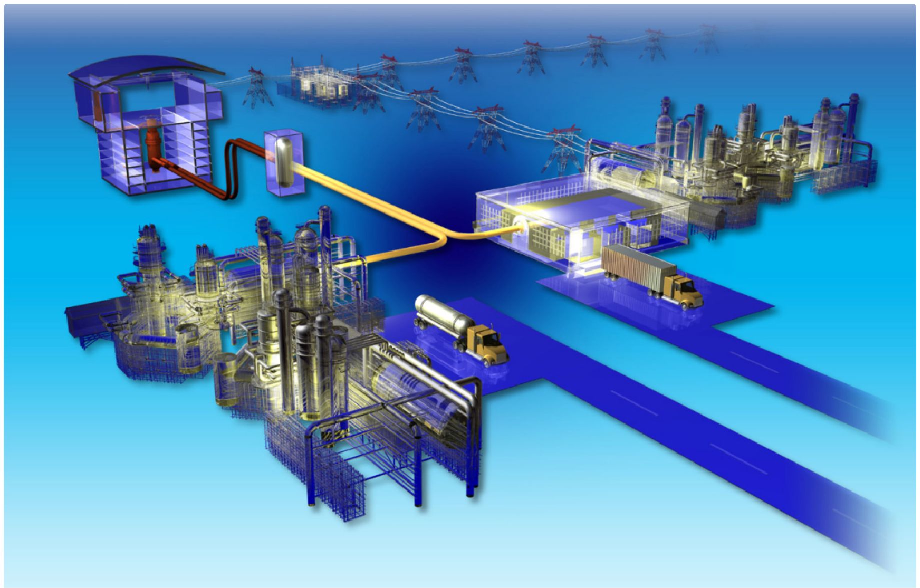
INL/EXT-09-17436

Transforming the U.S. Energy Infrastructure

L. E. Demick

July 2010



Idaho National Laboratory

Tab 8

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July 2010

Idaho National Laboratory
Next Generation Nuclear Plant Project
Idaho Falls, Idaho 83415

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Next Generation Nuclear Plant Project

Transforming the U.S. Energy Infrastructure

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July 2010

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EXECUTIVE SUMMARY

The U.S. energy infrastructure is among the most reliable, accessible and economic in the world. On the other hand, the U.S. energy infrastructure relies heavily on foreign sources of energy, experiences high volatility in energy prices, does not practice good stewardship of finite indigenous energy resources and emits significant quantities of greenhouse gases (GHG). This report presents a Technology Based Strategy to achieve a full transformation of the U.S. energy infrastructure that corrects these negative issues while retaining the positives.

Addressing Vulnerabilities in Energy Infrastructure

The following are necessary to address all of the vulnerabilities in the energy infrastructure:

- Provide permanent and self-sustaining remedies that directly address the negative issues summarized above
- Maintain the reliability of the energy infrastructure
- Ensure that the impact of the transformation on the costs of energy reflect real costs for upgrade of the energy infrastructure
- Result in a predictable increase in the cost to the consumer of energy that is introduced consistently over the long term to facilitate accommodation of the increases on the individual and the economy
- Develop U.S.-based engineering, manufacturing and construction resources for implementation of the remedies, with the creation of permanent jobs and reduction in flow of capital offshore.

The above will not be achieved through the forces of the foreseeable competitive marketplace, but must be enabled through comprehensive and enduring U.S. Government energy and economic policies.

The U.S. energy infrastructure produces and consumes energy in three principal areas; (1) generating electricity primarily by the burning of coal (50%), operating nuclear plants (20%) and natural gas (20%), renewable including hydro (10%), (2) burning natural gas in residential, commercial and industrial applications, and (3) producing, refining and combusting crude oil based petroleum products and biomass based products, (e.g., corn ethanol) for transportation.

Vulnerabilities in Energy Security

In 2008, combustion of liquid fuels accounted for ~40% of energy consumption; natural gas and coal combustion combined accounted for ~46% and nuclear power, renewable and other forms of energy accounted for the remaining ~14%. The country relies heavily on imported crude oil (~ 9 million barrels per day in 2009) and some natural gas to sustain the rate of consumption of these commodities. This has negative impacts:

- Reduces the security of our energy infrastructure by relying on foreign sources.
- Leads to price volatility; the prices of crude oil and natural gas have fluctuated over large ranges the past several years contributing to instability in the economics of sectors using these commodities.
- In burning of natural gas we are depleting a natural resource that has higher value for other purposes, such as feedstock for petrochemical processing.
- Our use of coal, the largest energy resource in the country, for electricity production is a major contributor to CO_2 emissions.

Emissions

From an emissions perspective, the large percentage of U.S. energy production and consumption that relies on the combustion of fossil fuels contributes to the United States being among the largest emitters of greenhouse gases (GHG), (e.g., CO_2) in the world as follows:

- The United States is responsible for ~1/3 of the world-wide GHG emissions.
- The energy sector accounts for about 84% of the GHG emissions in the United States
- The global thrust to reduce emissions and the current Administration and Congressional objectives of pursuing massive reductions in GHG emissions contributes to the uncertainty in the economics of these fuels.

