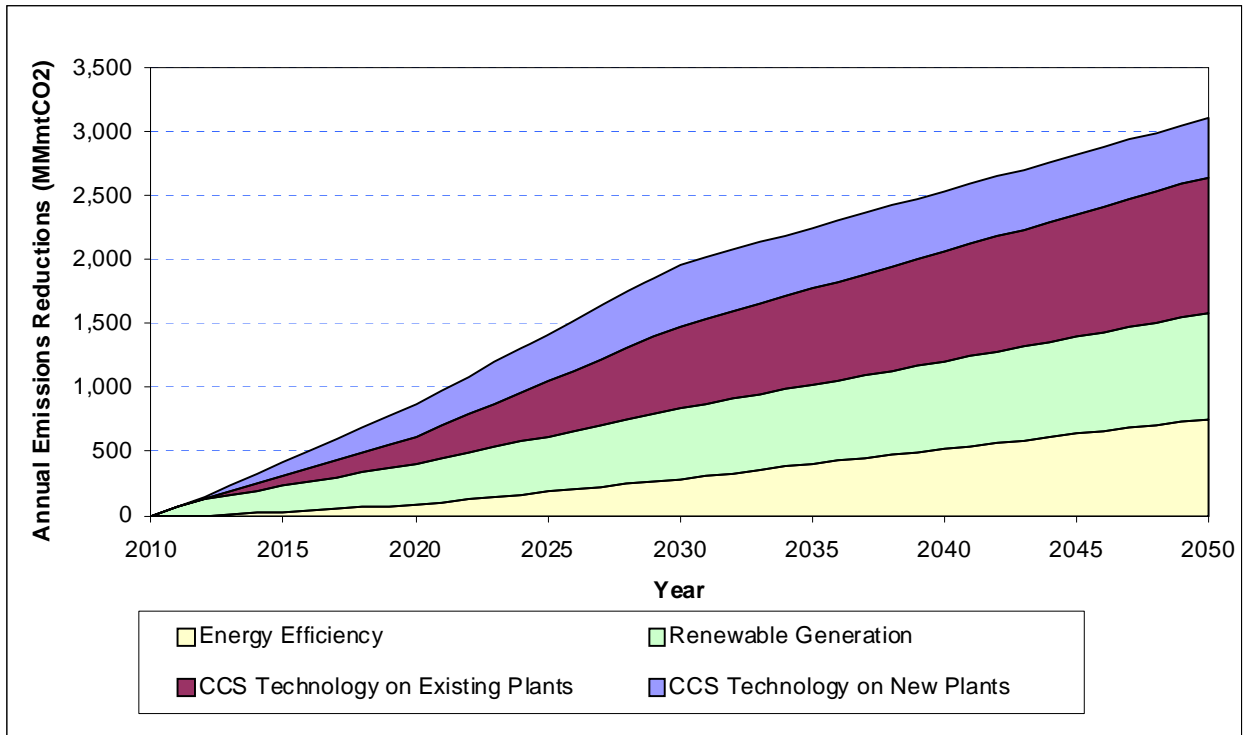
Figure 6: Electricity Sector CO₂ Emissions from Coal-Fired Power Plants: Obama Plan



CO₂ emissions from the existing coal-fired power plant fleet are almost completely abated by 2050, due to a combination of CCS retrofits, retirements and refueling with biomass. The small amount of remaining emissions in 2050 are from retrofitted and new coal and natural gas plants, from which we assume 90% of CO₂ emissions are captured and stored. CO₂ emissions are also greatly reduced due to the increasing market penetration of renewables in the Electricity Sector.

Of the Electricity Sector CO₂ emission reduction pathways, CCS provides the largest “wedge” of reductions from the existing coal-fired power plant fleet. Our assumption about the availability and pace of CCS retrofits is aggressive, but, in our opinion, doable. By 2050, we assume that 146 GWs out of the 314 GWs of today’s existing coal fired fleet have been retrofit with CCS equipment that captures 90% of the plant’s emissions, with a parasitic load of 25%.

Figure 7: CO₂ Emission Reductions: Electricity Sector



The Obama Administration's Renewable Generation target also plays a major role in reducing CO₂ emissions from the Electricity Sector. To meet the renewable generation target of 25% by 2025 (which includes hydro and geothermal), we assume that areas of the country with little solar or wind potential will convert smaller capacity coal fired power plants to run on 100% biomass. Because of the carbon neutrality of biomass, we assume these plants produce essentially zero-emissions. Overall, we assume that 88 GW of today's coal fired capacity is refueled with biomass.

Energy efficiency targets, in conjunction with renewable generation, act to retire a significant number of existing, low efficiency fossil-fuel fired power plants. Gains in energy efficiency keep electricity demand almost flat through from 2012 to 2050. The requirement that 25% of generation come from renewables in 2025 and 40% by 2050 leads to the retirement of 79 GWs of existing coal fired capacity by 2050.

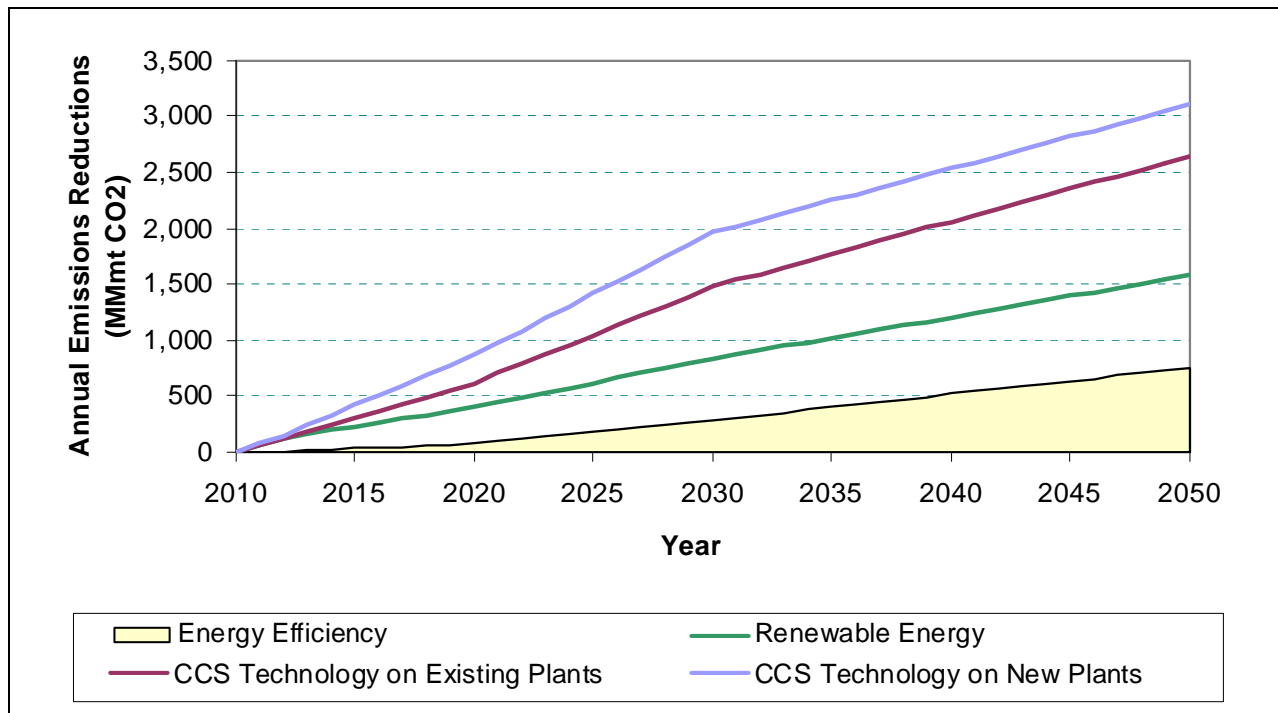
Through 2020, we assume only a portion of those nuclear plants with current hard orders for equipment or currently well along in the permitting phase are constructed. In the absence of explicit goals or subsidies for nuclear energy, and the halting of research into the Yucca mountain nuclear waste disposal facility, we assume that, after 2020, no additional nuclear plants are constructed. As such, new nuclear plants add 15 GW to the existing 101 GWs of nuclear capacity.

Electricity Sector Pathway #1: Improved Energy Efficiency

The Obama Administration has placed much emphasis on achieving greater efficiency in the Residential, Commercial and Industrial Sectors to reduce demand for electricity and other fossil fuels. For example, the Administration's Energy Plan calls for the weatherization of 10 million homes, and the recently passed stimulus plan allocates \$12 billion toward various energy efficiency initiatives⁹.

We project that these and other initiatives by year 2050 will reduce gross demand for electricity by 25%, compared to the Reference Case. This would lead to annual CO₂ emission reductions of 753 MMmt in 2050 from the Electricity Sector, Figure 8 and Table 7.

Figure 8: Electricity Sector CO₂ Emission Reductions: Energy Efficiency



⁹ Wall Street Journal, See Appendix C.

Table 7: Contribution of Energy Efficiency to Electricity Sector CO₂ Emission Reductions

Year	2012	2020	2030	2050
Electricity Sector Emissions: Reference Case	2,501	2,653	2,988	3,375
CO₂ Emission Reduction Potential				
• Energy Efficiency	-	81	284	753
• Renewable Electricity	124	325	550	826
• Carbon Capture and Storage				
Application to Existing Plants	-	208	644	1,062
Application to New Plants	25	251	484	461
Total CO₂ Emission Reductions	150	865	1,962	3,102
Electricity Sector Emissions: Obama Plan	2,351	1,788	1,026	274

In policy documents released during the campaign, the Obama Administration stated that efficiency improvements could reduce the amount of electricity demand by 15% in year 2020. To account for economic growth, we assume that this reduction occurs in the electricity intensity of the economy, in kWh of electricity demand per dollar GDP of output. As such, from 2012 through 2020, we assume that electricity intensity decreases 15% from 0.33 (kWh/\$GDP) to 0.28 (kWh/\$GDP), or by 2% annually. From 2020 onward, we assume that the electricity intensity continues to decrease at the same annual rate of 2%, Table 8.

Table 8: Electricity Demand Reduction from Increasing Energy Efficiency

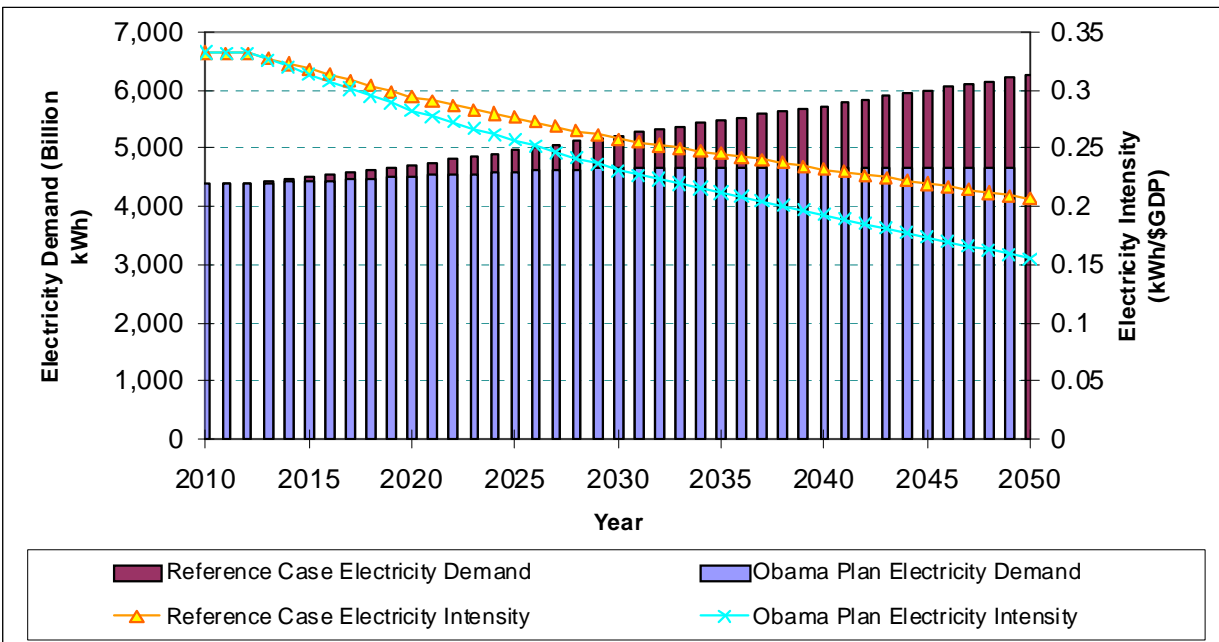
Year		2012	2020	2030	2050
GDP (Billions)		13,204	15,984	20,219	30,243
Reference Case	Electricity Demand	4,386	4,706	5,219	6,257
	Electricity Intensity (kWh/\$GDP)	0.332	0.294	0.258	0.207
Obama Energy Policy	Electricity Intensity (kWh/\$GDP)	0.332	0.283	0.231	0.155
	Electricity Demand	4,382	4,518	4,676	4,682
Reduction in Electricity Intensity			15%	21%	40%
Reduction in Electricity Demand			4%	10%	25%

The impact of these energy efficiency improvements is that, though GDP more than doubles from 2012-2050, electricity demand during this time period increases by less than 10%. When measured against the Reference Case, the Obama Plan energy efficiency initiatives would reduce annual electricity demand by 25% in 2050, Figure 9.

Through 2030, our estimates are in-line with a recent analysis by EPRI on the potential for energy efficiency in the Electricity Sector¹⁰. For example, in 2030, the last year of their analysis, EPRI finds that, under their “Maximum Achievable Potential” scenario, in which only behavior and technology are limiting factors, electricity demand can be reduced by 8% from the Reference Case. This compares favorably with our assessment, which indicates a demand reduction potential of 10%.

Relative to the Reference Case, further reductions in demand also support CO₂ emission reductions by lowering the need for new power plants and providing room for the retirement of older, inefficient power plants.

Figure 9: Electricity Demand in Reference Case and Obama Plan Case



¹⁰ Assessment of Achievable Potential From Energy Efficiency and Demand Response Programs in the U.S. (2010-2030). EPRI, Palo Alto, CA: 2009. 1018363

Electricity Sector Pathway # 2: Renewable Energy

The Obama Administration has set somewhat ambitious targets for the amount of renewable energy that will be produced in future years. The Administration's Energy Plan calls for 10% of electricity to be generated from renewable sources (including hydro, geothermal, biomass, wind and solar) by 2012, scaling up to 25% by 2025.

The current Reference Case, with 480 billion kWh of renewable generation, exceeds the 10% target set for 2012, primarily from already installed hydro power. However, since little additional hydro power capacity can be added, the growth in renewable energy based power generation from 2012 onward will need to rely on other sources, particularly wind power and biomass.

Assuming that renewable energy generation meets the year 2050 Obama Administration targets, and ultimately reaches 38% of total generation by 2050, this pathway could reduce annual CO₂ emissions by 826 MMmt, Figure 10 and Table 9.

Figure 10: Electricity Sector CO₂ Emission Reductions: Renewable Energy

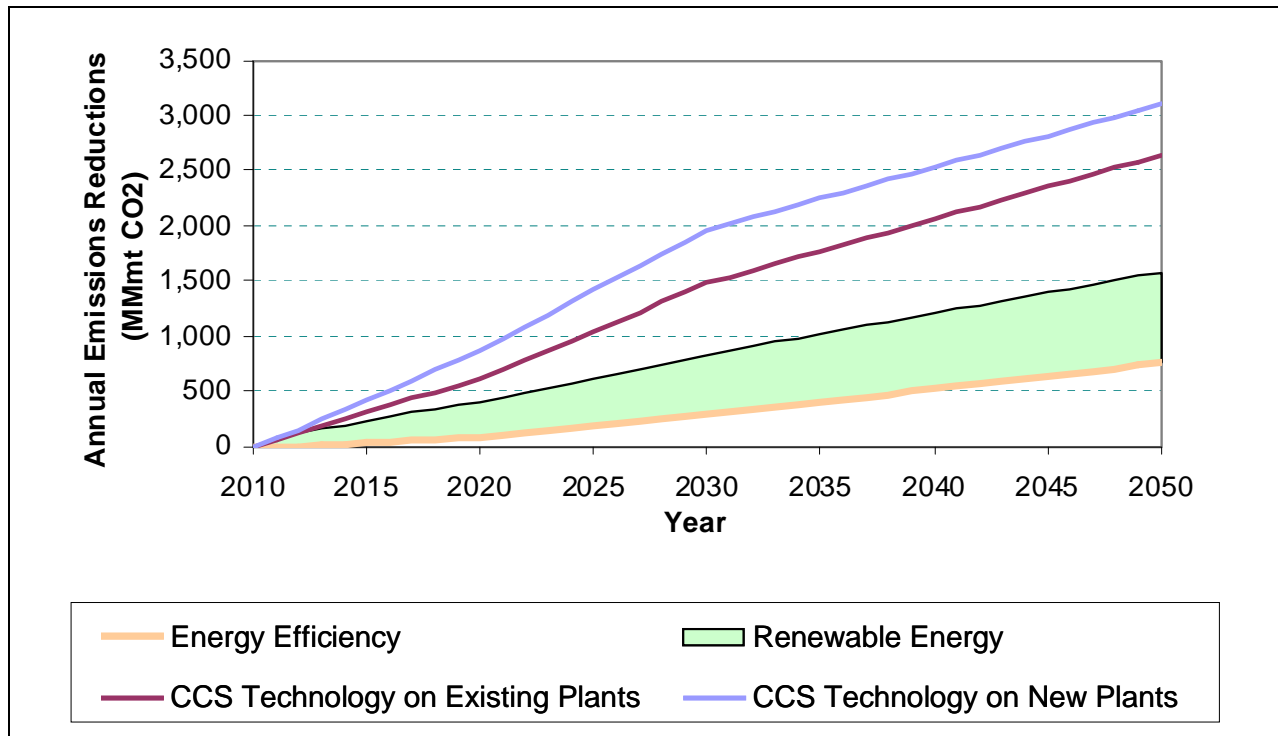


Table 9: Contribution of a Renewable Energy to Electricity Sector CO₂ Emission Reductions

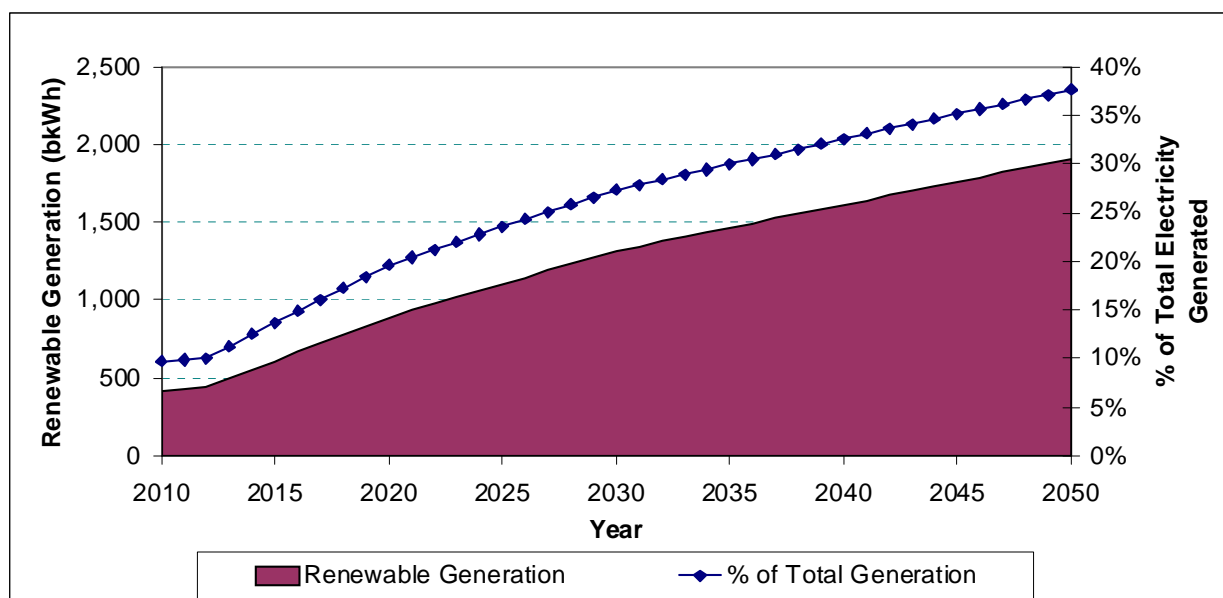
Year	2012	2020	2030	2050
Electricity Sector Emissions: Reference Case	2,501	2,653	2,988	3,375
CO₂ Emission Reduction Potential				
• Energy Efficiency	-	81	284	753
• Renewable Electricity	124	325	550	826
• Carbon Capture and Storage				
Application to Existing Plants	-	208	644	1,062
Application to New Plants	25	251	484	461
Total CO₂ Emission Reductions	150	865	1,962	3,102
Electricity Sector Emissions: Obama Plan	2,351	1,788	1,026	274

To reach the year 2025 target of 25%, generation from renewable energy will need to increase from 480 bkWh in 2012 to 1,173 bkWh in 2025, an addition of 693 bkWh of generation. After reaching the 2025 target, we assume that the rate of renewable energy capacity additions slows, due to fewer high quality sites and other constraints. We assume that the amount of renewable capacity added in the 25 years between 2025 and 2050 is the same, in absolute power generation terms, as was added between 2012 and 2025. As such, renewable energy provides 38% of total power generation in 2050, Table 10 and Figure 11.

Table 10: Renewable Generation Targets

Year	2012	2020	2025	2030	2050
Percent of Total Generation from Renewables	10%*	20%	25%*	27%	38%
Energy Demand (bkWh)	4,388	4,557	4,692	4,828	5,069
Renewable Target (bkWh)	439	891	1,173	1,317	1,907
*Obama Administration Target. Reference Case renewable generation in this period is 480 bkWh					

Figure 11: Renewable Generation Under Obama's Energy Plan



Producers in states with comparatively little wind or solar opportunities will face an especially difficult challenge in meeting renewable generation targets. One promising option, currently under serious investigation, is to refuel smaller existing coal-fired power plants to run on biomass fuels such as wood scrap from lumber yards. Because the carbon in the biomass was taken from the air by plant matter, not removed from the ground, the net CO₂ emission from a biomass fired power plant is assumed to be negligible.

We believe this option has significant potential to help utilities meet their renewable power generation requirements. Furthermore, under certain situations, the biomass firing option may provide significant cost savings over equipping an older, inefficient coal-fired power with CCS.

From years 2012 through 2030, we assume that all coal fired power plants under 250 MW are refueled to burn 100% biomass. We assume that these refueled plants will run at 80% capacity (the average coal fired power plant has a 83%-90% capacity factor) to represent some capacity de-rating due to the lower energy content of the biomass feedstock.

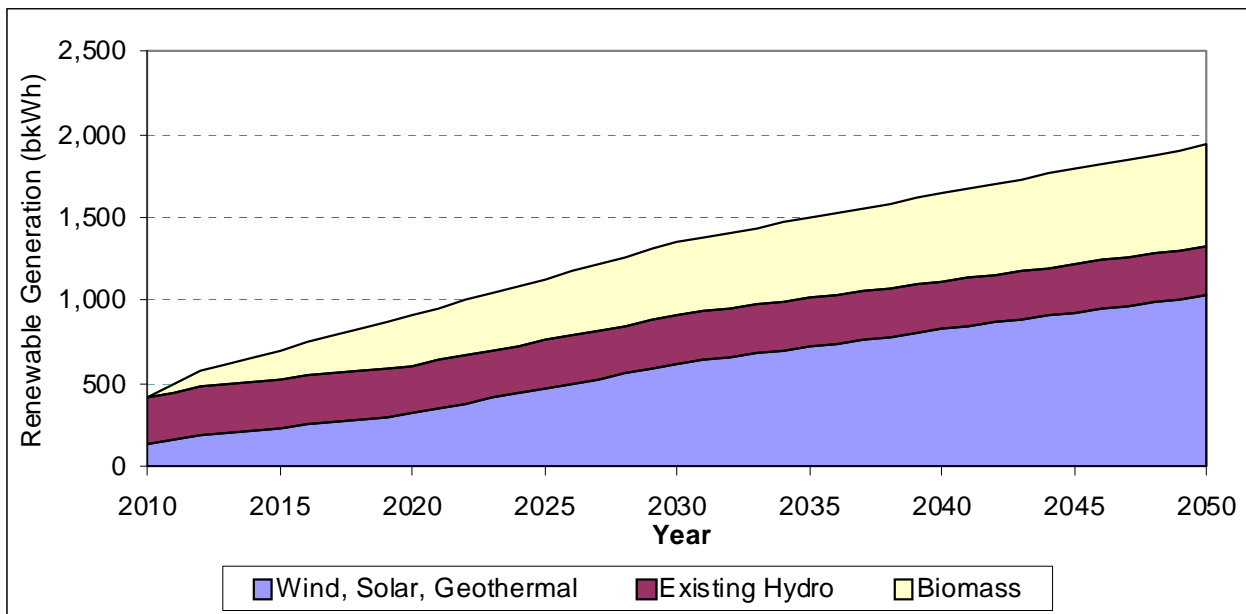
As Table 11 shows, bio-mass firing can significantly help meet renewable generation standards. Under the assumptions discussed above, existing coal fired power plants refurbished to burn biomass would meet about a third of the renewable energy target from year 2020 onward.

Table 11: GWs of Coal-Fired Capacity Re-Fired to Burn Biomass Feedstock

Year	2012	2020	2030	2050
Cumulative Capacity (GW)	14	43	63	88
Annual Generation (bkWh)	98	301	442	617
% of Renewable Target Generation	22%	34%	34%	32%

In addition to the 617 bkWh from biomass and 291 bkWh from existing hydro, we assume a combination of wind, solar, geothermal and other renewable generation will generate the 999 bkWh of renewable energy to meet the remainder of the goal, Figure 12. While we do not identify how much electricity generation each of these technologies would provide, we believe that wind power will account for much of the near-term increase in renewable generation.

Figure 12: Renewable Generation by Type in the Obama Plan Scenario



Electricity Sector Pathway # 3: Applying Carbon Capture and Storage (CCS) to Existing Plants

Applying CCS technology to coal and natural gas-fired power plants is a major option for reducing CO₂ emissions in the Electricity Sector. Our analysis shows that aggressive application of CCS technology to existing plants can reduce annual CO₂ emission from the Electricity Sector in 2050 by 1,062 MMmt of CO₂, Table 12 and Figure 13.

Figure 13: Electricity Sector CO₂ Emission Reductions: Carbon Capture and Storage

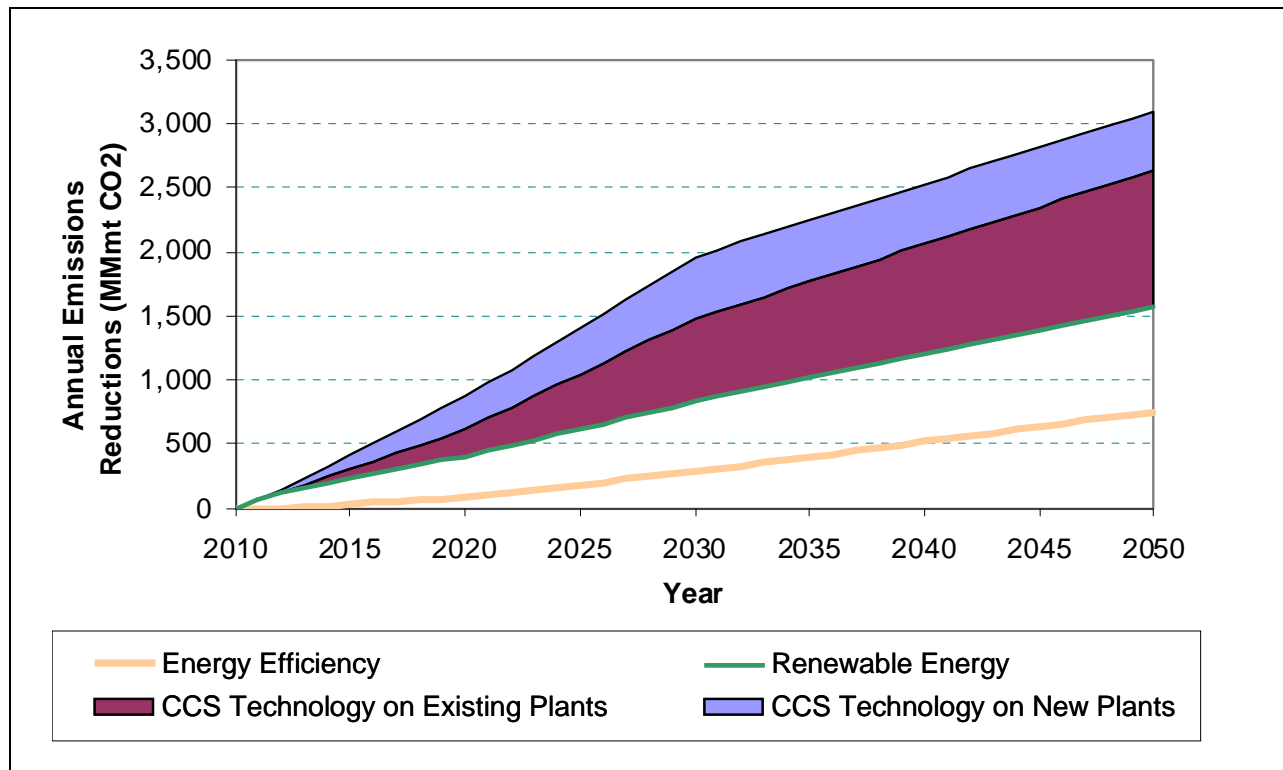


Table 12: Contribution of CCS Technology to Electricity Sector CO₂ Emission Reductions

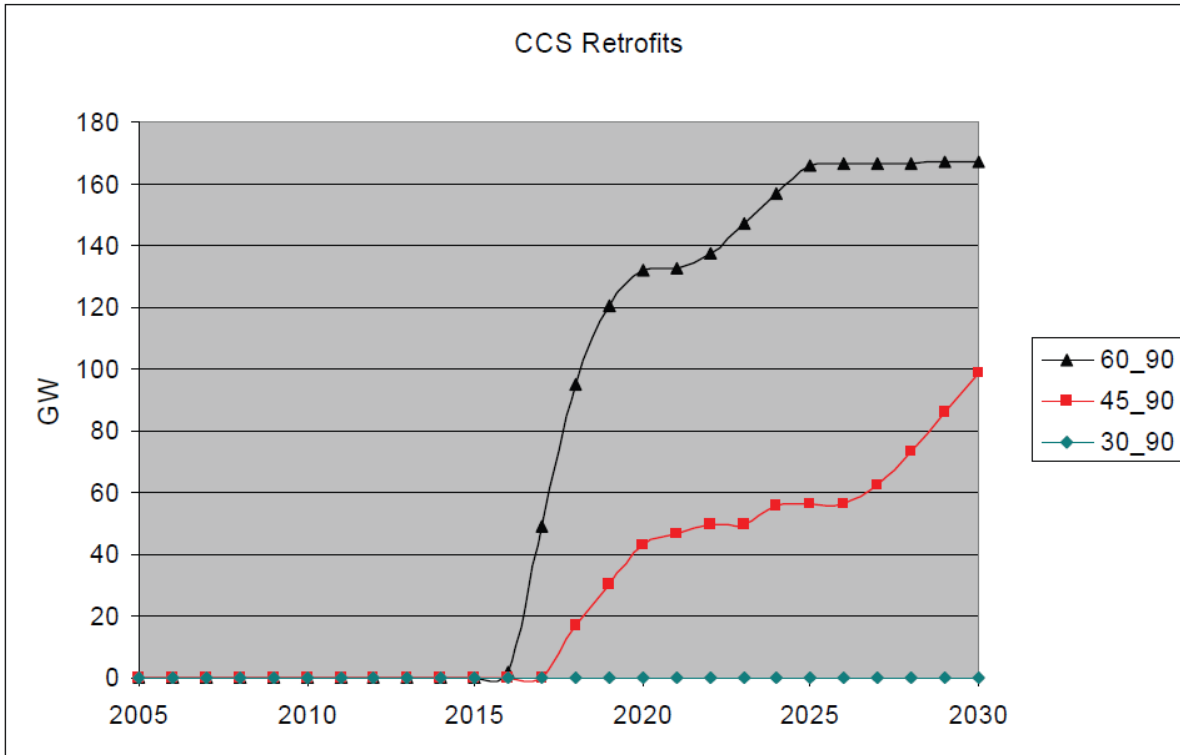
Year	2012	2020	2030	2050
Electricity Sector Emissions: Reference Case	2,501	2,653	2,988	3,375
CO₂ Emission Reduction Potential				
• Energy Efficiency	-	81	284	753
• Renewable Electricity	124	325	550	826
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Application to Existing Plants	25	251	484	461
Application to New Plants	-	208	644	1,062
Total CO₂ Emission Reductions	150	865	1,962	3,102
Electricity Sector Emissions: Obama Plan	2,351	1,788	1,026	274

Today's electric power sector has 314 GW of coal-fired capacity, which accounts for over 50% of all electricity generated. Though a significant portion of this capacity is old and inefficient, it cannot be readily retired. Additionally, many of these plants have been running for decades, are paid for, and thus provide significant revenues for their parent companies and low cost electricity to consumers.

One option for addressing the CO₂ emissions from these plants is to retrofit them with CCS technology. However, the costs of installing carbon capture as a retrofit, in terms of capital expenditures and lost plant output, is significant. To develop a set of realistic guidelines for the number of CCS retrofits possible, we use a paper by Geisbrecht and DiPietro¹¹. In this paper, the authors use the NEMS model and detailed retrofit cost data to forecast carbon capture retrofits under a broad range of policy and economic conditions. Figure 14, taken from this paper, shows the amount of coal fired capacity that is retrofitted under various prices for carbon. For this analysis, we use the capacity retrofit trend for a \$45/ton CO₂ price case.

¹¹ Geisbrecht, R., DiPietro, J. P., *Evaluating options for U.S. coal fired power plants in the face of uncertainties and greenhouse gas caps: the economic of refurbishing, retrofitting, and repowering*. U.S. Department of Energy, 2008. Presented at GHGT-9

Figure 14: Geisbrecht and Dipietro Analysis of CCS Retrofits for Existing Coal-Fired Power Plants*



* Legend Key: 60_90 case refers to a scenario with a \$60/ton carbon price and 90% carbon capture

Based on the Geisbrecht and Dipietro work, we find that, by 2030, 100 GWs of existing coal-fired capacity would have installed CCS technology. To schedule the application of CCS installation, we used efficiency guidelines for each plant vintage (year of construction), Table 13.

Table 13: Existing Coal Fired Capacity Retrofit by Plant Efficiency and Year (GW)

Vintage/Year	2012-2020	2021-2030	2031-2050	Total
Efficiency Cutoff	Above 36.5%	Above 33%	Above 30%	
Pre-1970	10	0	0	10
1971-1989	24	63	43	130
1990-03	2	3	3	8
Annual Retrofit (GW)	36	66	46	148

The first phase of retrofits, during 2013-2020, will target the most efficient existing plants. As the technology for CO₂ capture improves and storage sites are established, we assume that operators will expand the installation of CO₂ capture equipment. For CCS technology, we assume that 90% of retrofitted plants' emissions are captured with a parasitic load of 25%.

Electricity Sector Pathway # 4: Applying Carbon Capture and Storage to New IGCC and NGCC Plants

The Obama Administration's Energy Plan and the \$3.5 billion in the recently enacted stimulus package provide strong support for developing a new "clean" coal generating fleet through the use of CCS technology with Integrated Gasification Combined Cycle (IGCC) power plants and Natural Gas Combined Cycle (NGCC) Plants. We assume steady market penetration of CCS technology after year 2015 and that all new power plants built after 2020 employ CCS technology.

Table 14 displays the IGCC and NGCC capacity installed in each time period in this scenario. Our assumptions for this pathway are discussed below.

Table 14: New Builds of IGCC and NGCC Capacity (GW)

Power Plant	2008-2012	2013-2020	2021-2030	2031-2050
IGCC w/CCS (55% Capture)	-	21	-	-
IGCC w/CCS (90% Capture)	4	7	56	25
NGCC	29	20	-	-
NGCC w/CCS (90% Capture)	-	7	18	8

Introduction of New, Efficient Power Plants. Analysis by Emerging Energy Research suggests that 4 GWs of IGCC capacity will be online or under construction by 2013¹². With the benefit of directed federal and state funding, we assume an additional 14 GWs of IGCC and NGCC plants with 90% capture will be built by 2020. This assumes an annual addition of 1.4 GWs of capacity for each plant type, with a 3-4 year build time.

¹² Klien, A., Williams, B. *Flurry of State, Federal Policies Advance CCS*. Emerging Energy Research. Paper ID# CPG 715-090219

We assume that all new IGCC plants built between 2013 and 2020 would emit the same amount of CO₂ per kWh generated as natural gas plants, based on current experience. As such, IGCC plants will need to capture 55% of their CO₂ emissions to be at parity with NGCC plants. After 2020, we assume that all new fossil-fuel fired power plants built will employ 90% carbon capture.

Natural Gas Fired Power Plants. From 2013 through 2020, we assume that NGCC capacity is installed (or placed back into service) in a 1 to 1 ratio with IGCC plants. (The Reference Case, during this time period, uses a ratio between NGCC and IGCC capacity additions of approximately 1 to 5.) The increase in NGCC construction for this time period in our analysis is based on relative economics of NGCCs (without capture) and IGCCs (with partial capture), as well as the recently established abundance of near-term natural gas supply.

After 2020, we assume the ratio of NGCC to IGCC capacity additions decreases to 1 to 3, based on still unresolved uncertainties in as to the long-term abundance of natural gas supplies.

Existing Fossil Fuel Fired Plants. Our analysis assumes that, by year 2050, existing fossil-fuel fired power plants that have not been retrofit or re-fired to run biomass are retired. As justification for the retirement of these amortized assets, we note that power producers are eligible for financial support for constructing new, cleaner plants, and will be required to pay for the CO₂ they emit.

Table 15, below, displays the retirements of each type of fossil-fuel fired plant in this analysis*. The electricity demand reduction caused by efficiency improvements dictates how many retirements are attributed to that pathway; the remainder of the retirements are attributed to upgrading of the existing fossil-fuel powered fleet.

* The vast majority of fossil-fuel-fired generation comes from coal fired power plants. However, the AEO reference case also includes 169 GW of existing natural gas combined cycle assets, 145 GW of combustion turbine assets and 122 GW of "Other fossil steam" which are plants that use fossil fuels primarily for heating purposes. These assets are run at low capacity factors relative to the coal fired power plant capacity, so their contribution to existing fossil-fired plant emissions is lower than their numbers would suggest. For the sake of brevity in this analysis, we do not go into detail here about the relative contribution of the assets to the fossil-fuel-fired emissions mix.

Table 15: Retirements of Fossil-Fuel Fired Power Plant Capacity*

Year	2009-2012	2013-2020	2021-2030	2031-2050
CFPP	0	37	23	17
NGCC	0	0	0	15
Combustion Turbine (CT)	9	20	58	30
Other Fossil Steam (OFS)	0	35	44	17
Total Retirements	9	92	125	79
Due to Reduction in Electricity Demand	0	31	64	79
Due to Upgrading of Fossil-Fuel Power Plant Fleet	9	61	61	0

Our assumptions on the pace of retirements for these assets are as follows:

- Coal-Fired power plants are retired based on their efficiencies and year of construction ,Table 16

Table 16: Efficiency Cutoffs for Existing Coal-Fired Power Plant Retirements

Vintage	Efficiency Cutoffs		
	2013-2020	2021-2030	2031-2050
Pre 1970	< 30.5%	< 31%	< 32%
1970-1989	< 28%	< 29.5%	< 30%

- Older natural gas plants without CCS are retired after 2030.
- Combustion Turbine and Other Fossil Steam plants are retired assuming that the trend in retirements in the Reference Case from 2005 to 2012 is continued until all the assets are retired.

* Almost all retirements are to assets that existed as of 2005 as reported in the NEMS data. However, in the AEO 2008 reference case, combustion turbine assets are constructed in out years, which we assume are not built. For emissions reduction accounting purposes, this change is counted as a retirement.

Summary

The initiatives set forth in the Obama Administration's Energy Plan lead to dramatic reductions in CO₂ emissions from the Electricity Sector by reducing the use of fossil fuels (Renewable Energy and Energy Efficiency), by introducing new, more efficient power generation plants, and by de-carbonizing the remaining fossil fuel-fired electricity fleet with CCS technology.

In 2050, these initiatives could reduce annual CO₂ emission in the Electricity Sector by 92% below the Reference Case (to 274 MMmt) and 88% below year 2005 levels. Approximately half of the CO₂ emission reductions are due to decreased use of fossil fuels and the other half to deployment of CCS technology, Table 17 .

Table 17: Total Electricity Sector CO₂ Emission Reductions

Strategy	Pathway	2012	2020	2030	2050
Reduce Fossil Fuel Use	Energy Efficiency	0	81	284	753
	Renewable Energy	124	325	550	826
	Sub-Total	124	406	834	1,579
De-Carbonize Fossil Fuels	CCS Technology	25	459	1,129	1,522
Total CO₂ Emission Reductions		150	865	1,962	3,102

With deployment of CCS technology, coal and natural gas remain important components of future electricity production, providing 29% and 14% of power generation in 2050, respectively, Figure 15. Even though their relative percentage of electricity generation declines, the introduction of CCS technology, which reduces the CO₂ emission intensity of coal-fired generation from 0.98 MMmt CO₂/bkWh in 2005 to 0.13 MMmt CO₂/bkWh in 2050, (Figure 16), enables these two important domestic fuel sources together to provide 43% of power generation in 2050.

Figure 15: Electricity Generation by Fuel Type

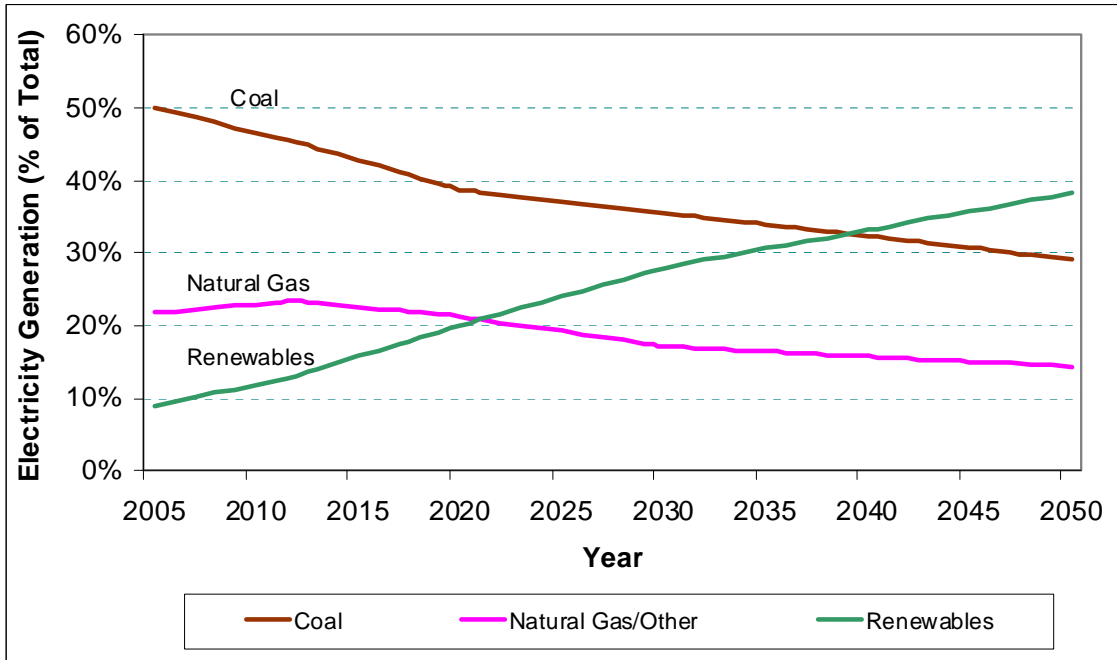


Figure 16: Reduction in CO₂ Intensity of Fossil-Fuel Fired Power Plants

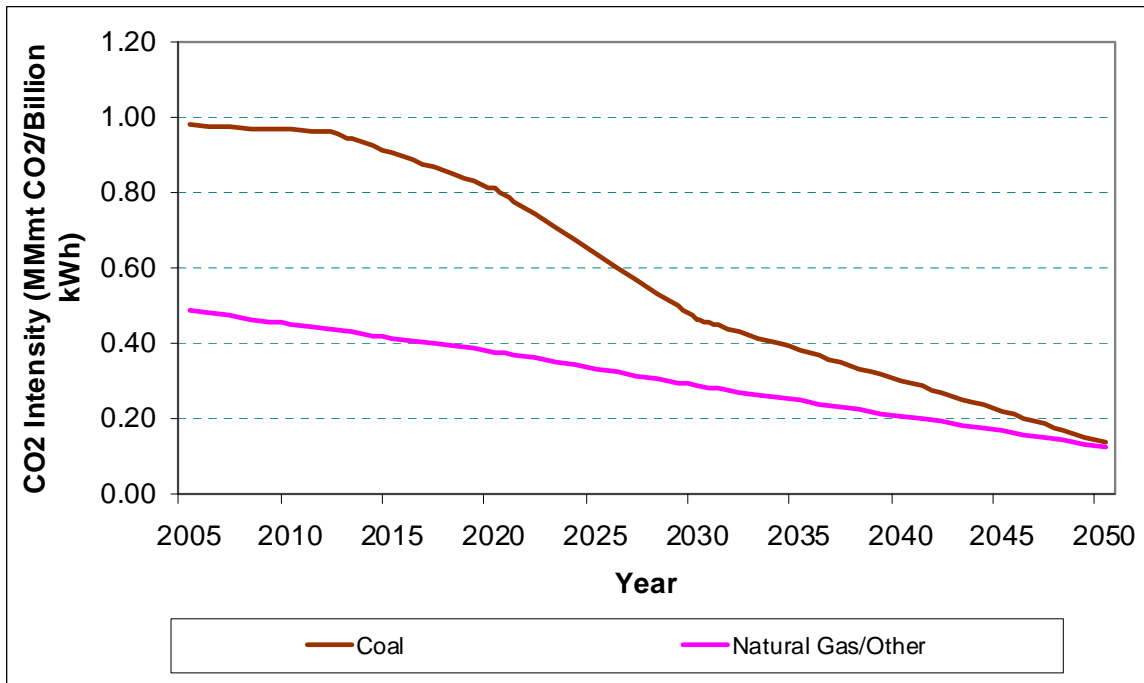
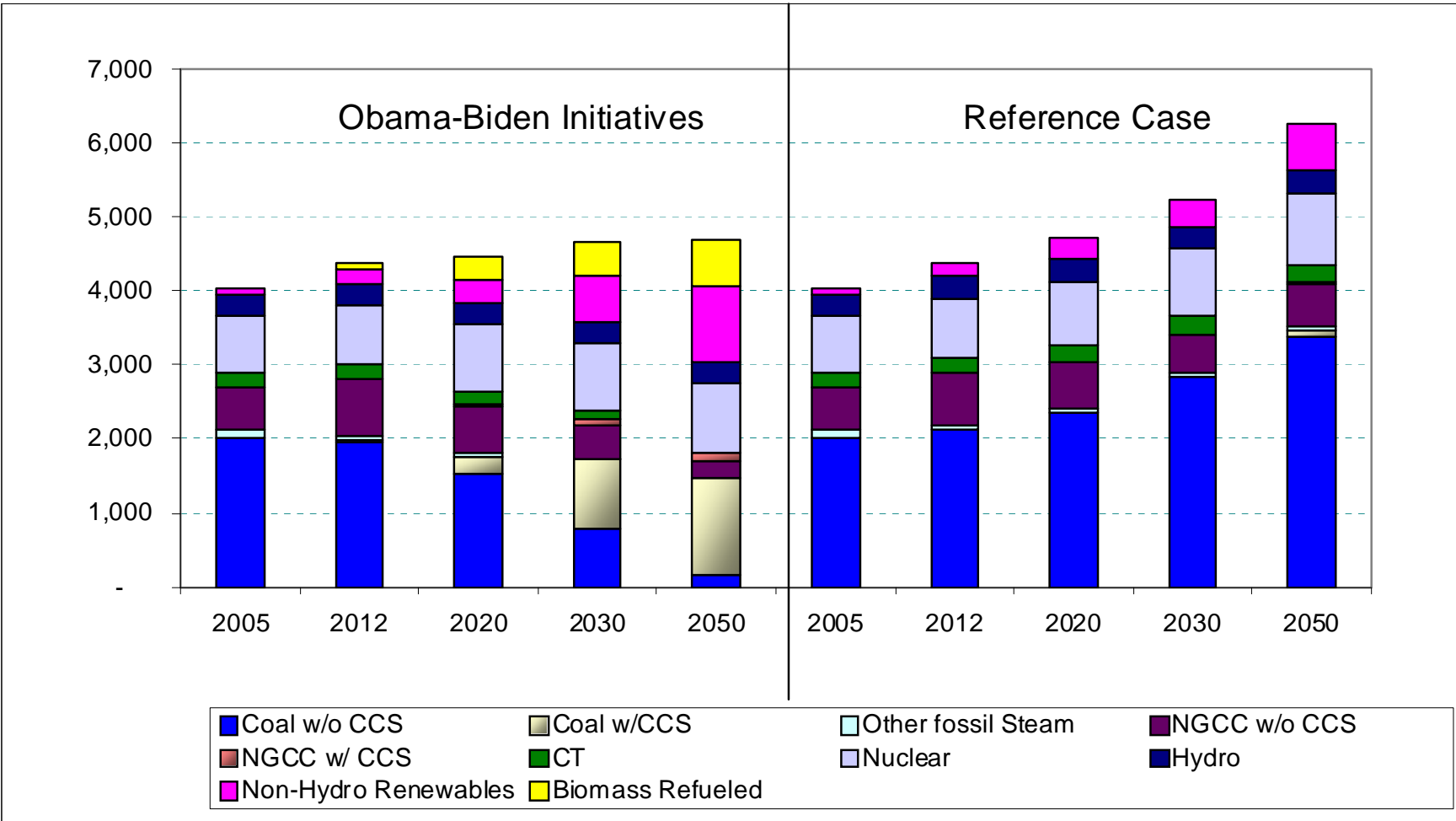