Referring to Figure E–1, the fraction referring to coal is from residential, commercial and industrial applications and is small and declining in time. The principal sources of the emissions from these sectors come from burning of coal and natural gas to produce electricity, burning of natural gas in residential, commercial and industrial applications and combustion of diesel, gasoline and ethanol in internal combustion engines and combustion turbines (e.g., airplane engines).

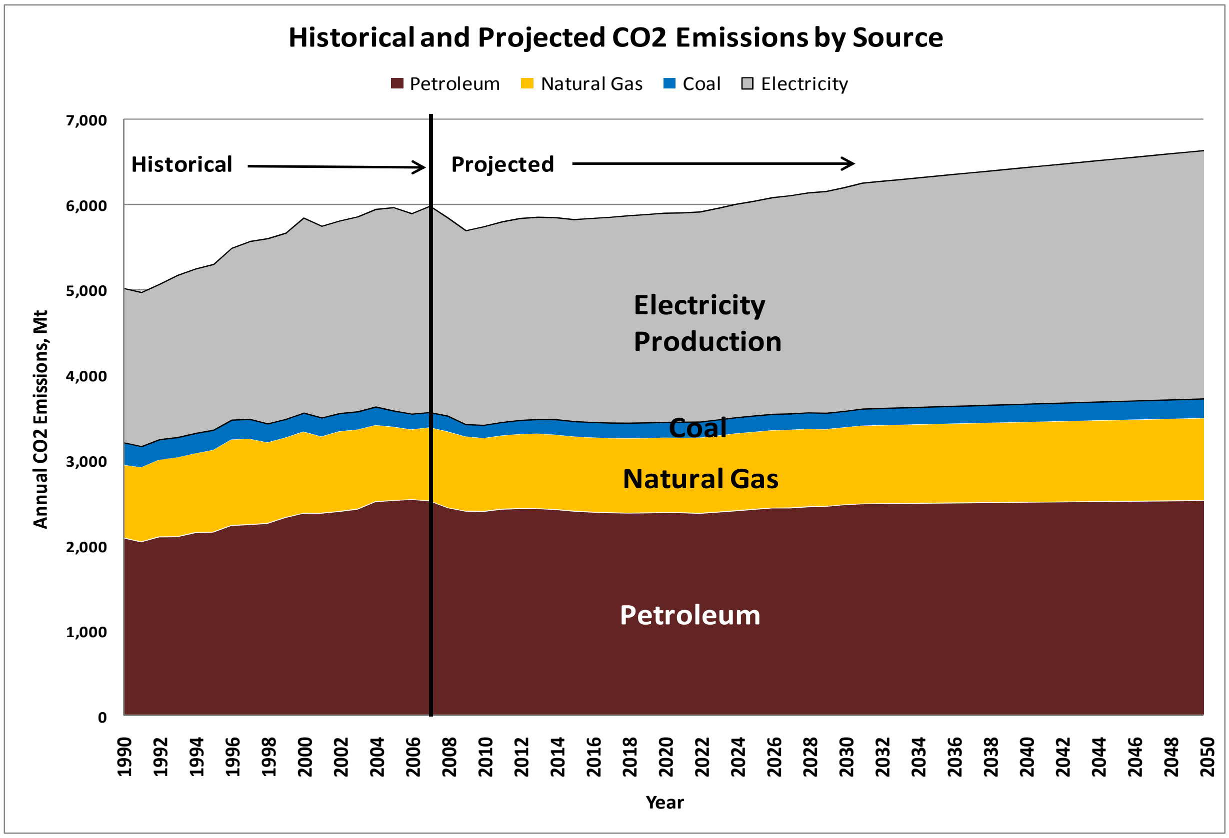

Figure E–1. Historical and projected emissions by source 1990 – 2050.

Approach

This report summarizes evaluations performed by the Idaho National Laboratory (INL) in assessing alternatives and developing a strategy to effect potential changes in the way in which energy is produced and consumed that are necessary and sufficient to correct the negative issues in the U.S. energy infrastructure. The strategy achieves all four of the transformation objectives, (e.g., reduced GHG emissions and price volatility, and improved energy security and resource stewardship) on a straightforward and permanent basis using U.S. technology and industrial infrastructure. The detailed summary and basis for this strategy – the so-called Technology Based Strategy – is the subject of this paper.

A realistic approach to establishing a strategy for transforming the energy infrastructure requires maximizing flexibility as components of national energy policy change, energy economics change, and energy technologies advance. A common theme that should be considered is ensuring that options exist in energy production and use that can address changing needs. However, these type options can take one to two decades to commercialize – and are hence beyond the practical reach of typical private sector business investment, thus requiring support of government through government-industry partnerships.

The strategy described herein is based on contemporary policies, (e.g., ARRA) and what appear to be emerging policies, (e.g., pending legislation such as HR2454, S1733). It is also based on minimizing the risk of technology development required to achieve the objectives of this strategy. Whereas higher risk technologies are described and applied at a level consistent with its risk level, lower risk technologies are used for drawing conclusions for fulfilling the objectives for the policies being considered.

The strategy attacks the vulnerabilities of the energy infrastructure by first addressing the GHG emissions reduction objectives developed by policy papers of the Administration and being codified in Congressional pending legislation. Figure E–1 depicts the DOE Energy Information Administration (EIA) summary of current and projected CO_2 emissions through 2050. These emissions are categorized in the four energy sectors shown in the figure. The data are shown in million metric tons of CO_2 emitted per annum; shortened to Mt for convenience.

Figure E–2 shows the rate of reduction per annum and the total reductions that are required to meet the full emission reduction objectives of the Administration and Congress (~5,640 Mt below projections in 2050). It is clear from review of these two figures that there is no one area that can be targeted to achieve the objectives. All GHG emitting sectors must be addressed.

Figure E–3 shows the results of applying the Technology Based Strategy to emissions reductions. A five prong approach has been developed using available or in development technology.

The initiatives of the five prong approach include:

- **Conservation & Efficiency –** Taking advantage of improving efficiency in energy production, consumption and conservation to reduce consumption at a rate of ~0.25% per annum (consistent with EPA estimates but higher than projected by EIA with no emissions reduction program); **reducing projected emissions in 2050 by ~800 Mt**
- **Transportation Initiatives –** Supporting more use of lower emitting transportation fuels in FLEX and hybrid vehicles, (e.g., replacing corn ethanol with cellulosic ethanol and/or other bio-fuels to improve environmental impact and reduce the impact on the food chain), use of bio-diesel in place of conventional diesel, improving vehicle mileage standards, (e.g., implementing proposed NHTSA CAFÉ standards), improving vehicle tailpipe emissions, (e.g., implementing the proposed EPA standards) and deploying hybrid and electric vehicles in place of conventional vehicles, **reducing projected emissions in 2050 by ~1000 Mt and reducing the consumption of gasoline and diesel by 6.5 million barrels per day or about 70% of 2009 consumption of imported crude oil.**

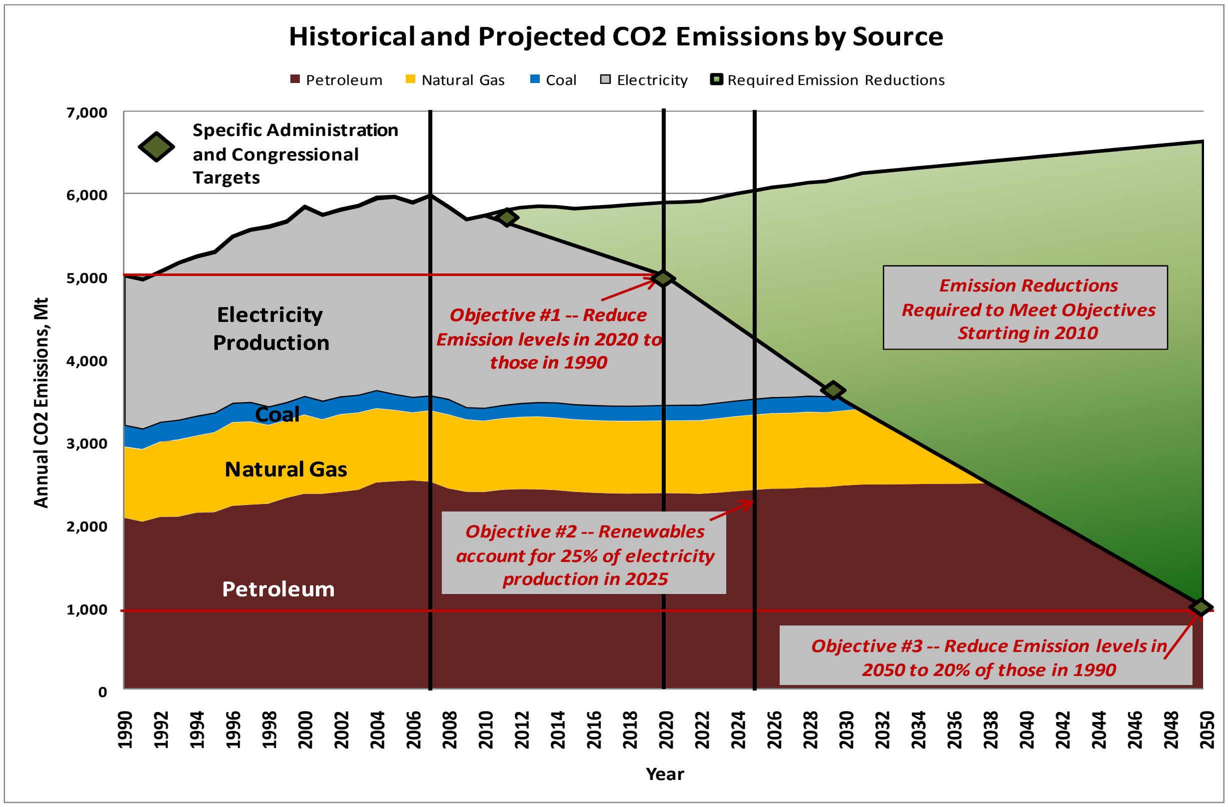

Figure E–2. Emission reductions required to meet objectives.