Figure 17: Annual Electricity Generation by Asset Type: Obama Energy Plan vs. Reference Case



III.B TRANSFORMING THE TRANSPORTATION SECTOR

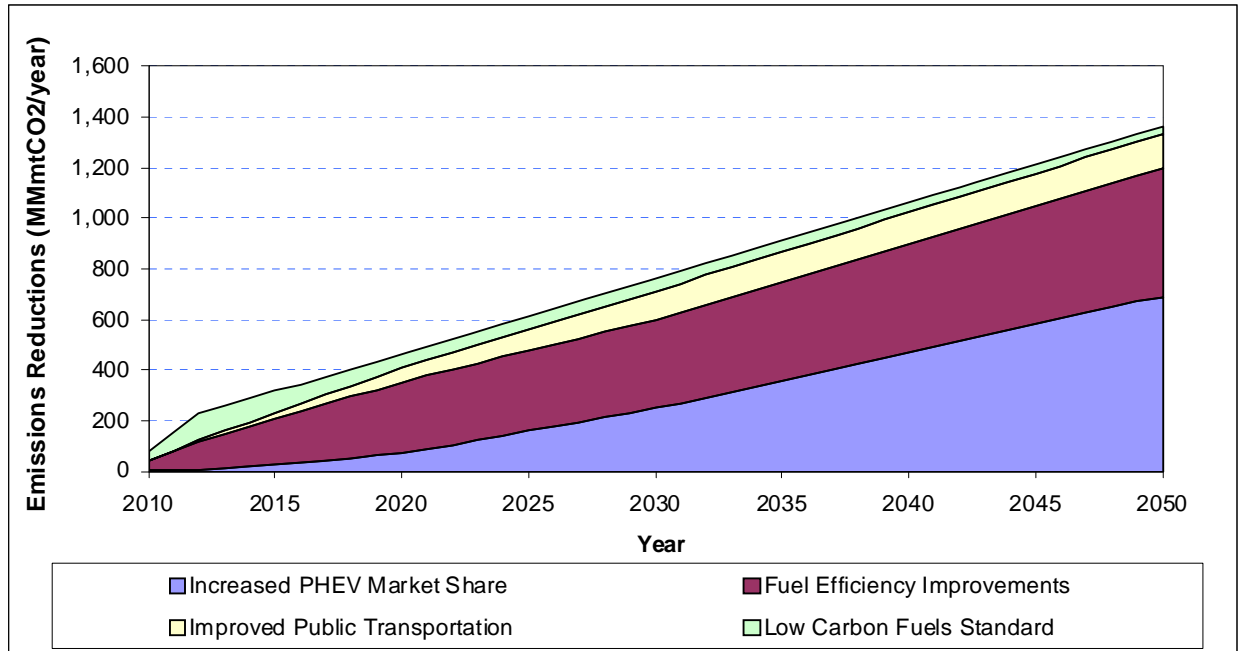
In the Reference Case, annual CO₂ emissions from the Transportation Sector in year 2050 are 2.5 billion metric tons, equal to 26% of economy-wide CO₂ emissions. The initiatives put forth in the Obama Administration's Energy Plan could reduce emissions from this sector by more than 50%, if pursued aggressively. The pathways we evaluate are: (1) Market Penetration of Plug-in Hybrid Electric Vehicles (PHEVs), (2) Increased Vehicle Fuel Efficiency, (3) Improved Public Transportation Infrastructure, and (4) Adoption of a Low Carbon Fuels Standard. Table 18 shows the annual CO₂ emission reduction potential of each of these four pathways.

Table 18: CO₂ Emission Reductions: Transportation Sector (MMmt CO₂)

Year	2012	2020	2030	2050
Transportation Sector Emissions: Reference Case	2,017	2,073	2,188	2,493
CO₂ Emission Reduction Potential				
• Increased PHEV Market Share	5	69	249	690
• Fuel Efficiency Improvements	114	284	349	508
• Improved Public Transportation	5	55	114	134
• Low Carbon Fuels Standard	106	52	49	33
Total CO₂ Emission Reductions	230	460	760	1,366
Transportation Sector Emissions: Obama Plan	1,787	1,613	1,428	1,127

Together, these four actions would reduce annual CO₂ emissions from the Transportation Sector by 1,366 MMmt CO₂ in 2050, Figure 18. Increased market penetration of PHEV technology has the largest potential, reducing annual CO₂ emissions by 690 MMmt CO₂ in 2050, followed by prescribed improvements in fuel efficiency, with 508 MMmt of annual CO₂ emission reductions in 2050.

Figure 18: CO₂ Emission Reductions Potential of Transportation Sector Pathways



As Table 19 shows, the majority (70%) of the emission reductions due to the Obama Administration's Energy Plan are from the fleet of Light Duty Vehicles (LDV).

Table 19: Transportation Sector CO₂ Emission Reductions by Transportation Mode

Year	2012	2020	2030	2050
Light Duty Vehicles				
Reference Case	1,107	1,088	1,104	1,270
Obama Plan Case	934	780	576	298
CO2 Emission Reduction	173	308	528	972
Commercial Light Trucks				
Reference Case	42	42	42	41
Obama Plan Case	38	34	28	18
CO2 Emission Reduction	4	7	14	23
Freight Trucks				
Reference Case	388	418	460	523
Obama Plan Case	342	341	347	331
CO2 Emission Reduction	46	77	113	192
Air				
Reference Case	221	256	299	353
Obama Plan Case	221	219	253	293
CO2 Emission Reduction	0	37	46	59
Rail				
Reference Case	44	47	52	58
Obama Plan Case	37	31	31	30
CO2 Emission Reduction	7	16	21	28
Domestic Shipping				
Reference Case	25	26	26	26
Obama Plan Case	25	26	27	26
CO2 Emission Reduction	0	0	0	0
Other				
Reference Case	191	197	205	222
Obama Plan Case	191	176	156	111
CO2 Emission Reduction	0	21	49	111
Sector Total				
Reference Case	2,017	2,073	2,188	2,493
Obama Plan Case	1,787	1,607	1,416	1,107
CO2 Emission Reductions	230	466	772	1,386

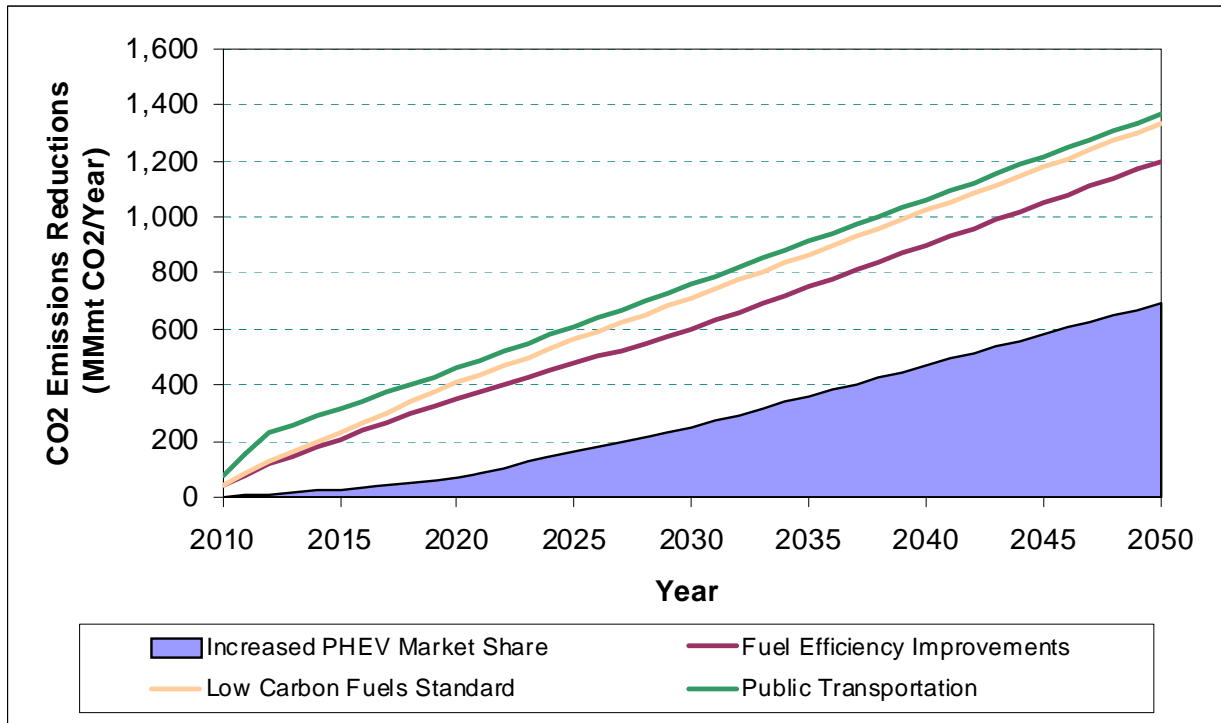
The sections below describe the assumptions and calculations used to model each of the CO₂ emission reduction pathways investigated in the Transportation Sector.

Transportation Sector Pathway #1: Increased PHEV Market Share

Plug-in hybrid vehicles (PHEVs) emit from 28% to 67% less CO₂ than a conventional vehicle, depending on battery storage capacity and the source of electricity used to charge the battery¹³. Touting these impressive figures, the Obama Administration has proposed incentives to spur the development and aggressive market penetration of PHEV technology.

The Administration's goal is to reach a target of 1 million PHEVs on the road in 2015, which it hopes to achieve by giving grant funding for battery research and tax incentives to PHEV buyers. Our analysis finds that aggressive market penetration of PHEV technology, if continued through 2050, could reduce annual Transportation Sector CO₂ emissions in year 2050 by 690 MMmt, Figure 19 and Table 20.

Figure 19: Transportation Sector CO₂ Emission Reductions: Increased PHEV Market Share



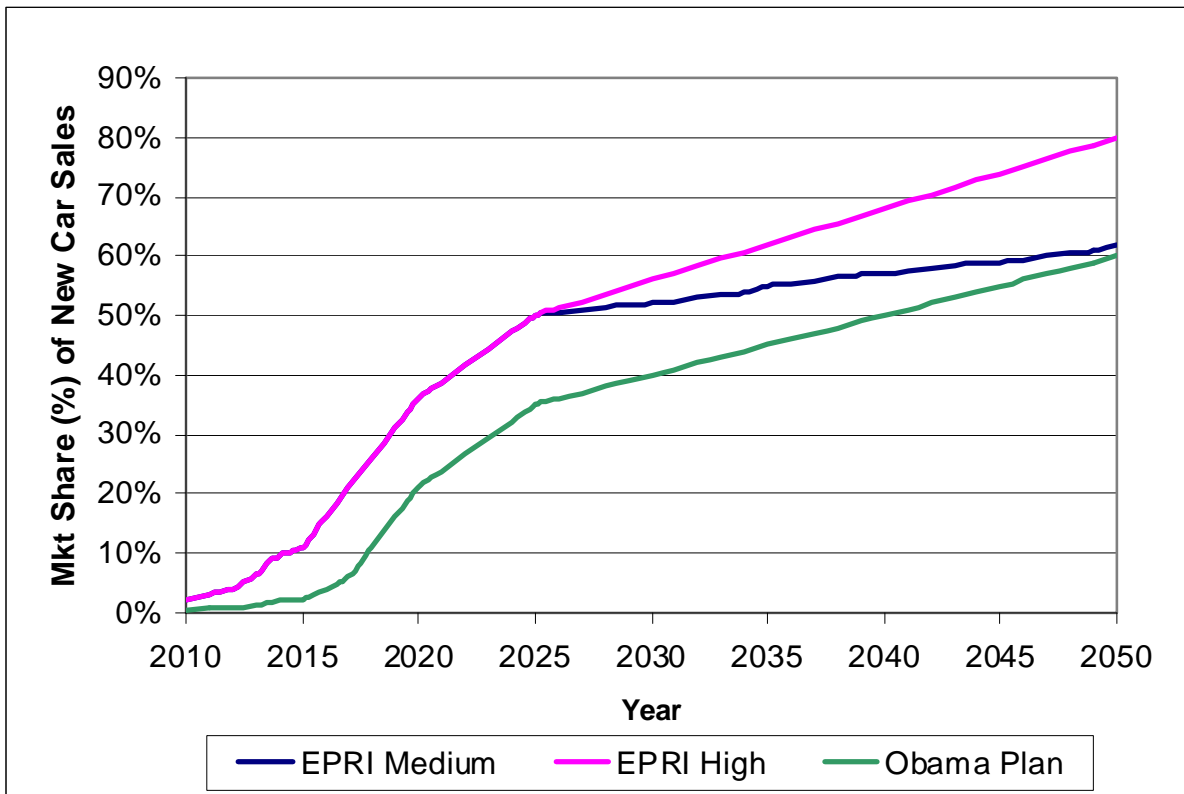
¹³ Electric Power Research Institute (EPRI), *Environmental Assessment of Plug-In Hybrid Electric Vehicles, Volume 1: Nationwide Greenhouse Gas Emissions*. Paper Number : 1015325. 2007

Table 20: Contribution of PHEV Technology to Transportation Sector CO₂ Emission Reductions

Year	2012	2020	2030	2050
Transportation Sector Emissions: Reference Case	2,017	2,073	2,188	2,493
CO₂ Emission Reduction Potential				
• Increased PHEV Market Share	5	69	249	690
• Fuel Efficiency Improvements	114	284	349	508
• Improved Public Transportation	5	55	114	134
• Low Carbon Fuels Standard	106	52	49	33
Total CO₂ Emission Reductions	230	460	760	1,366
Transportation Sector Emissions: Obama Plan	1,787	1,613	1,428	1,127

To model this CO₂ emission reduction pathway, we use a market penetration curve for light duty plug-in hybrid electric vehicles through 2050. This curve is based on an EPRI/NRDC analysis that modeled market acceptance of PHEV technology. Figure 20 shows some of these market penetration curves for PHEV technology as a percentage of new car sales.

Figure 20: PHEV Market Penetration Curves



The Obama policy goal of 1 million PHEV's on the road by 2015 is actually less ambitious than either of the EPRI cases we examined. The EPRI "Medium Case", shown above, results in 6 million PHEVs on the road by 2015. Our analysis uses a more conservative "s-shaped" market penetration curve to correspond to the Administration's initiative. After 2025, we assume linear market share growth through 2050 to reach the year 2050 market share for PHEVs in EPRI's "Medium Case."

We calculate that 169 million PHEV's will be on the road by 2050, accounting for about 50% of the LDV fleet. Assuming industry standard vehicle usage trends, these PHEVs will be responsible for 2,512 billion vehicle miles traveled (VMT) in year 2050, Figure 21 and Table 21.

Figure 21: PHEV Fleet Sales and Market Share

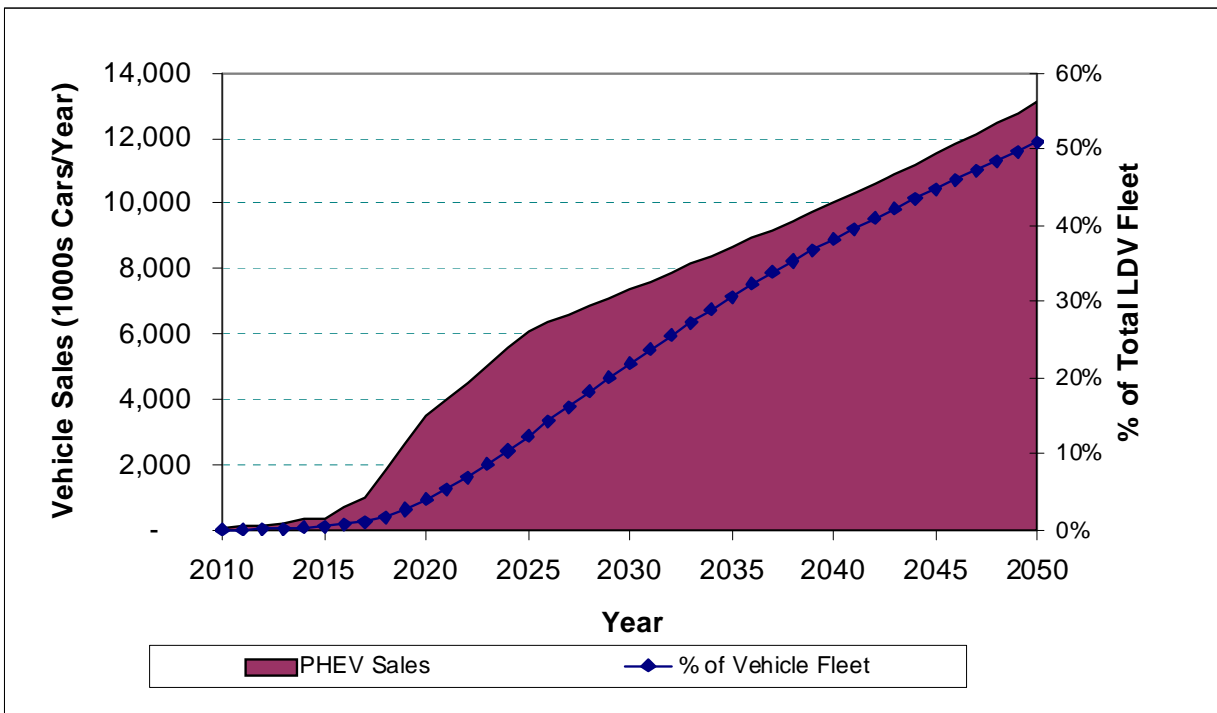


Table 21: PHEV Fleet Characteristics

Year	PHEV Sales (Thousands)	PHEV Fleet		VMT (Billions)
		Millions	% of All LDVs	
2010	62	0.1	0.0%	1
2015	371	1.2	0.5%	19
2020	3,489	10.7	3.9%	167
2030	7,373	64.5	21.9%	860
2050	13,105	169.4	50.9%	2,512

In the Obama Administration's Energy Plan, PHEVs are expected to achieve 150 miles per gallon. Analysis of current battery technology suggests that this is an ambitious but achievable goal. Table 22 gives a simplified calculation of the miles per gallon equivalent fuel efficiency of various PHEV battery technologies.

Table 22: Summary of PHEV Fuel Efficiency Performance

PHEV Technology ^{14, 15*}	% of Annual Miles Traveled With Electric Power	Efficiency of Onboard Internal Combustion Engine (mpg equivalent)	Annual Average Miles Per Gallon ^{***}
PHEV-20	40%	37.1	62.4
PHEV-40	63%	40	108
PHEV-60	75%	49.5 ^{**}	197

* The numbers after each technology indicate the vehicle's all electric range, or the mileage it can travel off battery power before needing to recharge.

** Assumes a series-hybrid architecture, which allows for more efficient internal combustion engine performance

*** This can be calculated using the following equation: $MPG = 1/((1-UF)/ICE)$. Where UF is the Utility factor, or the percentage of annual miles traveled under electric power, and ICE is the efficiency, in mpg equivalent, of the PHEV's onboard internal combustion engine.

¹⁴ Vyas, A., Santini, D. Duoba, M., et. Al. Plug-In Hybrid Electric Vehicles: How Does One Determine Their Potential for Reducing U.S. Oil Dependence? Argonne National Labs, 2008

¹⁵ Spreadsheet Tool for Calculating the Material Flows in a PHEV-CO2EOR-CCS-CBTL system. National Energy Technology Laboratory, 2008. Accessed at: http://www.netl.doe.gov/energy-analyses/pubs/PHEV-CO2EOR-CCS_12-16_CBTL.xls

As Table 22 shows, PHEVs with a 40 to 60 mile all electric range are capable of achieving the Obama administration's target of 150 MPG equivalent. However, the battery technology to make such a car economically feasible is still in development. The Chevrolet Volt, GM's flagship PHEV, is reported to have a 40 mile all electric range and a target commercialization date of 2010. We assume that, as PHEVs first enter the market in 2010, they will have a MPG of a PHEV 40, equal to 108 mpg. By 2050, we assume that PHEV-60 technology will have arrived and fuel efficiency will eventually reach 197 MPG. PHEV market share is assumed to come at the expense of conventional internal combustion engine vehicles; each additional PHEV sold replaces what would have been a conventional vehicle on the road.

Finally, we calculate the CO₂ emissions caused by PHEV electricity demand. Based on work by EPRI and the Department of Energy ^{16,17}, we calculate the electricity used by the PHEVs, and use CarBen's Electricity Sector module to calculate the resultant CO₂ emissions, Table 23. We assume that PHEV electricity demand is met by the full mix of generating assets, in proportion to their amount of installed capacity. As such, though PHEV electricity demand almost doubles from 2030 to 2050, CO₂ emissions only increase by about 70%, due to increasing market penetration of renewable generation technology in the Electricity Sector.

Table 23: PHEV Electricity Demand and CO₂ Emissions

Year	2012	2020	2030	2050
PHEV VMT (Billions)	19	167	860	2,512
PHEV Electricity Demand (bkWh)	2	39	131	377
PHEV CO ₂ Emissions (MMmt)	0.3	6.2	11.3	19.4

¹⁶ EPRI 2007

¹⁷ *Spreadsheet Tool for Calculating the Material Flows in a HEV-CO₂-EOR-CCS-CBTL System*. NETL, 2009. Accessed at: <http://www.netl.doe.gov/energy-analyses/benefit.html>

Transportation Sector Pathway #2: Increased Vehicle Fuel Efficiency

A key element of the Obama Administration's Energy Plan is to increase vehicle fuel economy standards. For this pathway, we assume significant increases in corporate average fuel economy (CAFE) standards for LDVs. We also incorporate increases in fuel efficiency for other transportation modes in line with industry goals. Our analysis indicates that this pathway could reduce annual CO₂ emission in 2050 by 508 MMmt, Figure 22 and Table 24.