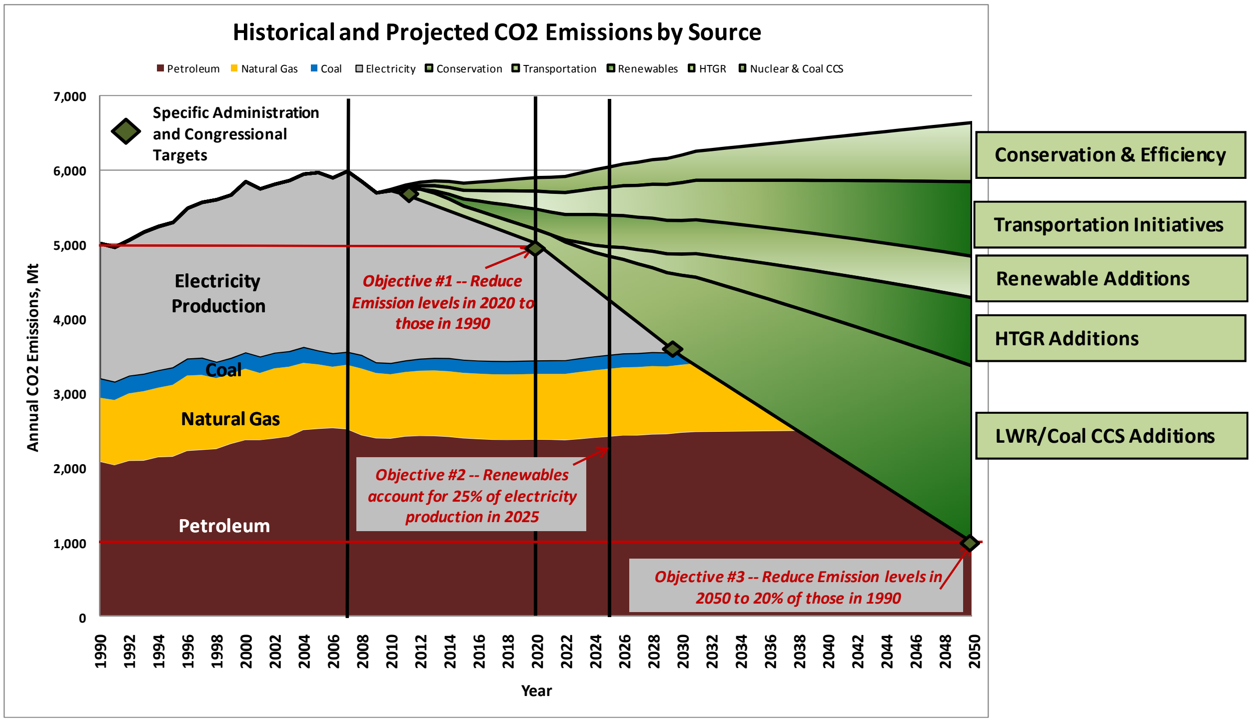

Figure E–3. Summary of the impact of all initiatives on reducing emissions.

- **Renewable Additions –** Increasing the use of renewables for electricity production in place of coal plants, (e.g., hydro-electric, wind, solar, biomass); meeting the Administration and Congressional Objectives of having renewables account for 25% of electricity production by 2025 and maintaining this level of production through 2050. Achieving this objective would **reduce projected emissions in 2050 by ~560 Mt. To meet this objective ~125 GWe (gigawatts electric) of renewable electric production will be required by 2025 and ~160 GWe by 2050 in addition to the capacity currently projected by EIA in these years.**
- **HTGR Additions –** Applying nuclear energy, in the form of high temperature gas-cooled reactor (HTGR) technology to replace the burning of fossil fuels in commercial and industrial applications and to provide a GHG emission free source of energy for production of synthetic fuels from coal and biomass; **reducing projected emissions in 2050 by ~915 Mt and producing 2.4 million barrels per day of gasoline, diesel and LPG; about 25% of the amount of crude oil imported per day in 2008. To meet this objective ~260 -- 2,400 MWt (megawatt thermal) HTGR plants supplying energy to a wide range of industrial processes and ~25 -- 13,200 Mwt HTGR /CTL plants would need to be deployed by 2050.**
- **LWR & CCS Additions –** Increasing the use of nuclear power and, if technically viable, coal and gas-fired plants with carbon capture and sequestration (CCS), as replacements for conventional coal fired and natural gas plants for the production of electricity; **reducing projected emissions in 2050 by ~2370 Mt**. **To meet this objective ~ 42 GWe of CCS plants and ~305 GWe of nuclear power based electrical production would replace retired conventional coal and natural gas plants by 2050.**

Results of Completing the Strategy

This Technology Based Strategy would result in a complete transformation that meets the criteria for correcting the vulnerabilities of the energy infrastructure in the United States:

- It will result in meeting the full objective of lowering greenhouse gas emissions on a permanent and self-sustaining basis using indigenous rather than offshore resources.
- It will result in more secure and more predictable costs of energy, (e.g., result in significant reductions, if not complete elimination, of the need to import crude oil or natural gas).
- It will promote more effective use of our indigenous sources of energy, (e.g., use of natural gas as feedstock for petrochemical processing instead of burning it, clean application of coal, our most abundant energy source).

It is estimated that full implementation of these initiatives would have a total cost of ~$3,850B (2007$) over four decades (<$100B per year) and result in an increase of ~54% in the real cost of energy by 2050. These estimates are in the same range as the EPA estimates for implementation of the Congressional bills; (i.e., $3,000B (2005$) and a 51% increase in the cost of energy). However the expenditures on the Technology Based Strategy have advantages when compared with current legislative proposals:

- The majority of the costs expended for the Technology Based Strategy would be for changes in the infrastructure rather than on the allowance and offset provisions of the current Congressional legislation that is being considered. The international offset provisions of these Congressional legislations result in a large flow of capital out of the country and do not reduce emissions in the United States.
- These expenditures would promote job growth in the suppliers to the energy sectors and in the energy sectors themselves.

- Energy costs will be predictable and increases introduced gradually into the energy sectors allowing the economy to adjust over the long term.

The total costs estimated for the completion of these initiatives are a reasonable fraction of the U.S. GDP so will add significant numbers of jobs and stimulation to the production sector of the economy. About 8 million man years of effort is estimated required to complete the infrastructure changes over the 40 year period of this strategy. On average this would require an additional labor force over the 40 year period of about 200,000. About 350,000 permanent jobs would also be developed in the production portion of the revised energy infrastructure. An additional several hundred thousand jobs would be required to support continued operation, maintenance and upgrade of the revised energy infrastructure.

Fulfilling National Interests

These are national issues which require a national strategy and governmental commitment to address. The United States has the capabilities and has shown the ability to address these needs with innovation and economy. Consistent and focused attention to addressing these needs domestically could make the United States a principal competitive supplier of the technologies, engineering, equipment and construction methodologies internationally. Such an effort could spread to and reinvigorate the broader manufacturing industry in the United States potentially promoting a material shift toward a production oriented economy in the United States away from the services economy that has dominated the last few decades.

Clearly there is no single strategy that will be effective in meeting these challenges – and the best overall strategy will change over time. The strategy evaluated herein is a fully technical approach to address energy security, price volatility and preservation vulnerabilities of the current energy infrastructure and addresses the plants and processes that are responsible for emitting GHGs today. It is based on using technologies that are currently available or are being actively developed. This is not the only approach that could be taken nor could one be developed today that would be static in its implementation to address the emissions issues. Implementing any strategy will require:

- A long term consistent commitment by the government to provide the policies, requirements and incentives necessary for industry and the public to accept these objectives and the means to address them,
- A long term commitment from the government and the private sector to raise the necessary capital to make the changes,
- Adapting the best technologies from both technical as well as economic aspects, (e.g., the selection of technologies should be based strongly on economics), and
- A commitment to support identification and adoption of emerging and evolving technologies as they are shown to provide improved benefits over the longer standing technologies.

The objective in fleshing out the strategy developed herein is to scope the magnitude of the effort that will be required to address the negative issues in our energy infrastructure and to stimulate discussion of the objectives and the means to address them.

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NOTE

The evaluations in this report pertaining to reductions in Greenhouse Gas Emissions were started in early 2009. These evaluations were based on the Obama-Biden Policy paper, “Promoting a Healthy Environment”. Subsequently, Congressional bills were drafted to codify the emission reduction objectives of this paper; in the House, HR2454 has been passed and in the Senate, S1733 is still pending. Although, the objectives of these latter Congressional Bills for net emissions reductions are stated in different specific terms than the Obama-Biden Policy paper the results are materially the same. Accordingly, this draft report still uses the original Obama-Biden policy objectives for emissions reductions.

The majority of the specific data on energy generation and consumption and emissions used in this paper was originally developed from the March 2009 issue of DOE/EIA AEO2009. Where there were substantive differences the data of the evaluations were updated in this draft report using information from the April 2009 update of AEO2009 that takes into account the effects of the American Recovery and Reinvestment Act and from the early release of AEO2010 in December 2009.

1. INTRODUCTION

The U.S. energy infrastructure is among the most reliable, accessible and economic in the world. On the other hand, the U.S. energy infrastructure relies heavily on foreign sources of energy, experiences high volatility in energy prices, does not practice efficient stewardship of finite indigenous energy resources and emits significant quantities of greenhouse gases (GHG). This report presents a Technology Based Strategy to achieve a full transformation of the energy infrastructure that corrects these negative factors while retaining the positives.

The Technology Based Strategy was developed by the Idaho National Laboratory and has the following objectives:

- Provide permanent and self-sustaining remedies that directly address the issues, (e.g., achieve substantive and effective reductions in greenhouse gas emissions in the United States)
- Reduce the reliance on imported energy resources
- Provide stability in energy costs
- Optimize the use of indigenous natural energy resources, (e.g., coal, natural gas)
- Maintain the reliability of the energy infrastructure
- Ensure that the impact of the transformation on the costs of energy reflect real costs for upgrade of the energy infrastructure
- Result in a predictable increase in the cost to the consumer of energy that is introduced consistently over the long term to facilitate accommodation of the increases on the individual and the economy
- Develop U.S.-based engineering, manufacturing and construction resources for implementation of the remedies, with the creation of permanent jobs and reduction in flow of capital offshore.

These will not be achieved through the forces of the competitive marketplace, but must be enabled through comprehensive and enduring U.S. Government energy and economic policies.