Figure 22: Transportation Sector CO₂ Emission Reductions: Increased Vehicle Fuel Efficiency

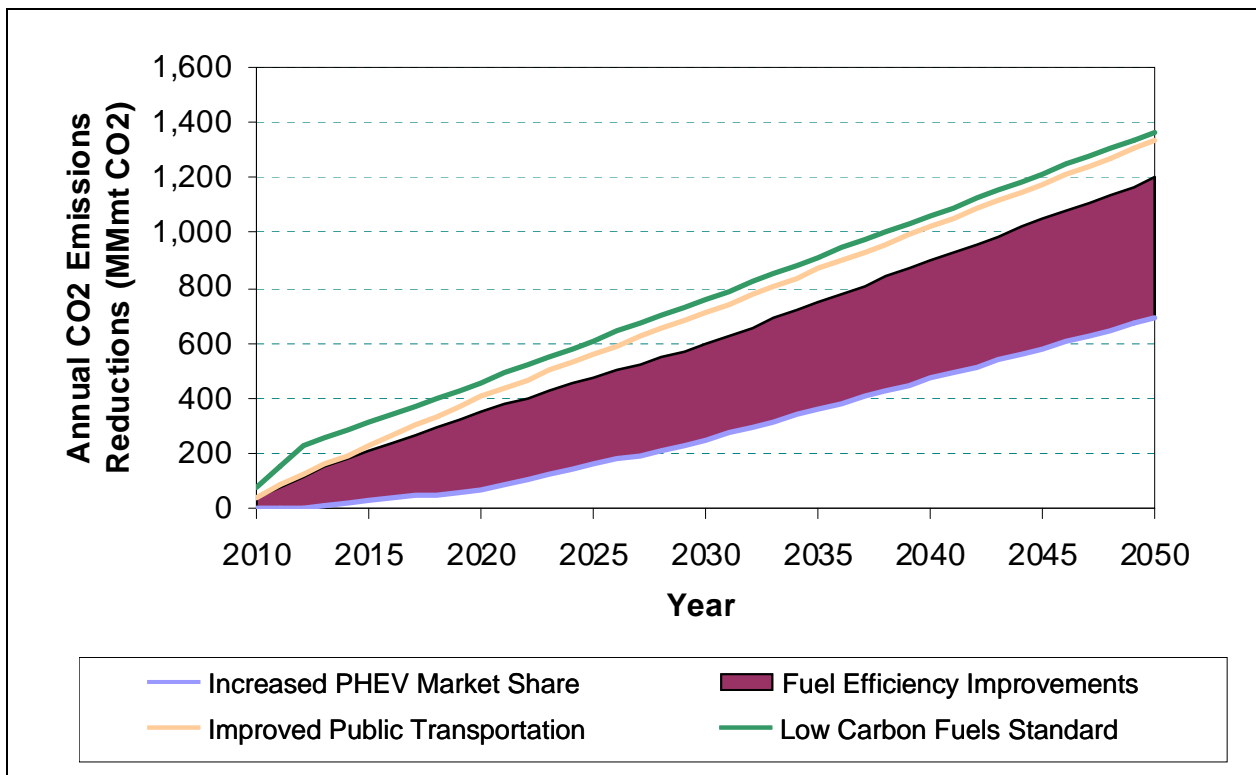


Table 24: Contribution of Increased Fuel Efficiency to Transportation Sector CO₂ Emission Reductions

Year	2012	2020	2030	2050
Transportation Sector Emissions: Reference Case	2,017	2,073	2,188	2,493
CO₂ Emission Reduction Potential				
• Increased PHEV Market Share	5	69	249	690
• Fuel Efficiency Improvements				
LDV	61	128	107	93
Commercial Light Trucks	0	3	9	16
Freight Trucks	46	79	117	200
Air	0	37	46	59
Rail	7	16	21	29
Other	0	21	49	111
Total Fuel Efficiency	114	284	349	508
• Improved Public Transportation	5	55	114	134
• Low Carbon Fuels Standard	106	52	49	33
Total CO₂ Emission Reductions	230	460	760	1,366
Transportation Sector Emissions: Obama Plan	1,787	1,613	1,428	1,127

Conventional Light Duty Vehicles

As recently reported, the Obama Administration has set increased fuel efficiency targets for the 2011 model year light duty cars and trucks. The fuel efficiency of new cars will be raised to 30.2 MPG from 27.5 MPG, while truck fuel efficiency will be raised to 24.1 MPG from 23 MPG. We assume this is the beginning of an increased fuel economy initiative first outlined by the Obama campaign in August 2008, which set a target of annual fuel economy increases of 4%. From 2011 to 2020, we assume light duty car and truck MPG increases by 4%. From 2021-2050, we assume that this fuel economy improvement rate slows to 2% annually, Table 25 and Table 26.

Table 25: Calculation of New (Non-PHEV) LDV Fuel Efficiency Increases

Year	2012		2020		2030		2050	
Case	Reference Case	Obama Energy Plan	Reference Case	Obama Energy Plan	Reference Case	Obama Energy Plan	Reference Case	Obama Energy Plan
New Car MPG	32.3	31.4	42.0	43.0	42.1	52.4	42.2	77.9
New Truck MPG	25.3	26.1	31.4	34.3	32.4	42.6	33.3	62.1
Sales Weighted Average	28.8	28.2	36.6	38.5	37.3	47.1	37.7	70.0

Table 26: LDV Efficiency Assumptions

Year	2012	2020	2030	2050
Conventional Vehicle Sales (000s)	16,784	13,124	11,059	8,737
New Sales MPG*	28	39	47	70
Obama Plan, LDV Fleet MPG	22.1	28.9	37.1	58.1
Reference Case LDV Fleet MPG	20.7	23.7	27.9	34.6

*Sales Weighted Average of Car and Truck MPG

Implementation of higher LDV fuel efficiency standards would reduce annual CO₂ emissions in year 2050 by 93 MMmt. It is useful to note that the longer-term CO₂ emission reduction potential from improved LDV fuel efficiency is reduced by the massive rollout of PHEVs, discussed above.

Other Transportation Modes

We identified and placed into CarBen the stated industry goals for fuel efficiency improvements for commercial light trucks, freight trucks, airlines, and rail, Table 27 and Table 28. In total, meeting these industry goals would reduce annual CO₂ emissions from the transportation sector by 304 MMmt in 2050.

Finally, we assume that the “other” transportation category achieves fuel efficiency gains of 50% relative to year 2005 standards, providing 111 MMmt of annual CO₂ emission reductions in 2050.

Table 27: Assumptions of Fuel Efficiency Potential in Other Transportation Modes

Mode	Goal	Source
Commercial Light Trucks	Same Efficiency gains (in % terms) as experienced by Light Duty Trucks	Extension of Obama Energy Plan Goals
Air	Efficiency Improvement of 15% by 2012, 32% by 2020 50% by 2050 (Relative to 2005 levels)	International Civil Aviation Organization Group on International Aviation and Climate Change (ICAO GIACC) ¹⁸
Rail	Efficiency improvement of 20% by 2012 (relative to 2000), additional incremental improvement of 20% by 2020. We assume the trend is carried forward through 2050.	DOE/GE Heavy Vehicle Systems Optimization Plan: 21 st Century Locomotive Technology ¹⁹ .
Freight	Doubling of Fleet Fuel efficiency by 2050	Wal-Mart Corp, EPA/ICF Freight Trucking Efficiency Strategies Report ²⁰ .
Other*	50% Reduction by 2050 (relative to 2005)	To represent an aggressive effort to curb CO ₂ emission, we assume the same goal for "Other" as for the aviation industry.
* As discussed in the Reference Case Transportation Sector section, the other category is a catch all used by the EIA, but predominantly covers emission from military transportation activities.		

Our assumptions for improved fuel efficiency incorporate Wal-Mart Corporation's corporate goal of doubling the fuel efficiency of its freight truck fleet by 2012. Though this target is aggressive, the ICF/EPA report¹⁷ found that current modifications to the existing fleet could improve fuel efficiency by 50%, without considering technological developments or stock replacements.

¹⁸ Steele, P. *Industry Goals and Measures to Address CO₂ Emissions From Aviation* Presentation given at ICAO GIACC/3, Montreal February 16-19. Accessed at: http://www.icao.int/env/meetings/2009/GIACC_3/Docs/Giacc3_Pres_IndustryGoals.pdf

¹⁹ King, Robert, D. *21st Century Locomotive Technology*. DOE Heavy Vehicle Systems Optimization, 2006. Accessed at: http://www1.eere.energy.gov/vehiclesandfuels/pdfs/hvso_2006/22_salasoo.pdf

²⁰ ICF Consulting *Energy Efficiency Strategies for Freight Trucking: Potential Impact on Fuel Use and Greenhouse Gas Emissions*. Report prepared for the EPA, 2003. Accessed at: http://www.env-ne.org/public/resources/pdf/ENE_Road_Freight_EE_Program_P1.pdf

Table 28: Improvement in Other Transportation Modes of Fuel Efficiencies

Transportation Mode	Fuel Efficiency Unit	2012		2020		2030		2050	
		Reference Case	Obama Energy Plan	Reference Case	Obama Energy Plan	Reference Case	Obama Energy Plan	Reference Case	Obama Energy Plan
Commercial LT	MPG	15.2	15.2	17.4	19.0	19.8	25.5	25.5	46.1
Freight Trucks	MPG	6.1	6.9	6.5	8.0	6.8	9.1	7.5	12.0
Air	Seat MPG	64.1	64.0	67.2	78.5	70.0	82.8	76.0	91.4
Rail	Ton Miles/BTU	2.9	3.5	3.0	4.5	3.0	5.0	3.0	6.0
Other	% Reduction	-	0%	-	11%	-	24%	-	50%

Transportation Pathway # 3: Improved Public Transportation

One feature of the Obama Administration's infrastructure development plan is the expansion of public transportation. This pathway has the potential to reduce CO₂ emissions by decreasing the amount of miles each person drives. Assuming that increased use of public transportation is able to reduce total miles traveled by light duty vehicles by 15% in 2050, CO₂ emissions would be reduced by 134 million metric tons, Figure 23 and Table 29.

Figure 23: Transportation Sector CO₂ Emission Reductions: Public Transportation

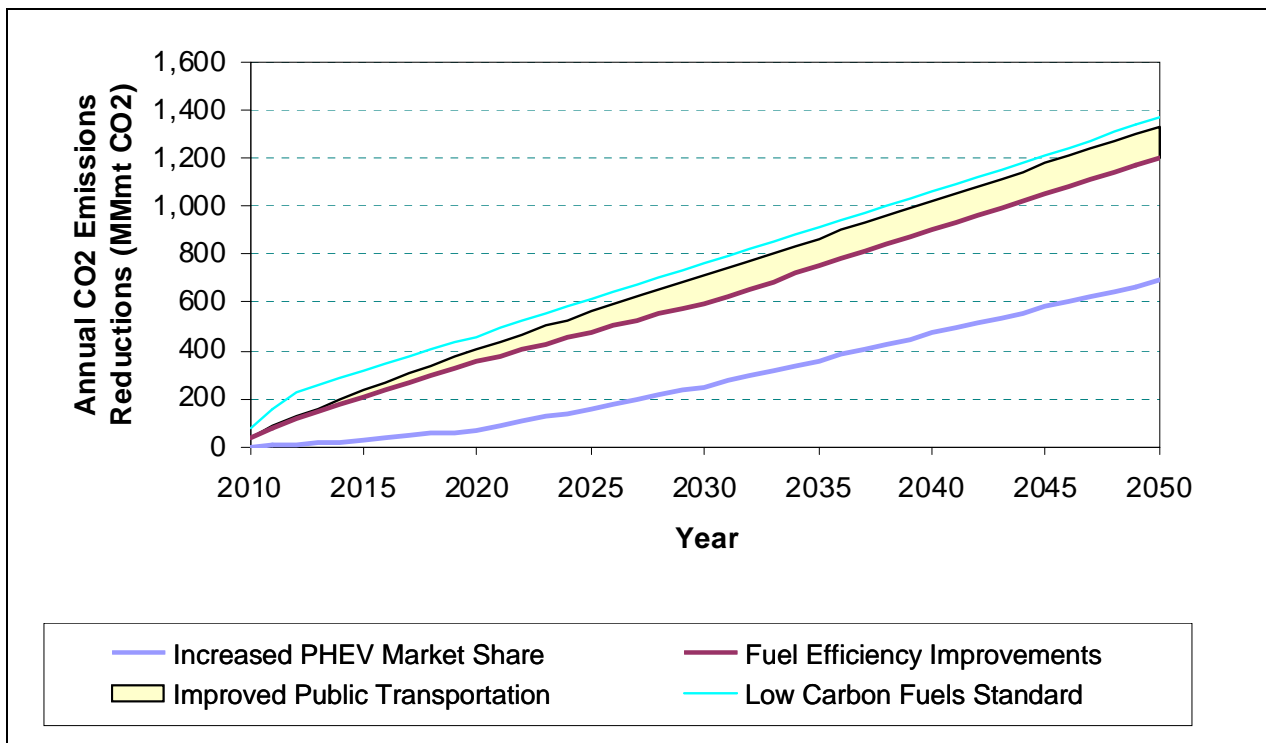


Table 29: Contribution of Public Transportation Infrastructure Investments to Transportation Sector CO₂ Emission Reductions

Year	2012	2020	2030	2050
Transportation Sector Emissions: Reference Case	2,017	2,073	2,188	2,493
CO₂ Emission Reduction Potential				
• Increased PHEV Market Share	5	69	249	690
• Fuel Efficiency Improvements	114	284	349	508
• Improved Public Transportation	5	55	114	134
• Low Carbon Fuels Standard	106	52	49	33
Total CO₂ Emission Reductions	230	460	760	1,366
Transportation Sector Emissions: Obama Plan	1,787	1,613	1,428	1,127

We assume that vehicle miles traveled (VMT) per person can be reduced incrementally by 0.25% per year beginning in 2010 through 2030. Then, due to new infrastructure developments such as high speed rail, the miles traveled by person can be reduced incrementally by 0.5% per year through 2050. This results in a cumulative reduction in miles traveled per person of 15% by 2050, which is consistent for the near term with Kuuskraa, et al and consistent with the Obama Administration's infrastructure plans for the longer term²¹. Table 30 displays these assumptions.

The CO₂ emission reductions from this policy slow between 2030 and 2050 due to interactions with policies that increase vehicle mileage efficiency, reduce the carbon content of transportation fuels, and introduce of PHEVs, causing the CO₂ emission footprint of a mile traveled to decrease.

²¹ Kuuskraa, V. A., DiPietro, J.P. Stabilizing Atmospheric Concentrations of CO₂: Role of Carbon Sequestration. Presentation given at 3rd Annual Conference on Carbon Capture and Sequestration.

Table 30: Reduction in VMT from Obama Administration Energy Plan

Year	2012	2020	2030	2050
US Population (Millions)	316	338	366	420
Reference Case LDV* VMT/Person (Billions/Million People)	9.1	10.0	11.1	13.8
Obama Plan LDV VMT/Person	9.1	9.7	10.6	12.4
Reference Case VMT (Billions)	2,881	3,375	4,069	5,796
Obama Plan VMT (Billions)	2,867	3,291	3,865	5,208

* Includes Conventional and Hybrid LDV Vehicles

Transportation Pathway #4: Low Carbon Fuels Standard

Combining calls for a Low Carbon Fuels (LCF) Standard with the need for lower oil imports, the Obama Administration's Energy Plan stresses greater production of non-petroleum based fuels. Our analysis of this pathway assumes a greater market penetration of bio-fuels, including cellulosic ethanol and bio-diesel in the LDV and Commercial LT fleets, and assumes that the previous Administration's policy of promoting corn ethanol is phased out. This pathway has the potential to reduce annual Transportation Sector CO₂ emission in 2050 by 33 MMmt, Figure 24 and Table 31

Figure 24: Transportation Sector CO₂ Emission Reductions: Low Carbon Fuels Standard

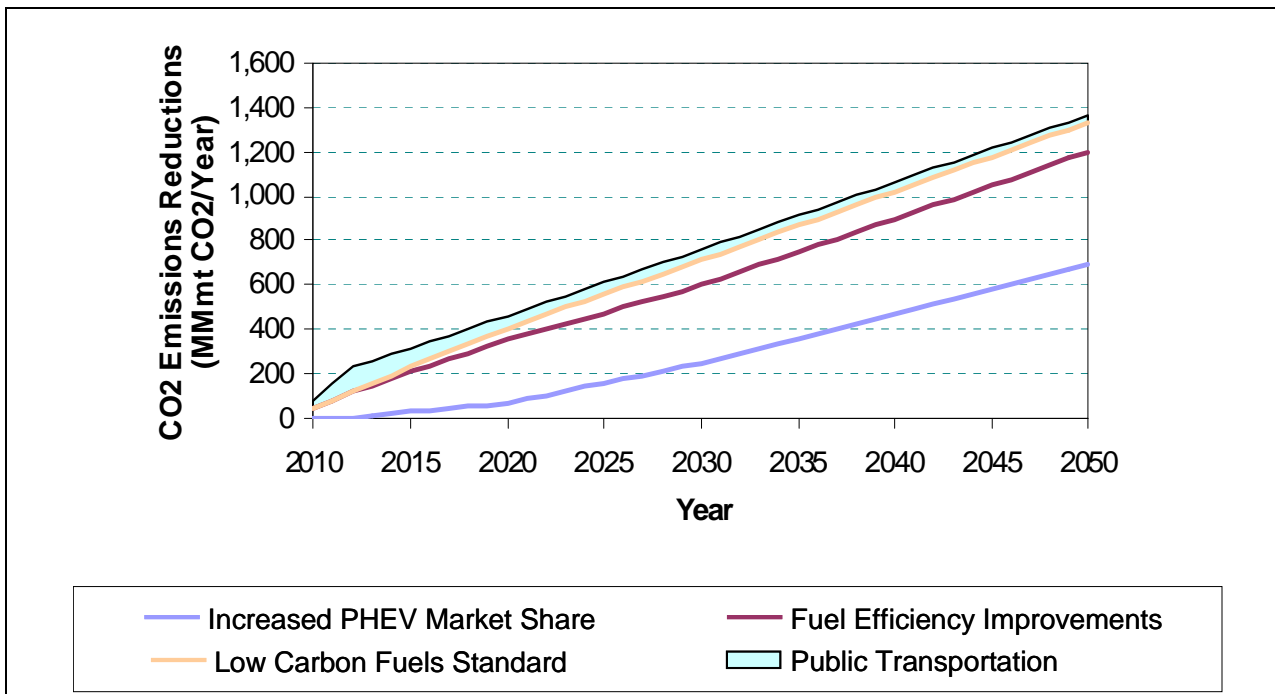


Table 31: Contribution of a Low Carbon Fuels Standard to Transportation Sector CO₂ Emission Reductions

Year	2012	2020	2030	2050
Transportation Sector Emissions: Reference Case	2,017	2,073	2,188	2,493
CO2 Emission Reduction Potential				
• Increased PHEV Market Share	5	69	249	690
• Fuel Efficiency Improvements	114	284	349	508
• Improved Public Transportation	5	55	114	134
• Low Carbon Fuels Standard	106	52	49	33
Total CO2 Emission Reductions	230	460	760	1,366
Transportation Sector Emissions: Obama Plan	1,787	1,613	1,428	1,127

Since the Administration has not provided concrete details for a LCF standard, we used information from a study by UC Berkley and UC Davis on California's low carbon fuels legislation²² *. In this study, ethanol produced from biological feed stocks (initially corn and subsequently cellulosic ethanol) is blended with gasoline at 5% by volume in 2010 and 25% by volume in 2020.

We find the assumptions in the California study to be overly aggressive. We assume that introduction of biofuels into the national market proceeds more slowly. As such, we assume that cellulosic ethanol and bio-diesel composes 10% of the gasoline market by 2020 and 20% by 2050, Table 32. We assume the technology for cellulosic ethanol and bio-diesel will become available by 2020, after which no corn ethanol will be used. Based on work by the Argonne National Laboratory, we set the emission factors for cellulosic ethanol/bio-diesel at an optimistic 5.4 MMmt of CO₂ per QBtu²³.

²² Farrell, A., Sperling, D. *A Low-Carbon Fuel Standard for California, Part 1: Technical Analysis* UC, Berkeley, U.C. Davis, 2007. Accessed at: http://www.energy.ca.gov/low_carbon_fuel_standard/UC_LCFS_study_Part_1-FINAL.pdf

* Scenario G10. Assumption numbers are used from the report.

²³ VISION Model, Argonne National Laboratory, 2008. accessed at: http://www.transportation.anl.gov/modeling_simulation/VISION/download.html

Table 32: Assumptions on Low Carbon Fuel Usage by Transportation Mode

Transportation Mode	2020	2030	2050
LDV	10%	15%	20%
Commercial Light Trucks	10%	15%	20%

We also examined the potential for increased market share of coal-to-liquids (CTL) diesel fuel to represent the Administration's goals of reducing dependence on oil imports. However, we do not attribute any CO₂ emission reduction to the use of CTL technology. Assuming that the CO₂ emissions from a CTL plant are captured and stored, we acknowledge that co-firing of coal-to-liquid (CTL) plants with biomass could lower the *lifecycle* net emission profile of CTL diesel below that of diesel as produced today. However, it is not clear the *lifecycle* emissions of diesel produced from CTL with biomass co-firing and CCS technology would be much less than diesel produced from a traditional refinery equipped with CCS technology.

Based on more recent work and studies, we recognize that the above CO₂ emission factor for cellulosic ethanol and bio-diesel are likely too optimistic in that they do not account for GHG emissions from the use of natural gas in ethanol distillation or from the increased use of nitrogen-based fertilizers. Recent research shows that including these factors would significantly increase the CO₂ emission factors for corn ethanol, making this fuel a net contributor rather than a net reducer of CO₂ emissions.