The production and consumption of energy in the United States is in four sectors; Residential, Commercial, Industrial and Transportation. As shown in Figure 1-1, the Industrial and Transportation sectors account for about the same fraction of the total energy and in total account for ~60% of the usage.[a] In 2008, combustion of liquid fuels accounted for ~40% of energy consumption; natural gas and coal combustion combined accounted for ~46% and nuclear power, renewable and other forms of energy accounted for the remaining ~14%. Coal, nuclear and renewable power account for the majority of the electricity production. The majority of the natural gas usage has traditionally been direct combustion in the residential, commercial and industrial sectors. Recently, there has been consideration of a shift from coal to natural gas for electricity production because of reductions in the price of natural gas and concerns with greenhouse gas emissions (natural gas produces about half the GHGs than coal per unit of energy). This has not yet affected the primary use of coal over natural gas in production of electricity.

The country relies heavily on imported crude oil and some natural gas to sustain the rate of consumption of these four sectors. This has negative impact on our energy infrastructure:

- It reduces the security of our energy infrastructure by relying on foreign sources.
- It leads to price volatility; the prices of crude oil and natural gas have fluctuated over large ranges the past several years contributing to instability in the economics of sectors using these commodities.
- In burning of natural gas we are depleting a natural resource that has higher value for other purposes, such as feedstock for production of plastics.
- We are not using coal effectively, the largest energy resource in the United States.

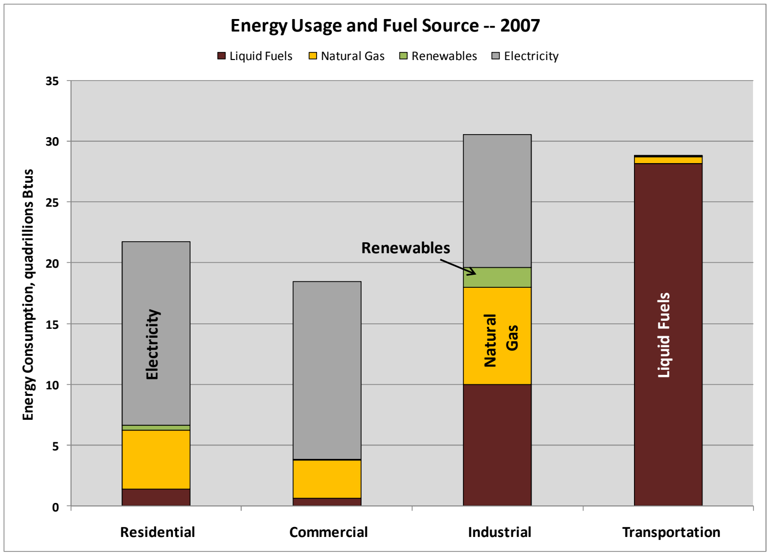

Figure 1-1. Energy usage and fuel source – 2007.

The large percentage of U.S. energy production and consumption that relies on the combustion of fossil fuels contributes to the United States being among the largest emitters of greenhouse gases (GHG), (e.g., CO_2) in the world.

- The United States accounts for about one-third of all GHG emissions world-wide
- The energy sector accounts for about 84% of the GHG emissions in the United States
- The global thrust to reduce emissions and the current Administration and Congressional objectives of pursuing massive reductions in GHG emissions contributes to the uncertainty in the economics of these fuels.

The current objectives of the Administration and Congress for reducing greenhouse gas emissions were used as the focus for developing the Technology Based Strategy. As the Strategy was developed additions to the emission reduction initiatives were made to address the other objectives, (e.g., use of

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[a] All of the energy production, consumption and emissions data in the report come from the DOE/EIA Annual Energy Outlook 2009 [2]

HTGR technology for the production of synthetic fuels reduces the need to import crude oil; addressing the energy security and price volatility issues while also reducing emissions from use of more conventional processes.)

In this regard, the current Administration and the Congress have proposed national initiatives for significant reductions in GHG emissions over the next four decades. These are detailed in Administration Policy papers [Obama/Biden] and in pending Congressional legislation HR2454 (The American Clean energy and Security Act) [HR2454] and S1733 (The American Clean Jobs and Power Act of 2009) [S1733]. The Administration policy papers call for reductions in carbon dioxide and other GHG emissions to 1990 levels by 2020, increases in the use of renewable sources of electricity production by 2025 and reductions in carbon dioxide equivalent emissions to 20% of 1990 levels by 2050. Although HR2454 and S1733 use different metrics to characterize the emissions reduction objectives, the result is the same as proposed in the Administration policy paper.

The portions of these bills that are relevant to development of the Technology Based Strategy are summarized in Appendix A.

The following first describes the major sectors in the energy infrastructure and their contributions to greenhouse gas emissions. Specific initiatives are then discussed with the objective of achieving the emissions reductions proposed by the Administration and Congress. Initiatives are included in five areas that address all four of the energy sectors:

- Conservation and Efficiency
- Transportation
- Renewable Power
- Application of HTGR Technology and
- Application of Nuclear Power and Coal with Carbon Capture and Sequestration.

The costs and benefits of these initiatives in resolving the other vulnerabilities of the current energy infrastructure are also summarized.