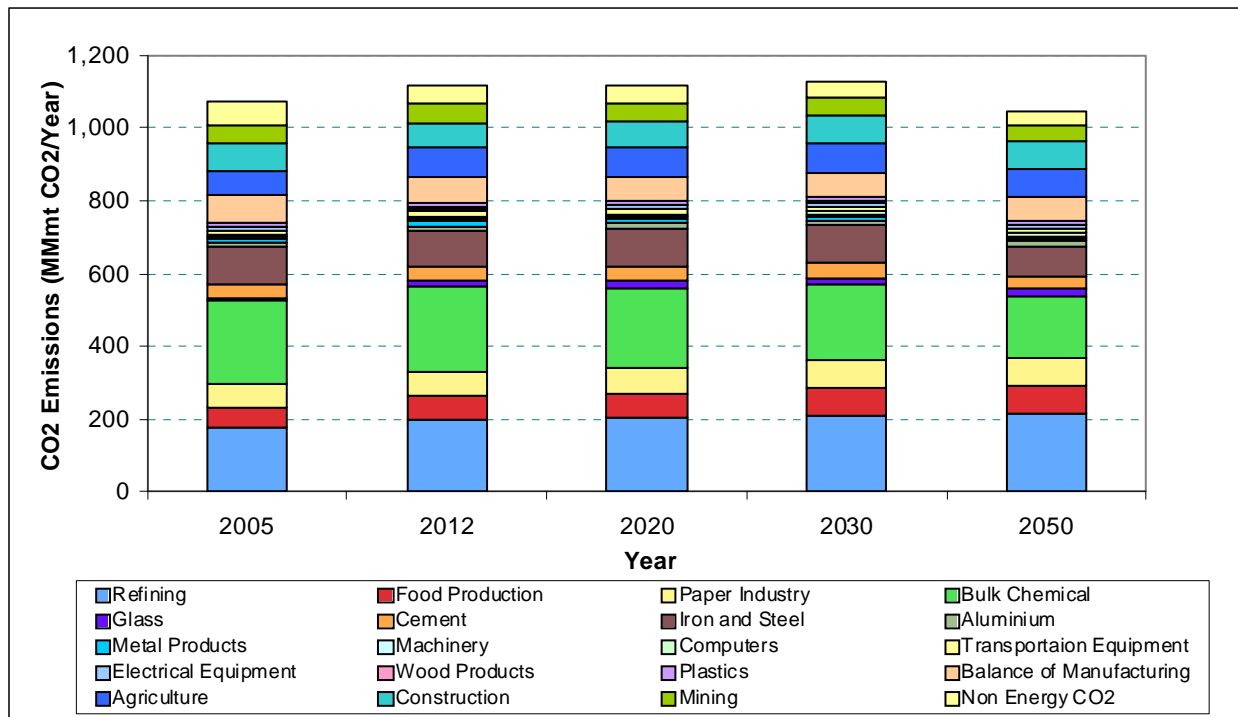
However, until more rigorous analysis is placed into the public sector, we have maintained the low CO₂ emission factors for cellulosic ethanol/bio-diesel. We have done so assuming that a new enzyme-based low energy fermentation process will be developed, that low carbon heat energy (such as from solar, use of biomass or low carbon electricity) will become more widely used, and that higher energy content materials (such as sugarcane) are considered. Should these assumptions on cellulosic ethanol and bio-diesel not materialize, the 33 MMmt of annual CO₂ emission reductions (in year 2050) from the Low Carbon Fuel Standard would be considerably less.

III.C REDUCING EMISSIONS IN THE INDUSTRIAL SECTOR

The Industrial Sector is responsible for 11% of the U.S. economy's CO₂ emissions, equal to 1,045 MMmt for year 2050 in the Reference Case. This includes emissions from the use of fossil fuel to provide energy to the 18 industries analyzed by the EIA within the Industrial Sector. Figure 25 shows how emissions from each of these industries contribute to the sector total. (CO₂ emissions associated with the production of electricity used by the Industrial Sector are included in the Electricity Sector.)

The industries with the largest CO₂ emissions in 2050 are Bulk Chemicals, projected to emit 170 million metric tons of CO₂ and Petroleum Refining, projected to emit 216 MMmt CO₂.

Figure 25: Industrial Sector CO₂ Emissions by Sector: Reference Case



We have analyzed two main pathways by which to reduce CO₂ emissions in the Industrial Sector.

- The first pathway involves the reduction of CO₂ emissions through improved energy efficiency. Our analysis suggests that this first pathway will be able to reduce annual CO₂ emissions by 220 MMmt in 2050.
- The second pathway is the implementation of carbon capture and storage (CCS) technology throughout the Industrial Sector. Though this pathway is not explicitly mentioned in the Obama Administration's Energy Plan, it follows logically from the implementation of CCS technology in the Electricity Sector. Our analysis indicates that this pathway could reduce annual CO₂ emissions by 473 MMmt in 2050, Table 33 and Figure 26.

Figure 27 shows the impact of pursuing these two pathways on Industrial Sector CO₂ emissions.

Table 33: CO₂ Emission Reductions: Industrial Sector (MMmt CO₂)

Year	2012	2020	2030	2050
Industrial Sector Emissions: Reference Case	1,116	1,118	1,131	1,045
• Energy Efficiency				
Refining and Bulk Chemicals	25	53	68	92
Other Industries	28	70	93	128
Sub-Total	53	124	161	220
• Carbon Capture and Storage				
Refining and Bulk Chemicals	0	17	84	208
Other Industries	2	38	118	265
Sub-Total	2	55	202	473
Total CO₂ Emission Reductions	55	179	363	693
Industrial Sector Emissions: Obama Plan	1,061	939	767	352

Figure 26: CO₂ Emissions Reductions: Industrial Sector

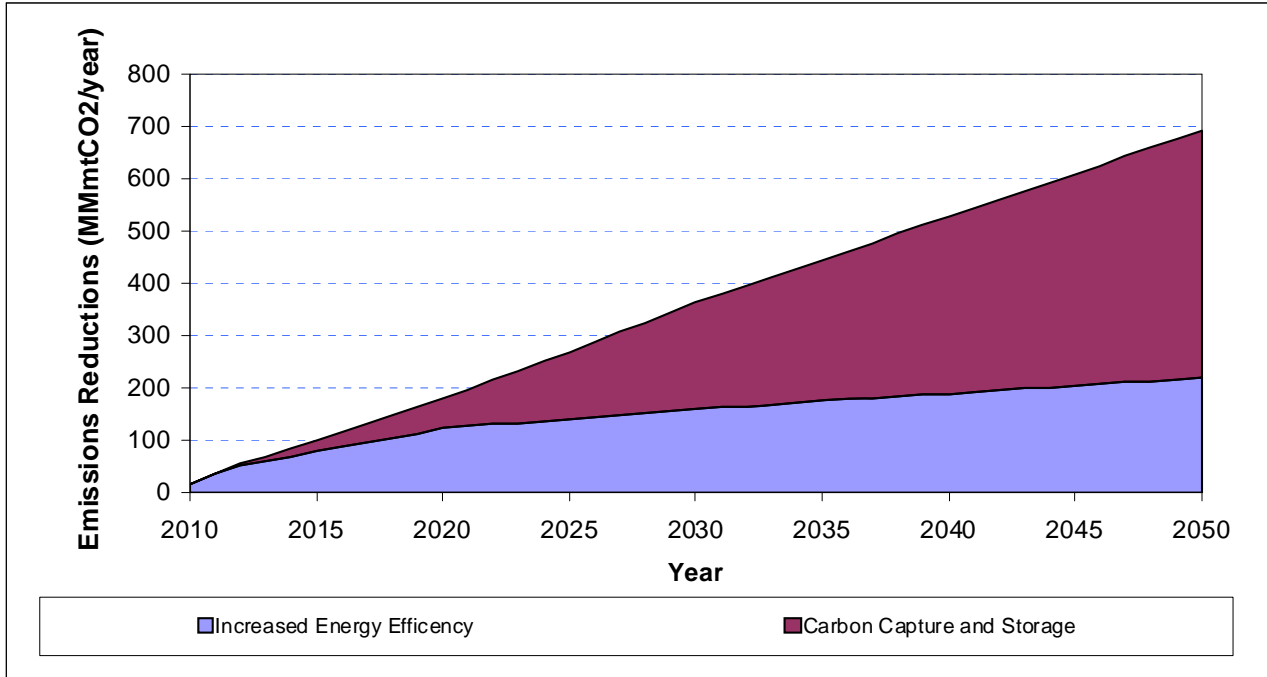
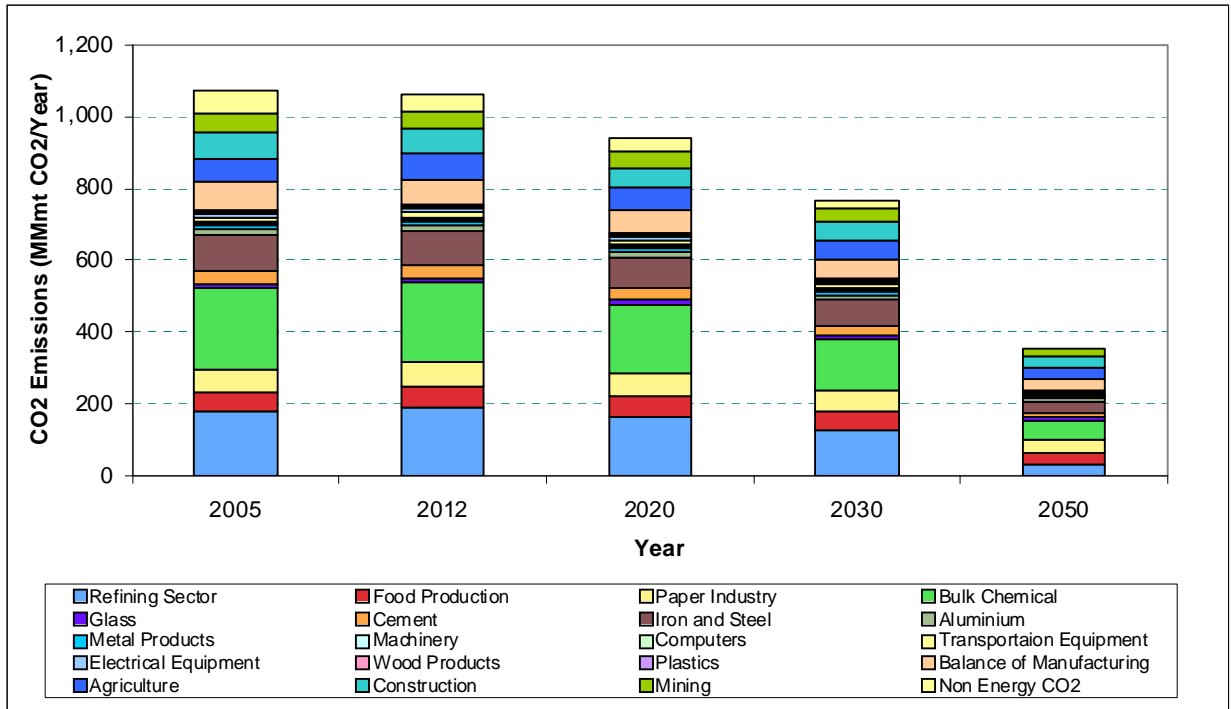


Figure 27: Industrial Sector CO₂ Emissions by Sector: Obama Plan

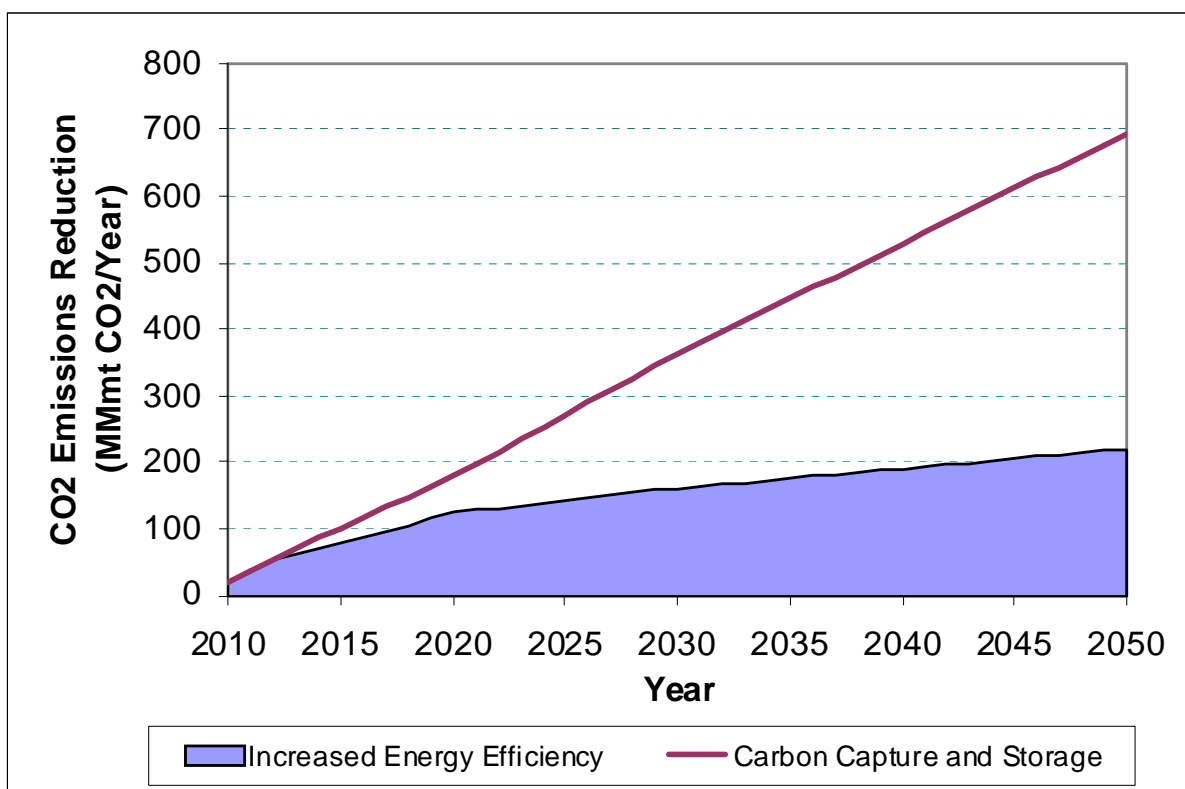


Industrial Sector Pathway #1: Increased Energy Efficiency

We assume that the Obama Administration's initiative to increase energy efficiency will apply to all sectors, including the Industrial Sector. A portion of the energy efficiency gains we model are captured in the previous discussion of the Electricity Sector. However, electricity provides, on average, only 14% of the delivered energy to industrial operations; the remainder is from fossil fuels, renewables and biomass energy²⁴.

Increases in non-electrical energy efficiency in the Industrial Sector can reduce CO₂ emissions relative to the Reference Case by 220 million metric tons annually in 2050, Figure 28. Approximately 42% of this reduction occurs in the Bulk Chemical and Refining industries, Table 34.

Figure 28: Industrial Sector CO₂ Emission Reductions: Energy Efficiency



²⁴ Annual Energy Outlook, 2008. Table 2.

Table 34: Contribution of Increased Energy Efficiency to Industrial Sector CO₂ Emission Reductions

Year	2012	2020	2030	2050
Industrial Sector Emissions: Reference Case	1,116	1,118	1,131	1,045
• Energy Efficiency				
Refining and Bulk Chemicals	25	53	68	92
Other Industries	28	70	93	128
Sub-Total	52	124	161	220
• Carbon Capture and Storage				
Refining and Bulk Chemicals	0	17	84	208
Other Industries	2	38	118	265
Sub-Total	2	55	202	473
Total CO₂ Emission Reductions	55	179	363	693
Industrial Sector Emissions: Obama Plan	1,061	939	767	352

Significant gains in industrial energy efficiency have already been built into the Reference Case, limiting the amount of additional energy efficiency gains available in the Industrial Sector. **Error! Reference source not found.** shows that, in the Reference Case, energy use per \$ of GDP from the Industrial Sector (from petroleum, natural gas and coal) declines from 3.4 (thousand btu/\$) in 2005 to 2.1 (thousand Btu/\$) in 2030, a 40% decrease.

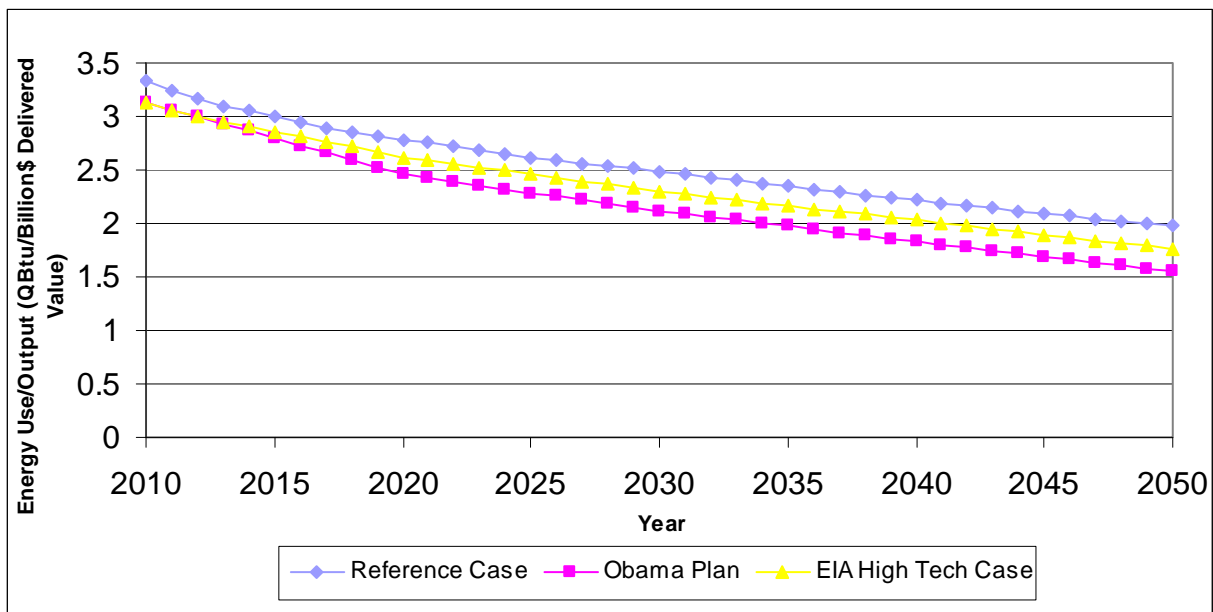
To model Reference Case reductions in energy intensity for the Industrial Sector, the EIA uses “technology possibility curves”. These curves are based on industry surveys of technology progress and process improvements. (Additional details are available in the methodology document accompanying the AEO and will not be provided here.)

Additionally, the EIA runs a High Technology Case which assumes that the rate of technology progress quickens noticeably. This higher rate of technology progress allows for timelier and greater reductions in energy intensity and lower resultant CO₂ emission. For the High Case, the EIA uses more aggressive assumptions for the rate of energy intensity reduction for the Industrial Sector.

For the Obama Plan, we assume that reductions in energy intensity in the Industrial Sector are further increased, relative to the High Technology Case discussed

above. We believe that the incentives provided by federal stimulus dollars and a price on carbon emissions will allow for the development of advanced technologies that will further reduce the amount of energy consumed per unit of industrial output*. Table 35 displays the reductions in industrial energy intensity by fuel for the Reference, High Technology and Obama Plan cases. The resulting decline in energy intensity for these cases is charted in **Error! Reference source not found.**

Figure 29: Reductions in Industrial Sector Non-Electricity Energy Intensity



* In its modeling of technological development, the EIA does not consider the potential for “breakthrough” technologies, which would have non-linear impacts on the trend in energy intensity reduction. The aggressive case we model in the current analysis, could be construed as one in which “breakthrough” technologies enter the market.

Table 35: Trends in Industrial Energy Use by Fuel (Qbtu)*

	Reference Case	High Technology Case	% Change from Reference Case	Obama Plan Sceneraio	% Change From Reference Case
2010					
Petroleum	7.34	7.2	2%	7.06	4%
Natural Gas	7.08	6.86	3%	6.64	6%
Coal	1.87	1.85	1%	1.83	2%
Total	16.29	15.91	2%	15.53	5%
2020					
Petroleum	6.73	6.14	9%	5.55	18%
Natural Gas	6.93	6.78	2%	6.63	4%
Coal	1.71	1.59	7%	1.47	14%
Total	15.37	14.51	6%	13.65	11%
2030					
Petroleum	6.55	5.82	11%	5.09	22%
Natural Gas	6.88	6.66	3%	6.44	6%
Coal	1.64	1.49	9%	1.34	18%
Total	15.07	13.97	7%	12.87	15%
2050					
Petroleum	6.20	5.23	16%	4.25	31%
Natural Gas	6.78	6.43	5%	6.07	10%
Coal	1.51	1.31	13%	1.11	27%
Total	14.49	12.96	11%	11.43	21%

*This table is modeled from EIA's AEO Appendix table D.2 and, as such, displays the figures in raw energy use exclusive of the refining sector. Industrial output is constant among the cases in each time period, so we assume the change in energy use is due to change in energy intensity. Our analysis scales up reductions in energy intensity to the entire sector, inclusive of the refining industry.

** Values are extrapolated by continuing the annual rate of change from years 2020 to 2030 to year 2050.

Industrial Sector Pathway #2: Carbon Capture and Storage

The Industrial Sector uses large volumes of natural gas, petroleum and coal as fuel inputs and feedstocks. The majority of CO₂ emissions from this sector occur when these fuels are burned or converted. Our analysis indicates that implementation of CCS technology in the Industrial Sector could reduce annual CO₂ emissions by 473 MMmt in 2050, Figure 30. Approximately 44% of this reduction occurs in the Bulk Chemical and refining industries, Table 36.

Figure 30: Industrial Sector CO₂ Emission Reductions: Carbon Capture and Storage

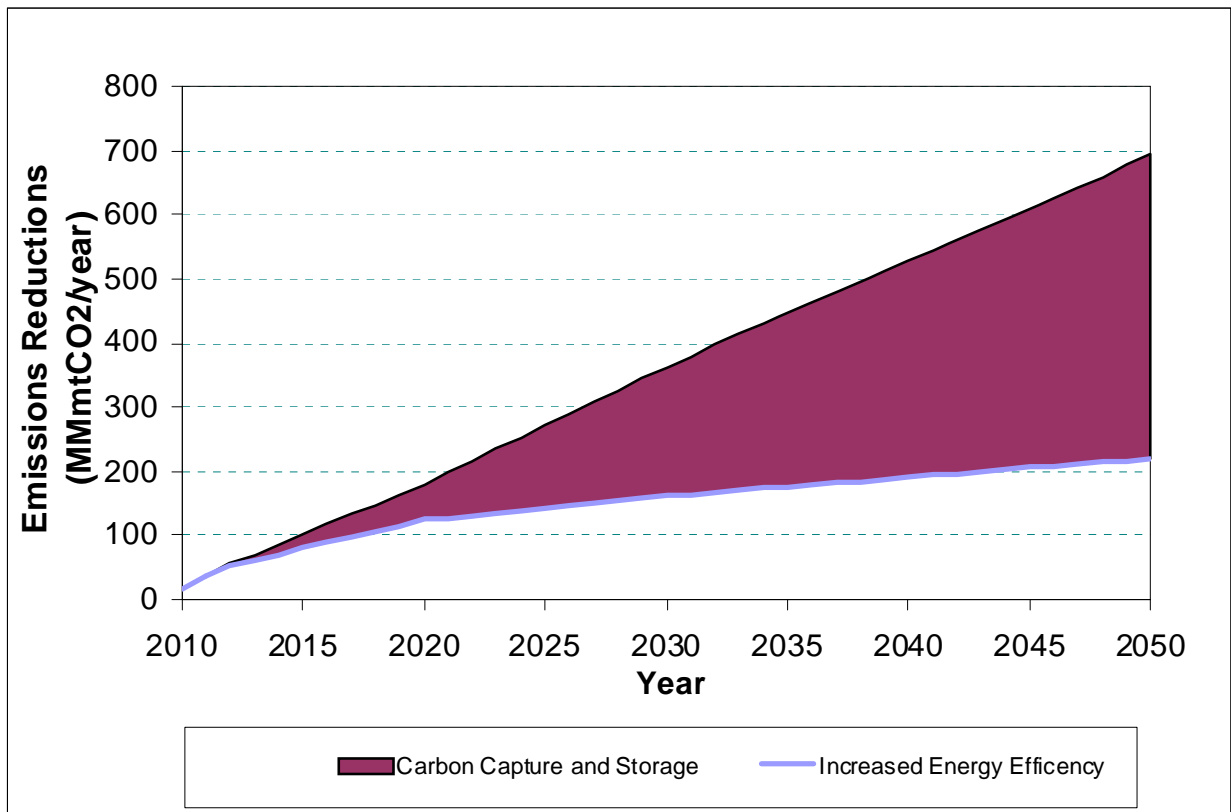


Table 36: Contribution of CCS Technology to Industrial Sector CO₂ Emission Reductions

Year	2012	2020	2030	2050
Industrial Sector Emissions: Reference Case	1,116	1,118	1,131	1,045
• Energy Efficiency				
Refining and Bulk Chemicals	25	53	68	92
Other Industries	28	70	93	128
Sub-Total	52	124	161	220
• Carbon Capture and Storage				
Refining and Bulk Chemicals	0	17	84	208
Other Industries	2	38	118	265
Sub-Total	2	55	202	473
Total CO₂ Emission Reductions	55	179	363	693
Industrial Sector Emissions: Obama Plan	1,061	939	767	352

The technology required for CCS in the Industrial Sector is similar to that being developed for capturing and storing CO₂ emissions from natural gas and coal-fired power plants. However, CCS technology will need to be adapted to the numerous activities and CO₂ sources in the Industrial Sector, due to the variety of processes and fuels used.