2. CURRENT AND PROJECTED ENERGY PRODUCTION AND CONSUMPTION

2.1 General

The Department of Energy (DOE) Energy Information Administration (EIA) issues annual reports summarizing the characteristics of energy production and consumption in the United States and internationally. These include historical records as well as projections over the next 20 years of production and consumption by source of the energy, (e.g., coal, petroleum, natural gas, nuclear, renewable, including hydro and other), and by sector, (e.g., residential, industrial, commercial and transportation). The data includes the annual production and consumption of (1) energy in quadrillion Btus (QBtus), (2) electricity in billions of kilowatt hours (BKwhe) and (3) GHG emissions, (e.g., CO_2) from use of fossil fuels in millions of metric tons (Mt).

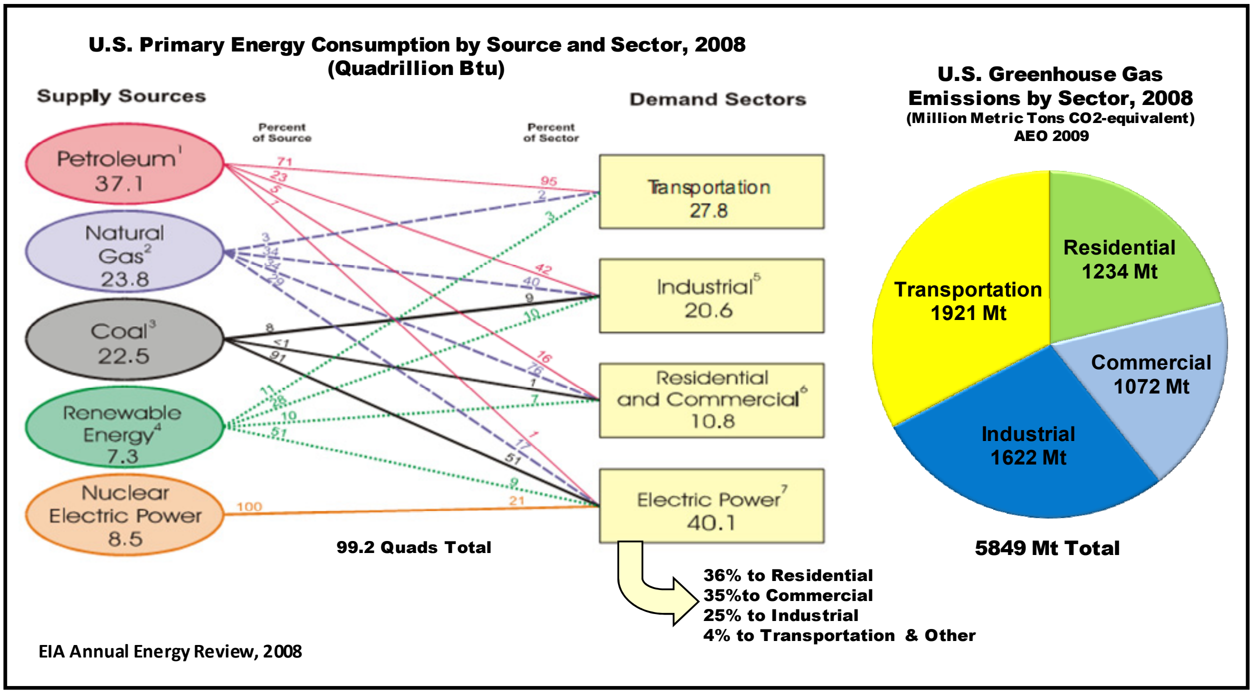
The 2009 report, the Annual Energy Outlook 2009 (AEO2009) [AEO 2009] and the more recent Annual Energy Outlook 2010 Early Release [AEO 2010], were used extensively in developing the data of this report. Specifically, the historical data, (e., emissions in 1990 and 2000) and the projections (e.g., through 2030) were used as the baseline to establish the reductions in emissions that are required to meet the Administration and Congressional objectives. AEO2009 and AEO2010 only provide projections through 2030. To address the objectives of 2050, the AEO2009 and AEO 2010 data were extrapolated using linear projections developed from the projections 2010 through 2030.

2.2 Energy Production, Consumption and GHG Emissions Projections versus GHG Emissions Reduction Objectives

Figure 2-1 summarizes the U.S. energy consumption and emissions by energy source and sector of consumption in 2008 [AEO2009]. As shown the electric power and transportation sectors account for the majority of emissions. The emissions from the transportation sector are associated with the refining of crude oil and combustion of petroleum products, (e.g., gasoline and diesel) and ethanol. The emissions from the electric power sector come from coal and natural gas fired power plants. In 2008 these plants accounted for 68% of electricity production. 71% of the electricity was consumed in the residential and commercial sectors; 25% in the industrial sector.

Figure 2-2 shows the historical and projected levels of GHG emissions by energy source 1990 – 2050. The data for this figure in the period 1990-2030 was taken directly from AEO2009. As noted above, the projections from 2030 to 2050 are based on extrapolation of the average annual rate of change in the AEO2009 data from 2010 to 2030. When the year-to-year increases are small, on the order of 1% or less, using linear projections rather than more complicated functions makes only a small difference in the final results. Figure 2-2 shows that EIA does not project any major changes in the relative usage of various energy forms, and therefore not in the CO_2 emissions from the sources.