- A main use of fossil fuels in the Industrial Sector is for combustion to generate electricity and/or process heat. Here, CO₂ is a dilute stream in the combustion flue gas, just as in existing coal fired power plants.
- Fossil fuels are also be used in the Industrial Sector as feedstocks for process chemical reactions. This method often results in a relatively pure stream of CO₂ emissions, such as from a refinery hydrogen plant, where CO₂ is separated from the main product of hydrogen and crude oil.

To estimate the potential for using CCS in the Industrial Sector, we consulted previous work performed by Advanced Resources which identified Industrial Sector activities with high concentration streams of CO₂²⁵. Then, we used a recent paper by Resources for the Future (RFF), which provided CO₂ abatement costs for high and low concentration CO₂ streams²⁶. As a final step, we developed assumptions about the

²⁵ DiPietro, J. P. *Summary Documentation for the Carbon Sequestration Benefits Modeling System (CarBen2)*

²⁶ Anderson, S., Newell, R. *Prospects for Carbon Capture and Storage Technologies*. Resources for the Future, 2003. Accessed at: <http://www.rff.org/RFF/Documents/RFF-DP-02-68.pdf>

market penetration of CCS technology in high and low CO₂ purity stream portions of the Industrial Sector.

We also estimate that the percent of high-concentration CO₂ emitted from refineries will increase from the current baseline of 22% to 72% in 2050. This assumption is based on current work by Petrobras and others examining the use of oxy-fuel technology to capture pure streams of CO₂ from catalytic cracking units and other refinery components. Our assumptions are summarized in Table 37.

Table 37: Assumptions for Industrial Sector CCS Potential

Industry	% of CO ₂ emissions in high concentration form			
	2012	2020	2030	2050
Refining Sector	22%	35%	52%	72%
Bulk Chemical Feedstock	100%	100%	100%	100%
Cement	50%	50%	50%	50%
CCS Market Penetration (% of CO ₂ emissions covered by CCS technology)				
Source	2012	2020	2030	2050
High Concentration Stream	0%	5%	37%	100%
Low Concentration Stream	0%	5%	18%	50%
Carbon Capture % (Percent of emissions captured from sources with installed CCS technology)				
High Concentration	95%			
Low Concentration	90%			

We assume that all high purity CO₂ sources in the Industrial Sector install CCS technology by 2050 which captures 95% of process emissions, starting at a baseline of 5% CCS installation in 2020. We assume that 50% of low purity CO₂ sources in the Industrial Sector install CCS technology by 2050, which captures 90% of process emissions, starting at a similar CCS usage baseline of 5% in 2020.

III.D IMPROVING ENERGY EFFICIENCY IN THE RESIDENTIAL AND COMMERCIAL SECTORS

The Residential and Commercial Sectors generate CO₂ emissions from the combustion of fossil fuel for heat and energy. In 2050, Reference Case annual CO₂ emissions from Residential and Commercial “end use” are projected to reach 644 MMmt. The majority of these emissions are from space heating, predominantly fueled by natural gas, Figure 31.

Our analysis finds that increased efficiency in the Residential and Commercial Sectors can reduce annual CO₂ emission by 264 million metric tons in 2050, primarily from more efficient use of natural gas in heating, Figure 32, Table 38 and Table 39.

Table 38: CO₂ Emission Reductions: Residential and Commercial Sector (MMmt)

Year	2012	2020	2030	2050
Sector Emissions: Reference Case	583	615	630	644
Energy Efficiency				
Building Shell Efficiency Upgrades	3	15	30	58
Appliance/Equipment Efficiency Upgrades	38	103	156	207
Total CO2 Emission Reductions	41	118	186	264
Sector Emissions: Obama Plan	542	497	444	379

Figure 31: CO₂ Emissions from the Commercial and Industrial Sector by Source: Reference Case

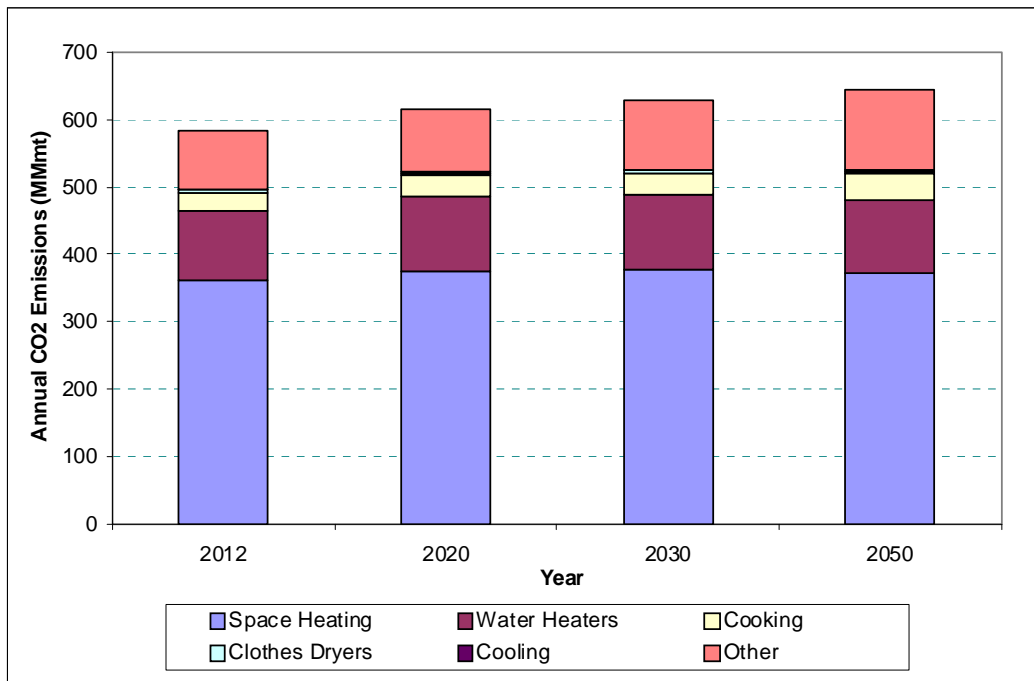


Figure 32: CO₂ Emissions from the Commercial and Industrial Sector by Source: Obama Plan

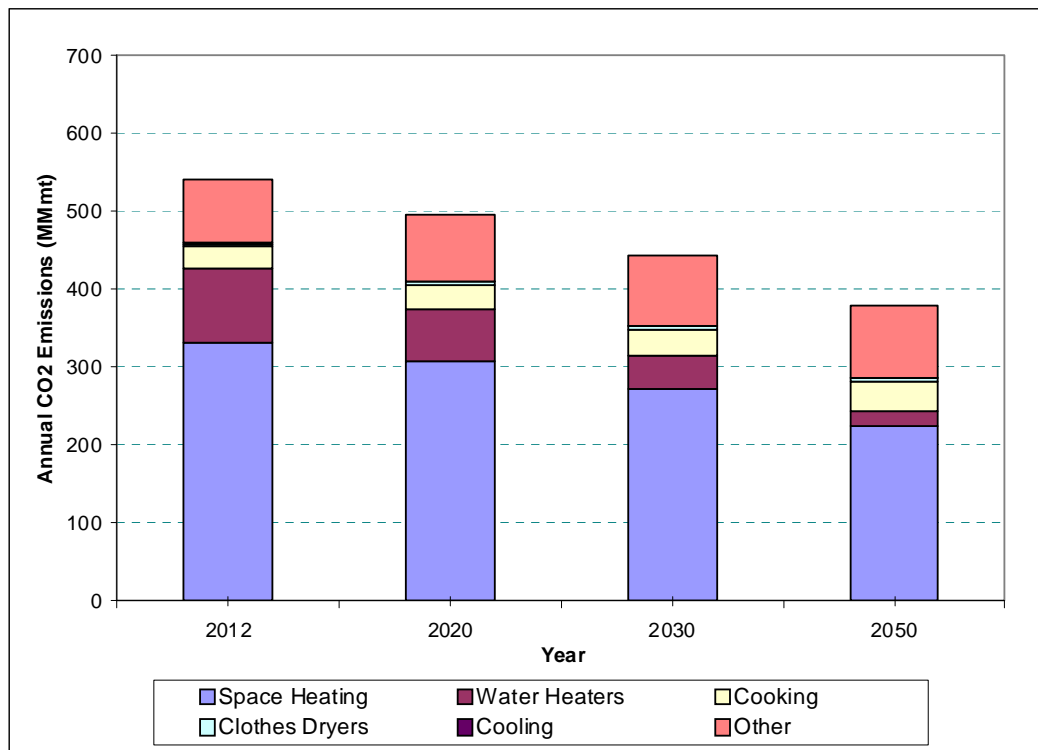


Table 39: Residential & Commercial Sector CO₂ Emissions by Source: Reference Case and Obama Plan

Source	2012	2020	2030	2050
Space Heating				
Reference Case	360	375	377	372
Obama Energy Plan	331	309	272	224
CO2 Emissions Reduction	29	67	105	148
Water Heaters				
Reference Case	104	111	111	109
Obama Energy Plan	96	67	43	20
CO2 Emissions Reduction	8	44	68	89
Cooking				
Reference Case	28	31	33	38
Obama Energy Plan	28	31	33	38
CO2 Emissions Reduction	0	0	0	0
Clothes Dryers				
Reference Case	4	4	4	5
Obama Energy Plan	4	4	4	5
CO2 Emissions Reduction	0	0	0	0
Cooling				
Reference Case	1	1	1	1
Obama Energy Plan	1	1	1	1
CO2 Emissions Reduction	0	0	0	0
Other				
Reference Case	86	93	102	119
Obama Energy Plan	82	86	90	92
CO2 Emissions Reduction	4	7	13	28
Total				
Reference Case	583	615	629	644
Obama Energy Plan	542	497	444	379
CO2 Emission Reductions	41	118	185	264

CO₂ emissions from the Residential and Industrial Sectors can be reduced through two types of efficiency improvements.

The first are upgrades to the “shell” of residential and commercial structures. These upgrades reduce the amount of energy required to heat or cool the structure, decreasing emissions. The Obama Administration’s goal to weatherize 10 million homes is an example of an action that would increase the shell efficiency of residential buildings. The results of our analysis indicate that improvements to residential and commercial building shells could reduce annual CO₂ emissions by 58 MMmt in 2050. Our assumptions about impacts in residential “shell” efficiency are guided by work done by Pacific Northwest National Laboratory, Table 40. Data on (non-electric) energy efficiency improvements in commercial building shells was not as easily available; in this analysis, we assume an improvement potential of 20%.

Table 40: Assumptions on Residential and Commercial Building Shell Efficiency (Heating Values)

Building Type	Reference Case Building Shell Efficiency in 2050*	Obama Plan Building Shell Efficiency in 2050	% Improvement
Residential	0.90	0.76 ²⁷	16%

* These units are index values that quantify the energy load required to heat a given area of residential or commercial building space; the index year is 2005. A value of .95 indicates that, relative to 2005, only 95% of the energy would be needed to heat the same space.

The second type of efficiency improvements in this sector are from the manufacture of higher energy-efficient residential and commercial equipment, such as water heaters, furnaces and air conditioners. As a step in this direction, the Obama Administration recently issued a memorandum directing the Department of Energy to finalize pending regulations mandating energy efficiency standards for commercial and residential appliances²⁸. Our analysis indicates that improvements to residential and commercial equipment could reduce annual CO₂ emissions by 207 MMmt in 2050.

²⁷ Smith, Steven, J., et al. *The value of End-Use Efficiency Technology*. Presentation given at the GTSP Technical Workshop, 2007. Accessed at: http://www.pnl.gov/gtsp/workshops/smith_gtsp_%20052307.pdf

²⁸ http://www.whitehouse.gov/the_press_office/ApplianceEfficiencyStandards/

In CarBen, we assume the untapped potential for efficiency improvement for each type of Residential and Commercial Sector end-use appliance is equal to the differential in efficiencies between the stock of appliances in the Reference Case and the most efficient version of the appliance identified by the EPA Energy Star Program. For the Obama Energy Plan, we assume that, by 2020, the efficiency of each type of appliance has reached the Energy Star standard. By 2050, we assume that this appliance efficiency gain is duplicated, Table 41.

Table 41: Increased Energy Efficiency: Residential and Commercial Appliances

	Reference Case Efficiency (2008)	Highest Energy Star Rated Efficiency	Efficiency Improvement by 2020	Achievable Efficiency Improvement by 2050
Space Heating/Furnaces				
Natural Gas	0.84	0.95	14%	28%
LPG	0.84	0.95	14%	28%
Fuel Oil	0.82	0.95	16%	32%
Water Heaters				
Natural Gas	0.58	0.82	41%	82%
LPG	0.60	0.82	33%	66%

The potential for additional efficiency gains in the Residential and Commercial Sectors is limited, in that these sectors include activities such as cooking and clothes drying which have limited potential for further energy efficiency improvements.

Finally, the composition of the “Other” category in the Residential and Commercial Sectors includes CO₂ emissions from a wide variety of municipal and combined heat and power sources. We assume that CO₂ emissions from this “Other” category can be reduced by 25% by 2050, compared to the Reference Case.

III.E REDUCING NON-CO₂ AND HIGH GLOBAL WARMING POTENTIAL GREENHOUSE GASES

Significant releases of GHG emissions stem from non-CO₂ GHGs such as methane, nitrous oxides and fluorinated compounds (HGWP gases). In the Reference Case, CO₂ equivalent emissions of these gases are 1,957 MMmt in 2050.

We assume that emissions of non-CO₂ and HGWP gases between now and 2050 will first be reduced in response to carbon prices, which we include in the set of Tier I pathways. To provide additional GHG reductions, we assume that the emissions of methane and fluorinated compounds will become progressively restricted through a set of Tier II mandates.

Our analysis suggests that a price on carbon could lead to 633 MMmt of CO₂ equivalent GHG reductions, while supplemental reduction initiatives could add 678 MMmt to the total. As such, the combination of these two actions could reduce annual CO₂ equivalent emission in 2050 by 1,311 MMmt, Table 44. Figure 33 and Figure 34 provide additional detail.

Table 42: GHG Emission Reductions: Non-CO₂ and High GWP Gasses

Year	2012	2020	2030	2050
Methane				
Reference Case	617	642	685	686
Price Driven Emissions Reduction	10	41	122	253
Supplimental Emission Reductions	10	50	100	200
Year 2050 Emissions	598	551	463	233
Nitrous Oxide				
Reference Case	318	332	353	395
Price Driven Emissions Reduction	1	6	28	66
Supplimental Emission Reductions	-	-	-	-
Year 2050 Emissions	317	326	325	329
Flourinated Gases				
Reference Case	220	321	506	876
Price Driven Emissions Reduction	2	8	88	314
Supplimental Emission Reductions	-	-	126	478
Year 2050 Emissions	219	313	293	84
Total				
Reference Case	1,156	1,296	1,545	1,957
Price Driven Emissions Reduction	13	56	238	633
Supplimental Emission Reductions	10	50	226	678
Year 2050 Emissions	1,134	1,190	1,081	646

Figure 33: CO₂ Equivalent Emissions of Non-CO₂ GHG Gases: Reference Case

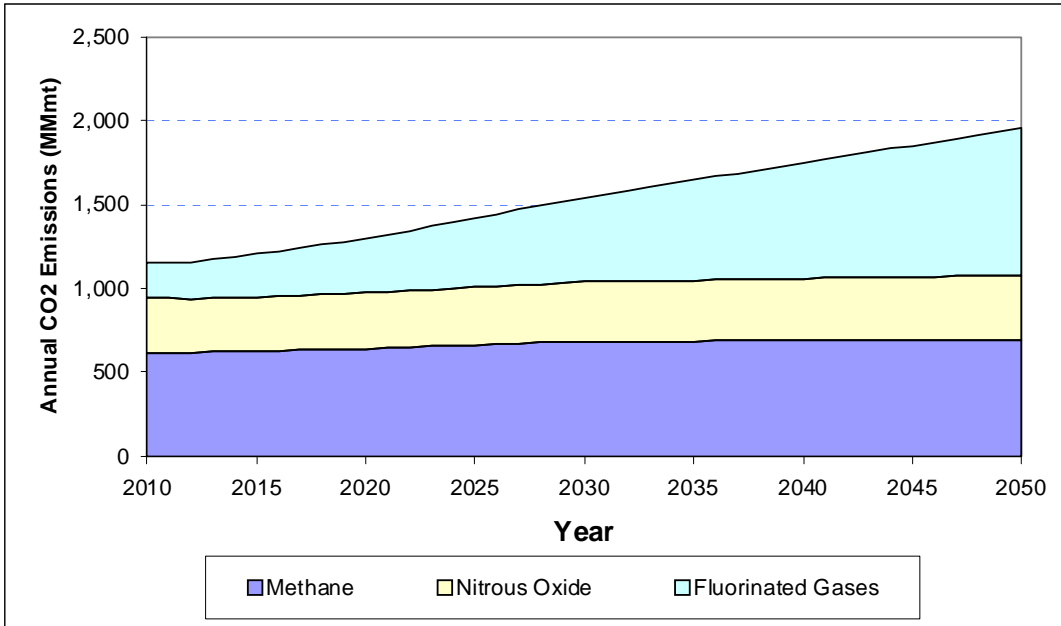
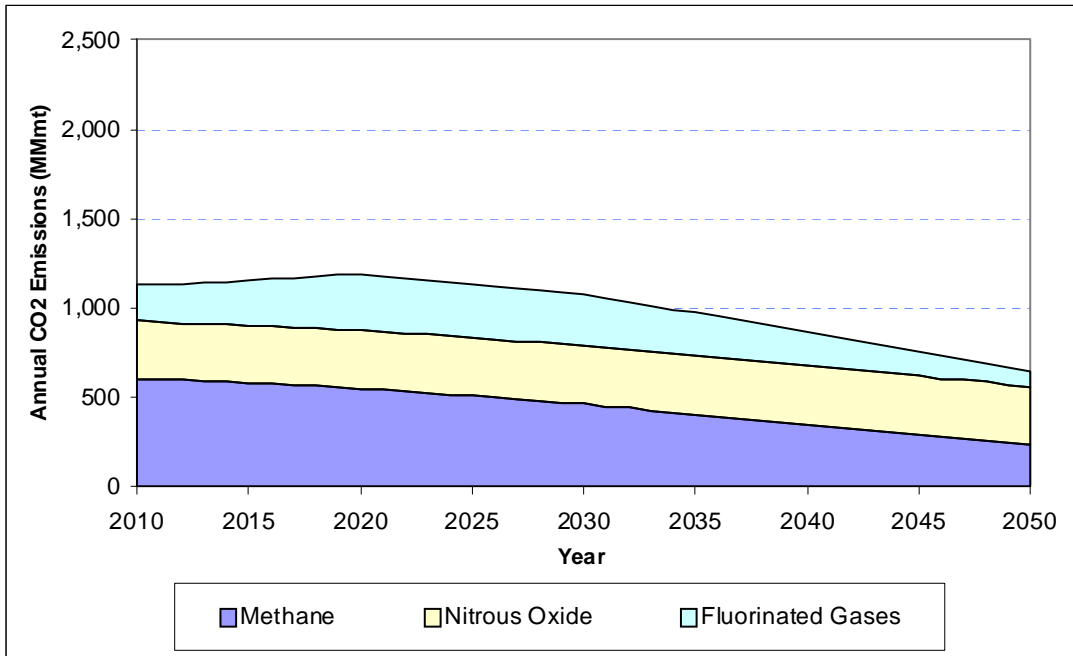


Figure 34: CO₂ Equivalent Emissions of Non Co₂-GHG Gases: Obama Plan



We start with a CO₂ price for incentivizing the reduction of non-CO₂ GHG emission of \$40 to \$50/mt of CO₂ equivalent and then use the non-CO₂ GHG emission abatement curves in EPA's analysis of S. 2191, the Liberman-Warner Climate Security Act of 2008. This analysis identifies the amount of reductions of non-CO₂ GHGs at alternative prices for carbon²⁹. We calculate that a \$40 to \$50/mt carbon price would reduce annual non- CO₂ GHG emission in 2050 by 633 MMmt, Table 43.

However, even under this relatively high price for carbon, significant volumes of methane and fluorinated gases are still emitted in year 2050. As such, we have included additional emission restrictions for these two gases in the CarBen Model.

The EPA's GHG emissions abatement curves for the oil and natural gas industries identify the potential for 10% and 20% emissions reductions from these industries, respectively. However, year 2050 GHG emissions from these industries, after including EPA identified abatement potential, are still 211 MMmt. Based on exploratory work by numerous producers (e.g., BP, Williams), a significantly larger portion of these methane emissions could be captured during well testing and production. In the Obama Case, we assume that the issuance of methane emission performance standards for the oil and gas sector could further reduce methane emissions by 200 MMmt in year 2050, leading to an overall reduction of methane emissions from this sector of 95%.

²⁹ EPA Analysis of the Climate Security Act of 2008, Data Annex. Accessed at: <http://www.epa.gov/climatechange/economics/economicanalyses.html>

Table 43: Non-CO₂ and High GWP Emission: CarBen Reference Case and Carbon-Price Based Reductions

Price	Gas	2020			2030			2050			
		EIA Reference Case	EPA Emission Reduction	CO2 Emission Reduction	EIA Reference Case	EPA Emission Reduction	CO2 Emission Reduction	EIA Reference Case	EPA Emission Reduction	CO2 Emission Reduction	
\$41	Methane										
		Coal	55	86%	47	55	86%	47	55	99%	54
		Landfills	140	74%	104	138	74%	102	136	85%	115
		Natural Gas	223	19%	8	266	19%	27	266	21%	57
		Oil Sectors		9%			9%			10%	
		Other/Agriculture	224	5%	11	225	10%	23	229	12%	26
		Sub-Total	642	27%	170	685	29%	200	686	37%	253
		NO2									
		Adipic Acid	16	96%	3	19	96%	10	23	100%	23
	Nitric Acid		89%			89%			100%		
	Other/Agriculture	316	5%	16	335	10%	33	372	12%	43	
	Sub-Total	332	6%	19	353	12%	43	395	17%	66	
\$45	Fluorinated Gases										
	HFCs	HFC 22 Production	8	86%	7	8	86%	7	9	99%	9
		Aerosols		39%			57%			66%	
		Fire Extinguishers	293	7%	5	479	39%	80	852	44%	299
		Foams		6%			18%			20%	
		Refrigerators		8%			30%			34%	
	PFCs	Solvents	6	26%	0	5	51%	1	5	59%	2
		Semi-Conductor		70%			32%			37%	
	SF6	Aluminum		18%			18%			21%	
		Electric Equip	14	41%	1	13	31%	3	11	36%	5
Magnesium	94%	90%		100%							
	Sub-Total	321	4%	14	506	18%	91	876	36%	314	
	Total	1,296	16%	204	1,545	22%	334	1,957	32%	633	

Emissions reductions are calculated assuming the EIA Reference Case emissions are distributed between industries in the same ratio as the EPA base case.

The family of fluorinated gases have an extremely large warming effect when released into the atmosphere. For example, one ton of HFC-23 in the atmosphere for 20 years has the same warming effect as 12,000 tons of CO₂.³⁰ In a carbon constrained economy, there will be strong impetus to reduce the emission of these compounds. Emission of fluorinated gases in the Reference Case are projected to reach 876 MMmt (CO₂ equiv.) in year 2050. The cost abatement curve of EPA (at \$40 to \$50/mt) would reduce these emissions by 314 MMmt in year 2050, resulting in 562 MMmt of CO₂ equivalent emissions in year 2050.

We assume that a ban on the production and emission of these gasses will be phased in starting in 2030, ultimately resulting in their total abatement by 2070. Industry, with the support of the EPA, has already had success in reducing the emission of these gases through voluntary programs. In CO₂ equivalent terms, we estimate that the progressive limitation on production and released of fluorinated gases will reduce emissions in 2050 by 478 MMmt annually, Table 44.

Table 44: Emission Reductions of Non-CO2 GHG Gases (MMmt CO2)

Year	2012	2020	2030	2050
Sector Emissions - Reference Case	1,156	1,296	1,545	1,957
CO2 Emission Reduction Pathways				
Carbon Price-Based Reductions	13	56	238	633
Oil and Gas Industry Performance Standards	10	50	100	200
Banning of High GWP Gases	0	0	126	478
Grand Total	23	106	464	1,311
Sector Emissions - Obama Plan	1,134	1,190	1,081	646

³⁰ IPCC AR4

III.F OFFSETTING GHG EMISSIONS THROUGH IMPROVED LAND USE PRACTICES AND AFFORESTATION

A price on carbon will stimulate agricultural, land use and forestry practices that sequester additional carbon. “Terrestrial Sequestration” is the final market-based initiative we analyze within the set of Tier I pathways.

To determine the emission reduction potential for “Terrestrial Sequestration,” we consulted recently released EPA data that determined the amount of CO₂ emissions which could be abated by land-use change and afforestation at alternate prices for carbon.

To account for uncertainty, we interpret the EPA’s analysis of Terrestrial Sequestration in a relatively conservative manner. We assume that terrestrial sequestration activities begin more slowly than what the EPA determined to be theoretically possible. As such, the supply of terrestrial offsets in year 2050 in CarBen is equal to the EPA’s estimates of offsets in year 2030, using a \$45/ton price of carbon, Table 45.

Table 45: CO₂ Emission Reduction: Land use Changes and Afforestation

Annual Emission Reductions (MMmt)	2012	2020	2030	2050
Land Use Changes	0	17	35	70
Afforestation	0	174	348	696
Total	0	191	383	765

III.G SUPPLEMENTAL GHG EMISSION REDUCTION ACTIONS

Our analysis shows that the Tier I and II initiatives discussed above would provide annual GHG emission reductions of 7,500 MMmt in 2050. However, to meet the Administration's goal, an additional 780 MMmt of GHG emissions need to be abated in 2050. This section explores remaining actions that could reduce GHG emission in 2050 to meet the Administration's goal. These "Supplemental" actions are provided merely as suggestions, as a host of other actions and initiatives could also be undertaken.

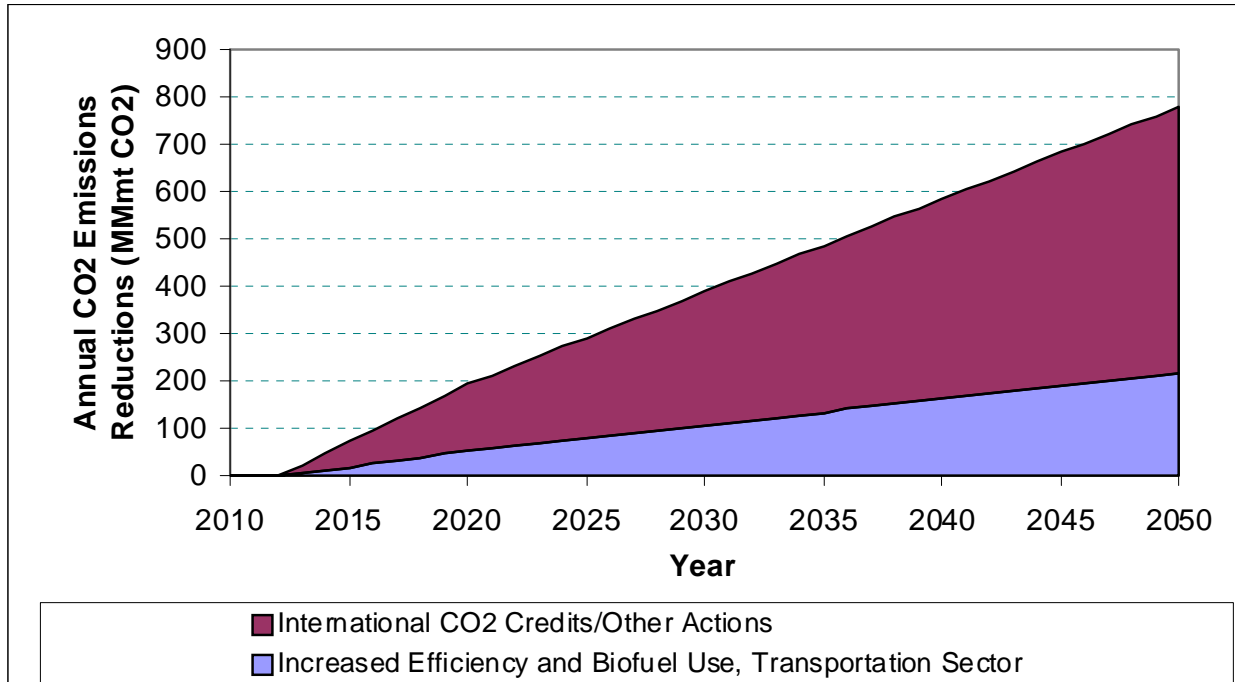
We have focused on the Transportation Sector because it has the highest remaining annual CO₂ emissions in 2050, 1,127 MMmt. We find that a set of programs that would increase fuel efficiency and use of biofuels in the Transportation Sector has the potential to reduce annual GHG emission in 2050 by 218 MMmt.

The remaining 562 MMmt of GHG emission reductions will need to come from additional domestic actions or from the purchase of CO₂/GHG emission reduction credits from abroad. By continuing to invest in R&D and technologies that help reduce domestic GHG gases, we believe that we can minimize the amount of CO₂ emission credits that will need to be purchased from international sources.

Table 46: GHG Emission Reductions: Supplemental Pathways

Year	2012	2020	2030	2050
Annual GHG Emission Reductions (MMmt)				
Increased Efficiency and Biofuel Use, Transportation Sector	11	55	109	218
International CO ₂ Credits/Other Actions	0	141	281	562
Total GHG Emission Reductions	11	195	390	780

Figure 35: GHG Emission Reduction Potential of Supplemental Pathways



Supplemental Actions in the Transportation Sector

Our analysis suggests that the Transportation Sector has the largest potential for additional CO₂ emission reductions in 2050. This is due to the large fleet of freight trucks and increased levels of air travel. In the sections below, we provide suggestions for programs that could reduce CO₂ emission from these transportation modes.

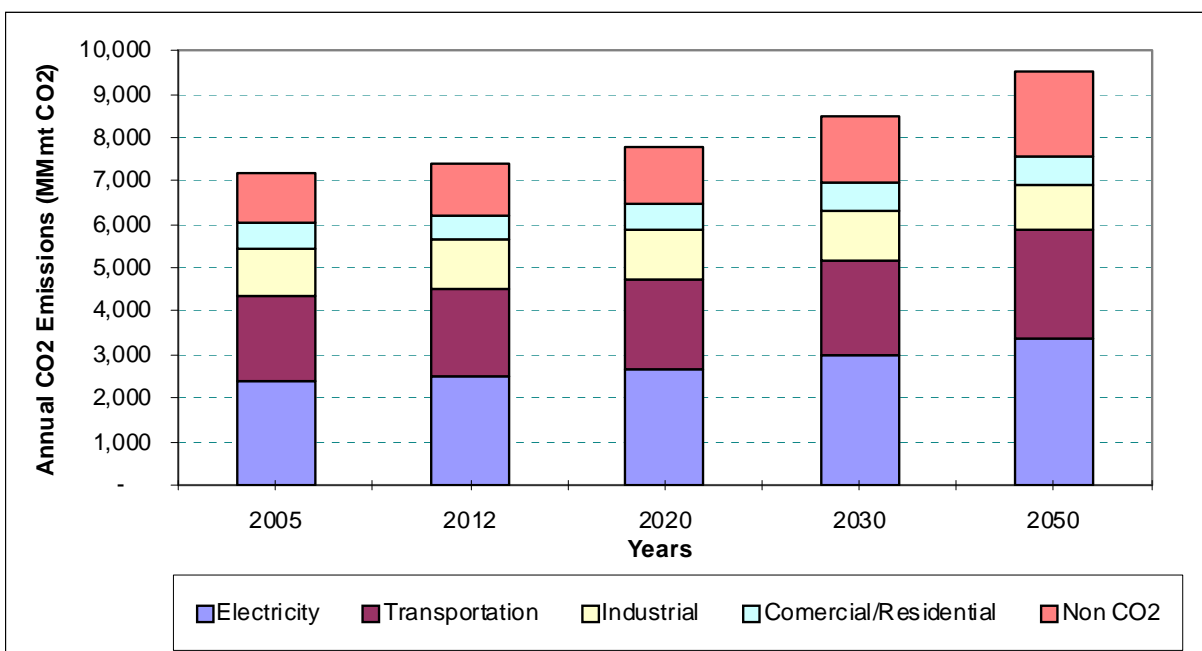
Suggestion # 1: Increase Freight Truck and Aviation Fuel Efficiency. Freight trucking and air travel are the two largest sources of year 2050 annual CO₂ emissions in the Transportation Sector. Though these two transportation modes are expected to achieve significant improvements in fuel efficiency (relative to 2005, freight truck MPG doubles and aviation fuel efficiency increases by 50%), together they still emit 624 MMmt of CO₂ in year 2050. With increased fuel efficiency in these two transportation modes, to 15 MPG for freight trucks and 100 SMPG for airlines (from 12 MPG and 91 SMPG, respectively), annual CO₂ emission in 2050 could be reduced by 94 MMmt.

Suggestion # 2: Develop Low-Emission Bio-Diesel for Use In Commercial Light Trucks, Freight Trucks and Aviation. Using the CarBen model, we find that a 20% blending of low emission bio-diesel (with a similar emission factor to cellulosic ethanol of 5.5 MMmt CO₂/QBTU) for commercial light trucks and freight trucks could reduce annual CO₂ emission in year 2050 by 65 MMmt. Additionally, we find that a 20% blending of a low-emission bio-fuel alternative to jet fuel (with a 50% lower emission profile than current jet fuel) could reduce annual CO₂ emissions by 59 MMmt in year 2050. Together, the increased use of biofuels would reduce annual CO₂ emissions in year 2050 by 124 MMmt.

APPENDIX A: ESTABLISHING THE REFERENCE CASE

The Reference Case is modeled using the Energy Information Administration's (EIA) Annual Energy Outlook (AEO) 2008, which projects that annual economy-wide CO₂ emissions (including non-CO₂ GHGs) will increase from 7.26 billion metric tons of CO₂ in 2005 to 8.4 billion metric tons of CO₂ in 2030, a sustained annual growth rate of 0.9%. Using the CarBen model, we extend the time period covered to 2050, at which time we project annual CO₂ equivalent emissions of 9.5 billion metric tons of CO₂ (annual growth of 0.61% from 2030-2050), Figure A-1.

Figure A-1: CO₂ Emissions from the Reference Case by Sector



The CarBen model uses both a “Top-Down” and a “Bottom-Up” methodology to calculate annual CO₂ emissions from the U.S. economy. In the “Top-Down” version, CO₂ emissions are calculated by developing relationships between population, economic growth and CO₂ emissions. In the “Bottom-Up” version, CO₂ emissions are based on a detailed assessment of each sector of the economy.

TOP-DOWN METHODOLOGY

Population and Economy

In the “Top Down” version of CarBen, CO₂ emissions are driven by population and economic growth. Data on U.S. population in 2050 is provided by the US Census Bureau³¹. This data is used to calculate the size (GDP) of the economy in 2050 based on trends in GDP/capita growth. Our implicit assumption is that GDP per capita grows at an annual rate of 1.3% from 2031 to 2050. Based on this assumption, our calculations indicate that GDP in 2050 will be \$30.2 trillion, or \$72,000/capita in constant 2000 dollars, Table A-1.

Table A-1: Data Used to Calculate Economy Growth in Reference Case

Population	2005	2012	2020	2030*	2050**
U.S. Census Bureau	297.3	316.2	337.7	365.6	419.9
Growth Rate	1.2%	0.88%	0.83%	0.80%	0.7%
GDP/Capita	2005	2012	2020	2030	2050
GDP/capita (thousands\$/person)	37.0	41.8	47.3	55.3	72.0
Growth Rate	1.7%	1.7%	1.6%	1.6%	1.3%
GDP in current CarBen ref case, B\$	11,004	13,204	15,984	20,219	30,243
* Data from 2005 through 2030 are from EIA's AEO 2008					
** Data for 2050 are from CarBen model projections					

³¹ U.S. Census Bureau, interim projections consistent with the 2000 Census, released March 2004.

CO₂ Emissions

Economy-wide CO₂ emissions are calculated by extrapolating the 2012 to 2030 trend in CO₂ emission per dollar of GDP (emission intensity) to year 2050. Our assumption is that CO₂ emission intensity per dollar of GDP decreases by 1.4% annually from 2031 to 2050. This assumes that the energy intensity of the economy continues to decrease but at a decreasing rate, consistent with data from years 2012 through 2030. Based on this, we calculate that economy-wide CO₂ emissions in the Reference Case in 2050 will equal 9,514 million metric tones (MMmt), Table A-2.

This “top-down” approach is used as a check on the “Bottom-Up” individual sector level CO₂ emissions calculated in the CarBen model.

Table A-2: Calculation of CO₂ Emissions in the Reference Case

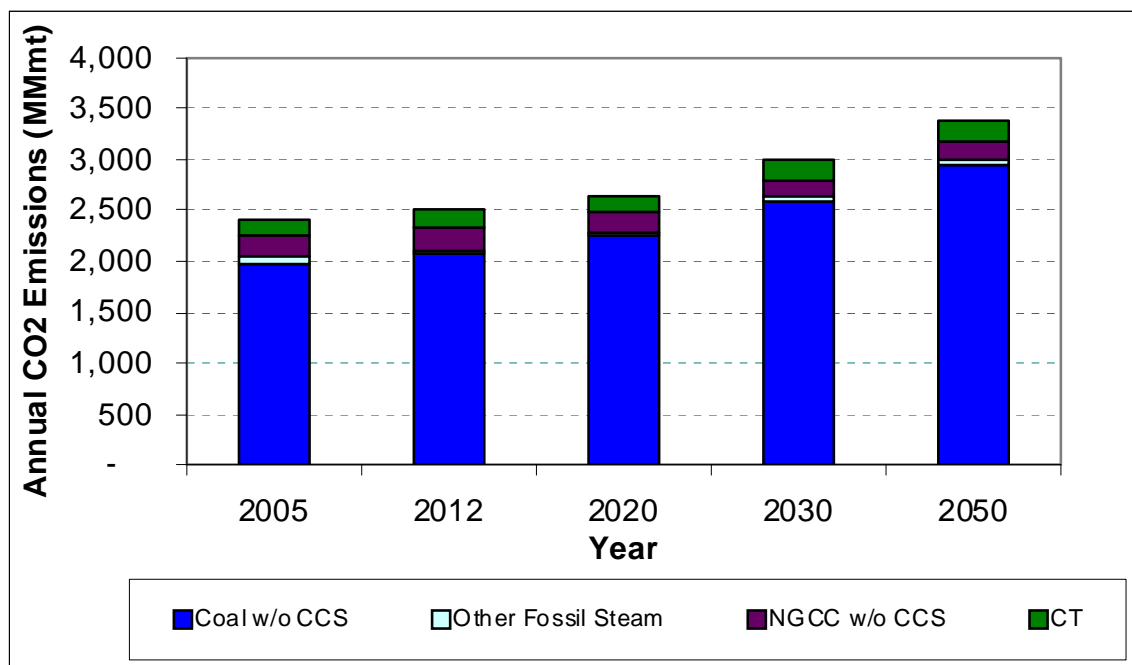
GDP/Capita	2012	2020	2030	2050
GDP in current CarBen ref case, B\$	13,204	15,984	20,219	30,243
GHG/GDP	2012	2020	2030	2050
U.S. GHG emissions, MMmtCO ₂ /yr	7,347	7,729	8,441	
GHG/GDP, kg CO ₂ eq/\$	0.556	0.484	0.417	0.15
GHG Intensity Reduction	-2.3%	-1.7%	-1.5%	-1.4%
U.S. GHG Emissions	2012	2020	2030	2050
U.S. GHG emissions, MMmtCO ₂ /yr	7,347	7,729	8,441	9,514

BOTTOM-UP METHODOLOGY

Electricity Sector

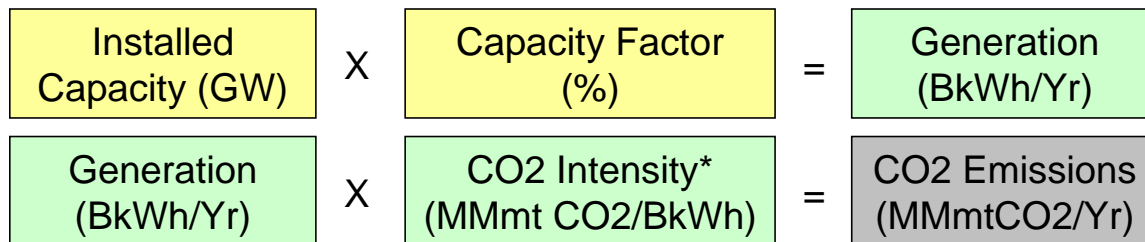
The Electricity Sector is the largest single source of CO₂ emissions, equal to 2,400 MMmt in 2005. In the EIA 2008 Reference Case, these emissions are projected to increase to 2,950 MMmt in 2030. We project that these emissions will continue to grow to 3,375 MMmt by 2050, Figure A-2

Figure A-2: Reference Case: CO₂ Emissions: Electricity Sector



The Electricity Sector Module in CarBen uses 2008 NEMS Reference Case data to calculate electricity demand to year 2030 and then projects electricity demand to year 2050. Electricity generation output and CO₂ emissions are calculated for each of the following electricity generating sources using the CO₂ emission calculation algorithm outlined below:

- Pulverized Coal (PC)/Integrated Gasification Combined Cycle (IGCC) with and without CCS
- Natural Gas Combined Cycle with and without CCS
- Combustion Turbine
- Nuclear
- Hydro
- Other Renewables (Wind, Solar, etc)



* CO2 intensity is a function of the plant's efficiency, measured in Qbtu/BkWh and the CO2 intensity of the fuel being used by the asset, measured in MMmt CO2/Qbtu. The product of these two factors yields the units displayed above.

Electricity Demand. Electricity demand in 2050 is calculated by extrapolating forward a trend in electricity demand per dollar of GDP, or “electricity intensity”. Based on the trend from 2020-2030, electricity intensity is decreasing, from -1.5% annually in 2020 to -1.3% annually in 2030. In this analysis, we assume that electricity intensity, in kWh/\$GDP, decreases at -1.1% annually from 2030 to 2050. This assumption, along with an estimation of GDP in 2050, discussed above, supports the calculation of electricity demand in 2050, Table A-4.

Table A-4: Calculation of Electricity Demand: Reference Case

Year	2020	2030	2050
GDP (Billions \$)	15,984	20,219	30,243
Electricity Intensity (kWh/\$GDP)	0.294	0.258	0.207
% Annual Change from Previous Period	-1.5%	-1.3%	-1.1%
Electricity Demand (billion kWh)	4,706	5,219	6,260

Electricity Supply. Based on the increase in electricity demand between 2031 and 2050, we estimate that 1,041 bkWh/year of generation capacity will need to be built in that time period, using the following guidelines.

- The ratio of electricity generated from newly built coal-fired capacity to electricity generated from newly built natural gas-fired capacity is equal in 2031 through 2050.
- 10% of the generation from newly built coal and natural gas plants in 2050 will be from facilities equipped with CCS technology that captures 90% of the plant's emissions.
- 15% of all electricity generated in 2050 comes from renewable sources (Hydro, Wind, Solar, Geothermal, ect).
- Continuing the trend from 2021-2030, where 4 GW of nuclear plants were constructed in 10 years, 8 GW of nuclear capacity is added between 2031-2050.
- One GW of coal fired capacity built before 1970 is retired each year from 2031-2050, resulting in 20 GW of retirements by 2050.

Based on these assumptions, annual CO₂ emissions from the Electricity Sector in 2050 are 3,375 million metric tons. (Additional vintage specific data on capacity factors, efficiency and other data for the Electricity Sector for calculating year 2050 CO₂ emissions are available in the CarBen model.)

Transportation Sector

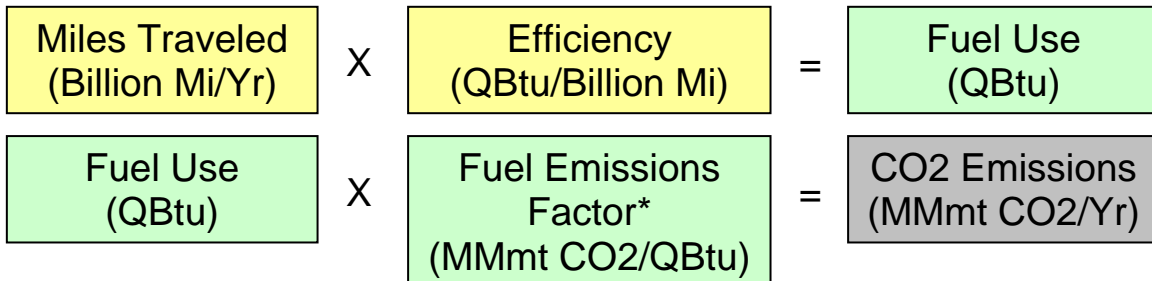
Approximately one-third of all CO₂ emissions, equal to 1,950 MMmt of CO₂ in 2005, are from transportation. In the AEO 2008 Reference Case, these emissions are projected to increase to 2,188 MMmt CO₂ in 2030. We project these emissions to further grow to 2,493 MMmt CO₂ by 2050.

CO₂ emissions in the Transportation Sector are from light duty vehicles, commercial vehicles, light trucks, freight trucks, air travel, rail and domestic shipping, Table A-5. These CO₂ emissions are calculated using the algorithm below.

Table A-5: Reference Case CO₂ Emissions: Transportation Sector (MMmt)

Transportation Mode	2005	2012	2020	2030	2050
Light Duty Vehicles	1,128	1,107	1,088	1,104	1,269
Commercial LT	42	42	42	42	41
Freight Trucks	345	388	418	460	523
Air	193	221	256	299	353
Rail	40	44	47	52	58
Domestic Shipping	23	25	26	26	26
Other*	185	191	197	205	222
Total	1,956	2,017	2,073	2,188	2,493

* Other Emissions are not explicitly broken out, though a majority are from military aviation and heavy fuel use.



* Many modes of transportation use a combination of several types of fuel. The fuel emission factor referenced above is a weighted average of the fuel specific emission factors of the fuels used by that transportation mode.

To calculate CO₂ emissions from the Transportation Sector in 2050, we extrapolated the trends from the 2021 to 2030 time period forward through 2050.

Transportation activity (miles traveled) for each transportation mode is calculated by extrapolating trends in miles traveled per \$ of GDP or per million people, depending on the transportation mode, from 2030 through 2050, Table A-6 and Table A-7.

Table A-6: Standardized Miles Traveled by Transportation Mode

Transportation Mode	2020	2030	Annualized Change (2021-2050)	2050*
Light Duty Vehicles, (Billion VMT/MM People)	9.993	11.129	1.08%	13.80
Commercial LT, (Billion VMT/\$ GDP)	0.005	0.005	-0.86%	0.005
Freight Trucks, (Billion VMT/\$ GDP)	0.019	0.017	-0.90%	0.015
Air, (Billion Seat Miles/000 People)	4.314	4.555	0.55%	5.08
Rail, (Billion Ton Miles/\$ GDP)	0.121	0.106	-1.29%	0.08
Domestic Shipping, (Billion Ton Miles/\$ GDP)	0.044	0.036	-2.04%	0.025
GDP (Billions of \$)	15,984	20,219	--	30,243
Population (Millions of people)	337.7	365.6	--	420

* Assuming the same annual rate of change from 2031-2050 as from 2021-2030.

Table A-7: Miles Traveled by Transportation Mode

Transportation Mode	2020	2030	2050
Light Duty Vehicles, Billion VMT	3,375	4,069	5,794
Commercial LT, Billion VMT	87	101	151
Freight Trucks, Billion VMT	304	351	454
Air, Billion Seat Miles	1,457	1,665	2,133
Rail, Billion Ton Miles	1,932	2,147	2,471
Domestic Shipping, Billion Ton Miles	701	721	765

Efficiency indicators for each transportation mode in 2050 were assumed to change by the same annual rate from 2031 to 2050 as they had from 2021 to 2030. For LDV fuel economy, we extrapolate trends in vehicle MPG (used in the AEO) forward through 2050 and determine fleet MPG using vehicle sales statistics and industry standard survival rates, Table A-8. The composition of fuels used by each transportation mode and fuel-specific emission factors are assumed to remain constant between 2030 and 2050.

Table A-8: Efficiency Indicators by Transportation Mode Through 2050

Transportation Mode	Unit of Efficiency Indicator	2012	2020	2030	Annualized Change (2021-2050)	2050*
Light Duty Vehicles	mpg (gasoline equivalent)	20.7	23.7	27.9	NA	37.3
Commercial LT	mpg (gasoline equivalent)	15.2	17.4	19.8	1.28%	25.5
Freight Trucks	mpg (gasoline equivalent)	6.1	6.5	6.8	0.47%	7.5
Air	SMpg (gasoline equivalent)	64.1	67.2	70.0	0.41%	76.0
Rail	ton miles per thousand btu	2.9	3.0	3.0	0.10%	3.0
Domestic Shipping	ton miles per thousand btu	2.0	2.0	2.0	0.10%	2.1

* Assuming same annual rate of change from 2031-2050 as from 2010-2030.

Based on the above, we project annual CO₂ emissions of 2,493 MMmt from the Transportation Sector in 2050. Implicit in this calculation are the fuel specific emission factors for each transportation mode's fuel composition, available in the CarBen model.

Industrial Sector

The Industrial Sector uses fossil fuels to provide process energy to a variety of industrial activities. Table A-9 shows the industrial activities that are covered in this analysis along with their respective CO₂ emissions. (Electricity use by the Industrial Sector is included in the Electricity Sector.) Also, the CO₂ emissions from non-energy related activities are included in this sector, shown at the bottom of Table A-9.

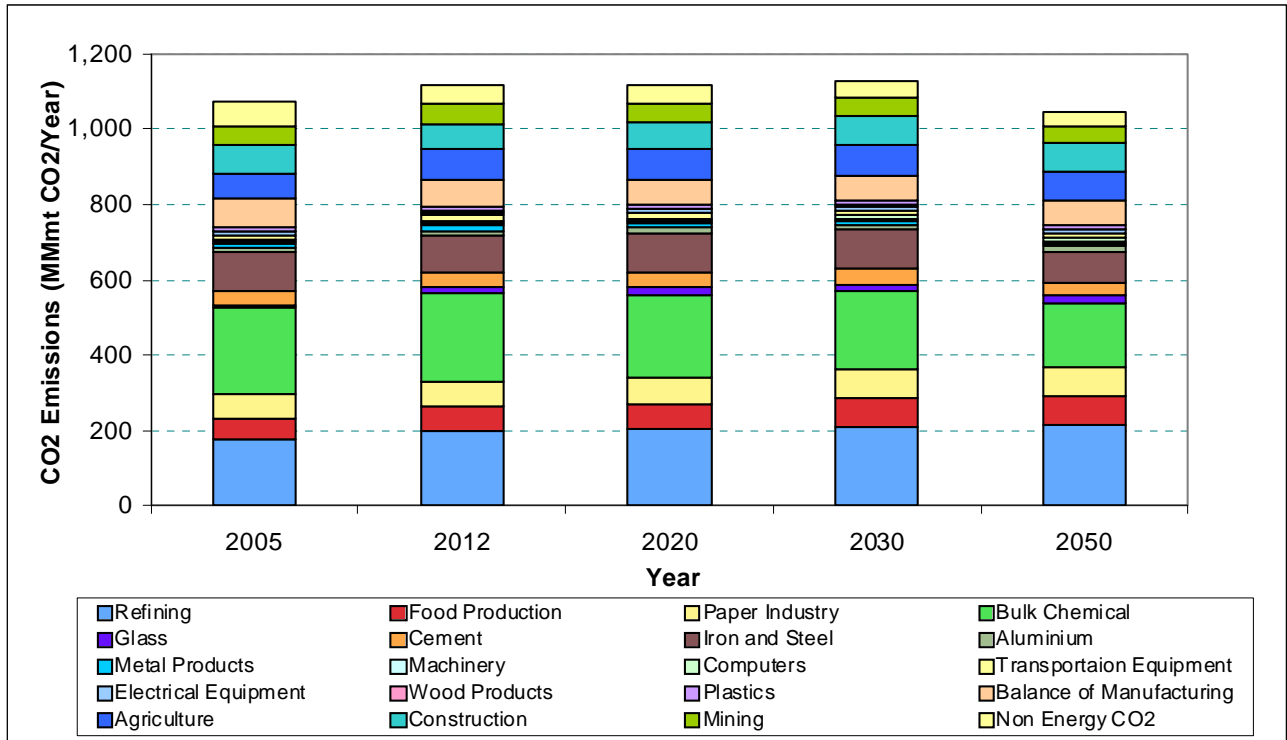
Table A-9: Industrial Sector CO₂ Emissions by Activity (MMmt)

Industrial Activity	2005	2012	2020	2030	2050
Refining	178	201	201	211	216
Food Production	54	62	67	72	73
Paper Industry	64	68	72	78	79
Bulk Chemical	228	236	221	209	170
Glass	11	13	17	18	21
Cement	35	38	39	40	33
Iron and Steel	101	99	104	103	84
Aluminium	14	14	15	15	13
Metal Products	12	13	13	11	8
Machinery	5	6	6	6	4
Computers	5	6	7	7	8
Transportation Equipment	12	14	13	13	11
Electrical Equipment	8	10	11	12	12
Wood Products	4	4	3	3	3
Plastics	10	10	10	10	11
Balance of Manufacturing	77	71	68	69	65
Agriculture	65	82	80	81	76
Construction	75	70	69	73	75
Mining	51	53	52	52	47
Non Energy CO ₂	63	47	49	45	36
Total	1,072	1,116	1,118	1,131	1,045

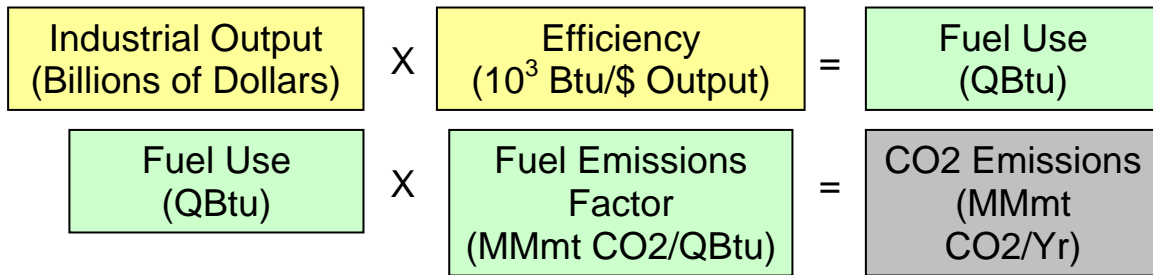
Table A-9 shows that Reference Case CO₂ emissions in the Industrial Sector decrease from 2030 to 2050, due to the continuation of aggressive efforts on reducing energy intensity. Because of the already significant energy efficiency efforts included in the Reference Case, fewer opportunities exist for reducing CO₂ emissions in future policy cases.

In the Reference Case, annual CO₂ emissions from the Industrial Sector in 2050 are 1,045 million metric tones, equal to 11% of economy wide emissions. Figure A-3 shows emissions from each industrial activity through year 2050.

Figure A-3: Industrial Sector CO₂ Emissions by Industrial Activity



The algorithm used to calculate CO₂ emission for each industrial activity within the Industrial Sector is provided below.



Industrial output to year 2050 was extrapolated based on the trend in output growth (or decline) per dollar of GDP during 2020-2030. Energy intensity for each fuel used by the Industrial Sector to 2050 was extrapolated based on the annual rate of change during 2020-2030. For simplicity, we assume emission factors stay constant between 2030 and 2050.

Residential and Commercial End-Use Sectors

In addition to consuming electric energy from the grid (accounted for in the Electricity Sector), the Residential and Commercial Sectors burn fossil fuels to meet a portion of their energy demand. As such, our analysis addresses the emissions from off-grid “end use” energy and CO₂ emission from the combustion of fossil fuels in homes, office buildings and other residential and commercial settings.

In the Reference Case, annual CO₂ emissions in 2050 are 644 million metric tons, equal to 7% of the economy total. The majority of end use CO₂ emissions are from space heating, which accounts for 60% of this sector’s CO₂ emissions in 2050, Figure A-4. The “Other” category accounts for energy used for “off grid” combined heat and power and other activities. Natural gas is the most widely used fuel in these sectors, Figure A-5.

Figure A-4: Residential CO₂ Emissions by Equipment Type

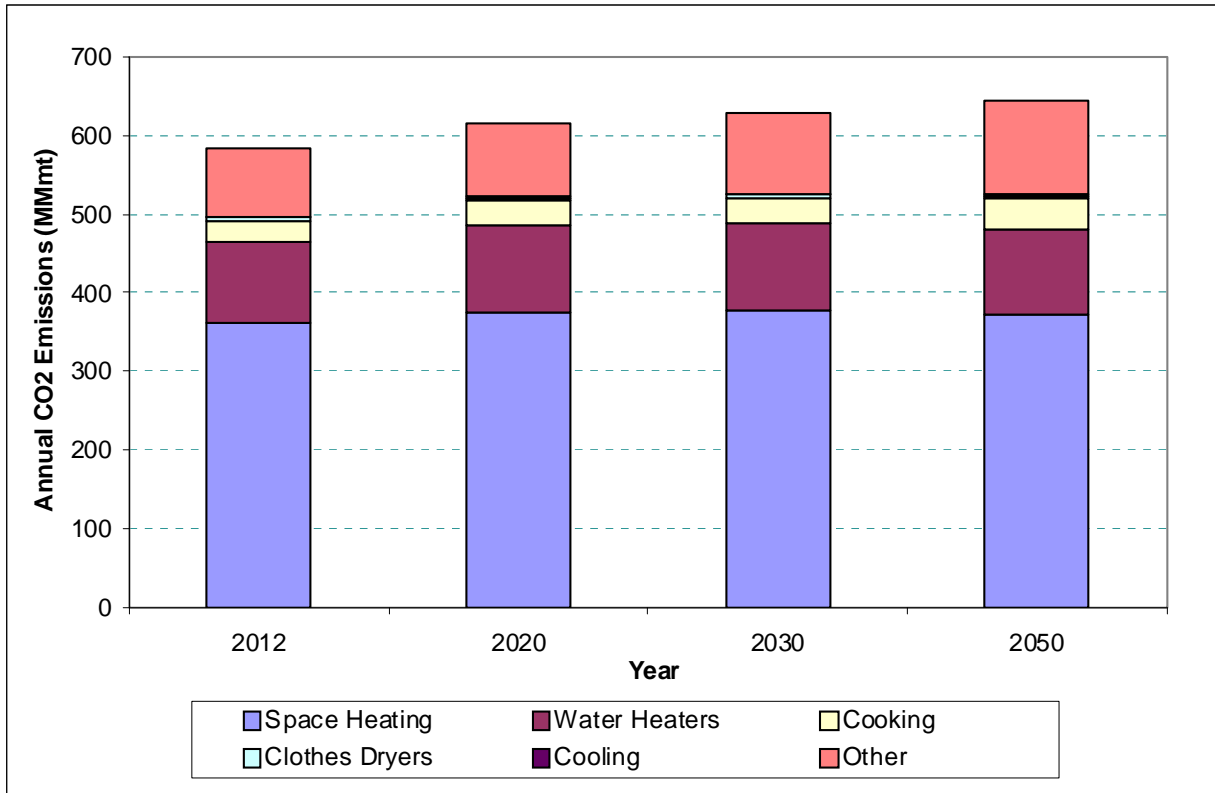
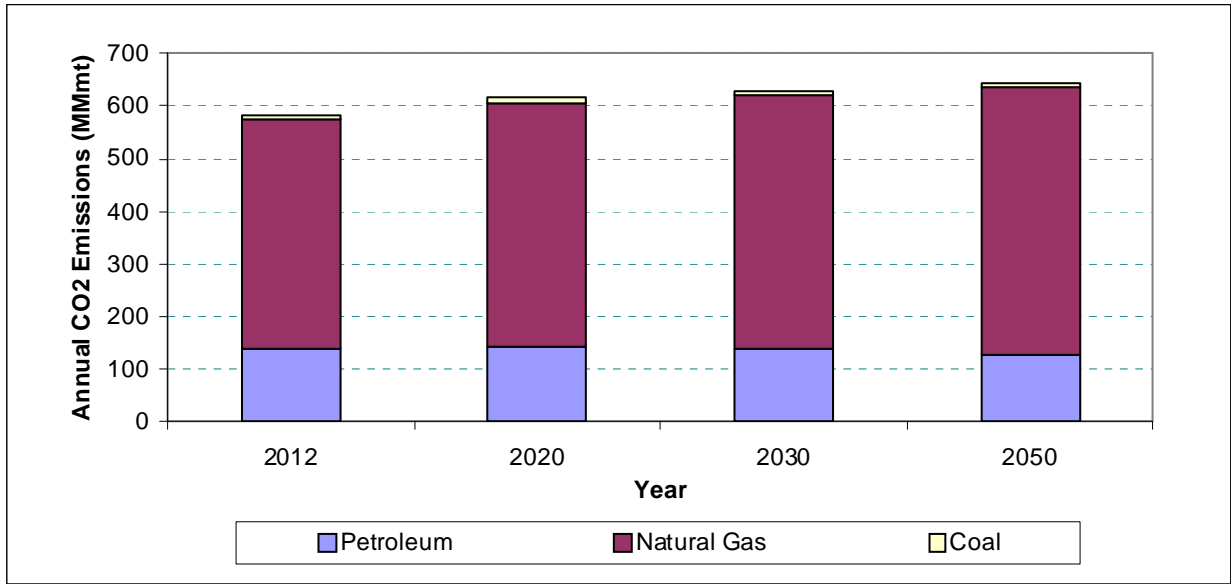
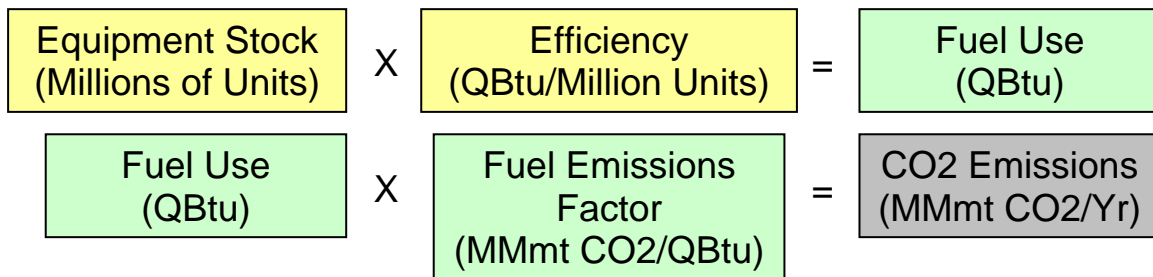


Figure A-5: Residential and Commercial CO₂ Emissions by Fuel Use



The algorithm used to calculate CO₂ emissions in this sector is provided below. We use data on equipment stock and fuel efficiency to calculate energy use by fuel and type of equipment. Based on emission factors for each fuel, we calculate emission by fuel type for each type of equipment used. In the Commercial Sector, data on equipment stocks is not provided by the EIA, so we calculate CO₂ emissions directly from fuel use.



To calculate emissions in 2050, we carry forward the change in the key variables in the above algorithm using trends and growth rates from 2020-2030, Table A-10.

Table A-10: Trends Used to Calculate Residential and Commercial Sector CO₂ Emissions in 2050

Sector	Trend*
Residential	
Equipment Stocks	Millions of Units/Millions of People
Equipment Efficiency	Annual Growth (Decline) Rate
Commercial	
Equipment Energy Use	Energy Use/Thousand Square Feet of Commercial Space
* All trends are carried forward to 2050 based on their rate of change from 2020-2030	

Non-CO₂ & High Global Warming Potential GHGs

Table A-11 provides a detailed description of the type and source of emissions that are included in the CarBen model for non-CO₂ and high GWP gases. The data for years 2005-2030 are taken from the EIA AEO 2008 Reference Case. For 2031- 2050, we assume a continuation of the growth or decline for each non-CO₂ emissions (except oil and gas industrial methane emissions), based on trends from 2020-2030. For the oil and gas industries, we hold the annual methane emission rate constant from 2031-2050, assuming a plateau in domestic oil and gas production.

As shown in Table A-11, annual emissions of non-CO₂ gases increase from 1,136 MMmt of CO₂ equivalent in 2005 to 1,545 MMmt CO₂ equivalent in 2030. Continuation of these changes in annual emissions results in the projection for non-CO₂ GHG emissions of 1,957 MMmt in 2050.

A-11: Annual Emissions of Non-CO₂ GHG Gases: Reference (MMmt CO₂e)

GHG/Source	2005	2012	2020	2030	2050
Methane					
Landfills	144	141	140	138	136
Coal Mining	66	58	55	55	55
Natural Gas and Oil Systems	176	194	223	266	266
Stationary Combustion and Mobile Sources	14	13	14	15	16
Other	208	210	210	211	213
Sub-Total	607	617	642	685	686
Nitrous Oxide					
Agriculture	279	235	243	255	277
Stationary and Mobile Combustion	69	62	66	74	88
Adipic and Nitric Acid Production	14	15	16	19	23
Other	6	6	6	7	7
Sub-Total	367	318	332	353	395
Fluorinated Gases					
HFC-23	17	9	8	8	9
Other HFCs and ODS Substitutes	121	191	293	479	852
PFCs	7	7	6	5	5
SF ₆	16	15	14	13	11
Sub-Total	161	220	321	506	876
	0	0	0	0	0
Methane	607	617	642	685	686
Nitrous Oxide	367	318	332	353	395
Fluorinated Gases	161	220	321	506	876
Total Emissions	1,136	1,156	1,296	1,545	1,957

APPENDIX B: OBAMA ENERGY PLAN GOALS

ENERGY AND THE ENVIRONMENT³²

The energy challenges our country faces are severe and have gone unaddressed for far too long. Our addiction to foreign oil doesn't just undermine our national security and wreak havoc on our environment -- it cripples our economy and strains the budgets of working families all across America. President Obama and Vice President Biden have a comprehensive plan to invest in alternative and renewable energy, end our addiction to foreign oil, address the global climate crisis and create millions of new jobs.

The Obama-Biden comprehensive New Energy for America plan will:

- Help create five million new jobs by strategically investing \$150 billion over the next ten years to catalyze private efforts to build a clean energy future.
- Within 10 years save more oil than we currently import from the Middle East and Venezuela combined.
- Put 1 million Plug-In Hybrid cars -- cars that can get up to 150 miles per gallon -- on the road by 2015, cars that we will work to make sure are built here in America.
- Ensure 10 percent of our electricity comes from renewable sources by 2012, and 25 percent by 2025.
- Implement an economy-wide cap-and-trade program to reduce greenhouse gas emissions 80 percent by 2050.

Energy Plan Overview

Provide Short-term Relief to American Families

- Crack Down on Excessive Energy Speculation.
- Swap Oil from the Strategic Petroleum Reserve to Cut Prices.

Eliminate Our Current Imports from the Middle East and Venezuela within 10 Years

- Increase Fuel Economy Standards.
- Get 1 Million Plug-In Hybrid Cars on the Road by 2015.
- Create a New \$7,000 Tax Credit for Purchasing Advanced Vehicles.
- Establish a National Low Carbon Fuel Standard.
- A "Use it or Lose It" Approach to Existing Oil and Gas Leases.
- Promote the Responsible Domestic Production of Oil and Natural Gas.

Create Millions of New Green Jobs

³² White House Website, accessed at: http://www.whitehouse.gov/agenda/energy_and_environment/

- Ensure 10 percent of Our Electricity Comes from Renewable Sources by 2012, and 25 percent by 2025.
- Deploy the Cheapest, Cleanest, Fastest Energy Source – Energy Efficiency.
- Weatherize One Million Homes Annually.
- Develop and Deploy Clean Coal Technology.
- Prioritize the Construction of the Alaska Natural Gas Pipeline.

Reduce our Greenhouse Gas Emissions 80 Percent by 2050

- Implement an economy-wide cap-and-trade program to reduce greenhouse gas emissions 80 percent by 2050.
- Make the U.S. a Leader on Climate Change.

APPENDIX C: SUMMARY OF FEDERAL STIMULUS SPENDING ON ENERGY AND ENVIRONMENTAL PROGRAMS

Table C-1: Federal Stimulus Spending on Energy and Environmental Programs³³

Classification	Description	Cost (Millions)
Spending	Home weatherization grants to low and middle-income families	\$5,000
Spending	Funding for Energy Star program offering tax credits to consumers purchasing new, efficient appliances	\$300
Spending	Advanced batteries manufacturing grants	\$2,000
Spending	Energy efficiency grants to states and local governments	\$6,300
Spending	Transport electrification grants	\$400
Spending	Funding for states and local governments to buy efficient alternative fuel buses and trucks	\$300
Spending	Research and development of renewable and efficient energy technology	\$2,500
Spending	Loan guarantees for standard renewables	\$4,000
Spending	Transmission loan guarantees	\$2,000
Spending	Fossil energy research and development	\$1,000
Spending	Research into low-emission coal plants	\$800
Spending	Grants for industrial carbon capture and energy efficiency improvement projects	\$1,520
Spending	Grants for identifying sites to store carbon dioxide emissions	\$50
Spending	Grants for training and research on safe storage of carbon emission\	\$20
Spending	Administration of funding program	\$10
Spending	Physics research including high-energy physics, nuclear physics and fusion energy sciences	\$1,600
Spending	High-risk research into energy sources and energy efficiency	\$400
Spending	Cleanup of former nuclear sites	\$483
Spending	Uranium enrichment decontamination and decommissioning	\$390
Spending	Cleanup of former nuclear defense sites	\$5,127
Spending	Money for federal power marketing administrations in electric power transmission systems	\$6,500
Spending	Construction and repairs for federal marketing administration	\$10

³³ Wall Street Journal

Spending	Modernization of the electric grid	\$4,400
Spending	Training of electric grid workers	\$100
Spending	Oversight of Energy Department spending	\$15
Tax provisions	Extending by three years the placed-in-service date for renewable energy investments	\$13,143
Tax provisions	Investment credits in lieu of production credits for renewable energy purchases	\$285
Tax provisions	Removal of cap on tax credits for purchase of small wind systems	\$604
Tax provisions	\$1.6 billion extra allocation of clean energy bonds	\$578
Tax provisions	\$2.4 billion extra qualified energy conservation bonds	\$803
Tax provisions	30% cap on tax credit for energy efficiency purchases by homeowners, up to \$1500 per residence	\$2,034
Tax provisions	Credit for purchase of residential solar, geothermal, wind and fuel cells	\$268
Tax provisions	50% tax credit for purchase of alternative refueling stations	\$54
Tax provisions	Tax credit for plug-in electric vehicle conversion	\$2,002
Tax provisions	Equalization of parking and transit tax-free employer benefits at \$230 for 2009	\$192
Tax provisions	Grants to states for low-income housing projects in lieu of credits	\$5
Tax provisions	Grants to states for energy projects in lieu of credits	\$69