These curves reflect the current distributions of energy consumption and distribution and show that emission levels due to energy production and consumption are projected to increase at a lower rate over the next four decades than from 1990 - 2007. Note that the reductions in predicted emissions in 2008 and 2009 are believed to be due to the economic downturn in the United States those years. It is against these projections that the objectives of the Administration and the Congress are compared and the strategies to meet the proposed reductions in emissions and the distribution of electricity production are crafted.



EIA Annual Energy Review, 2008

Figure 2-1. U.S. energy consumption and GHG emissions by source and sector in 2008.

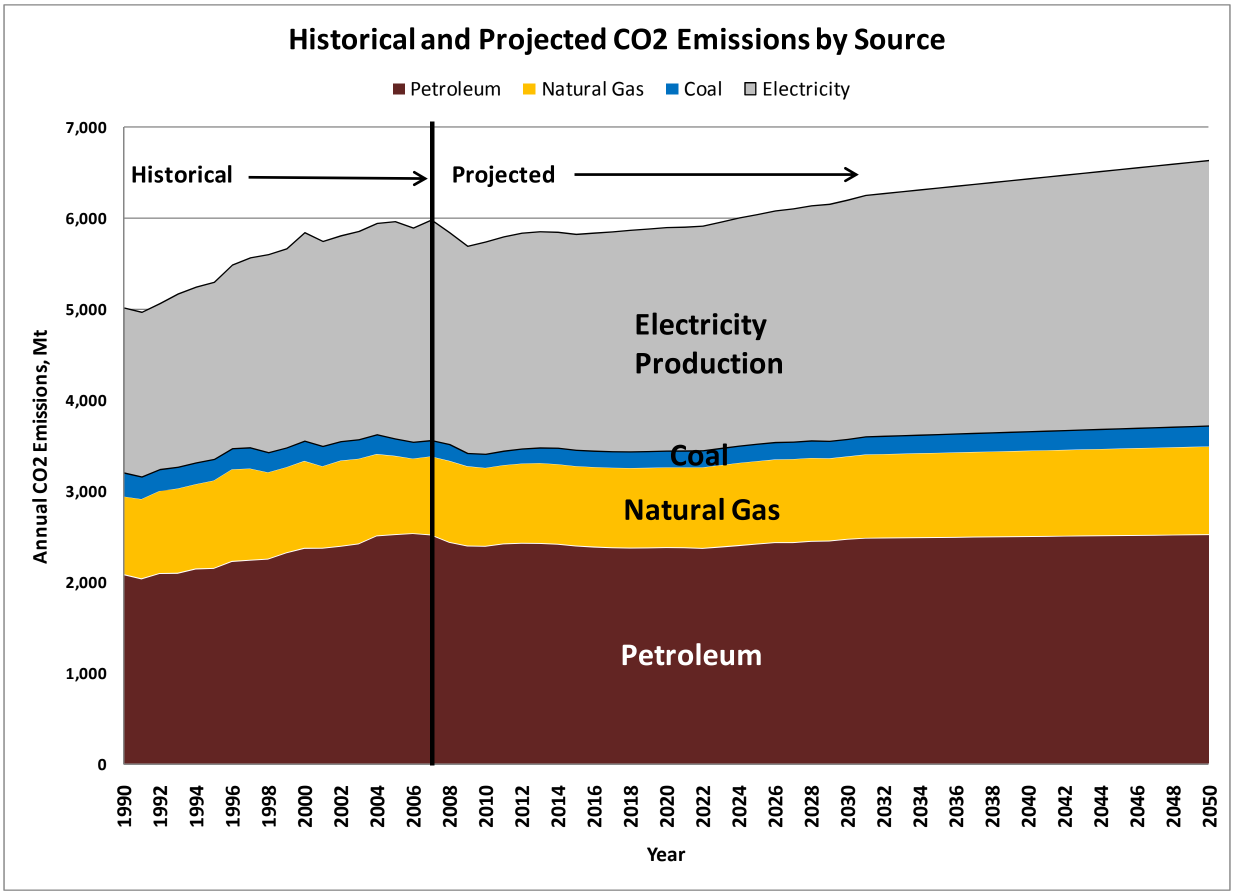


Figure 2-2. Historical and projected emissions by source 1990 – 2050.

Review of Figure 2-2 shows that petroleum usage and electricity production have the most impact on emissions; these are the principal areas to address to achieve significant reductions. It is noted, however, that even if all of the emissions currently projected for 2050 for electricity production and transportation were eliminated the emission reduction objectives would not be met. Cuts are also required in the emissions from natural gas used directly in the residential, industrial and commercial sectors. Coal as an energy source other than for electricity production is not a major factor in GHG emission reduction and is declining slightly in its use based on the EIA predictions.

Figure 2-3 shows the rate at which emission levels need to be cut to meet the Administration and Congressional objectives. As shown to meet objectives, ~800 Mt of GHG emissions must be reduced from the total projected in 2020 and ~5,600 Mt reduced in 2050. This will require reductions in every major energy production and consumption sector. The rate of change in emissions reductions shown on this chart was developed as a smooth fit to the administration objectives. An approach that affects a continuous reduction in emissions is judged to be more effective in utilization of resources, adapting new technologies, (e.g., bringing them on incrementally as they are proved beneficial) and for tracking of progress than an alternative which may address the reductions in a more step wise fashion.

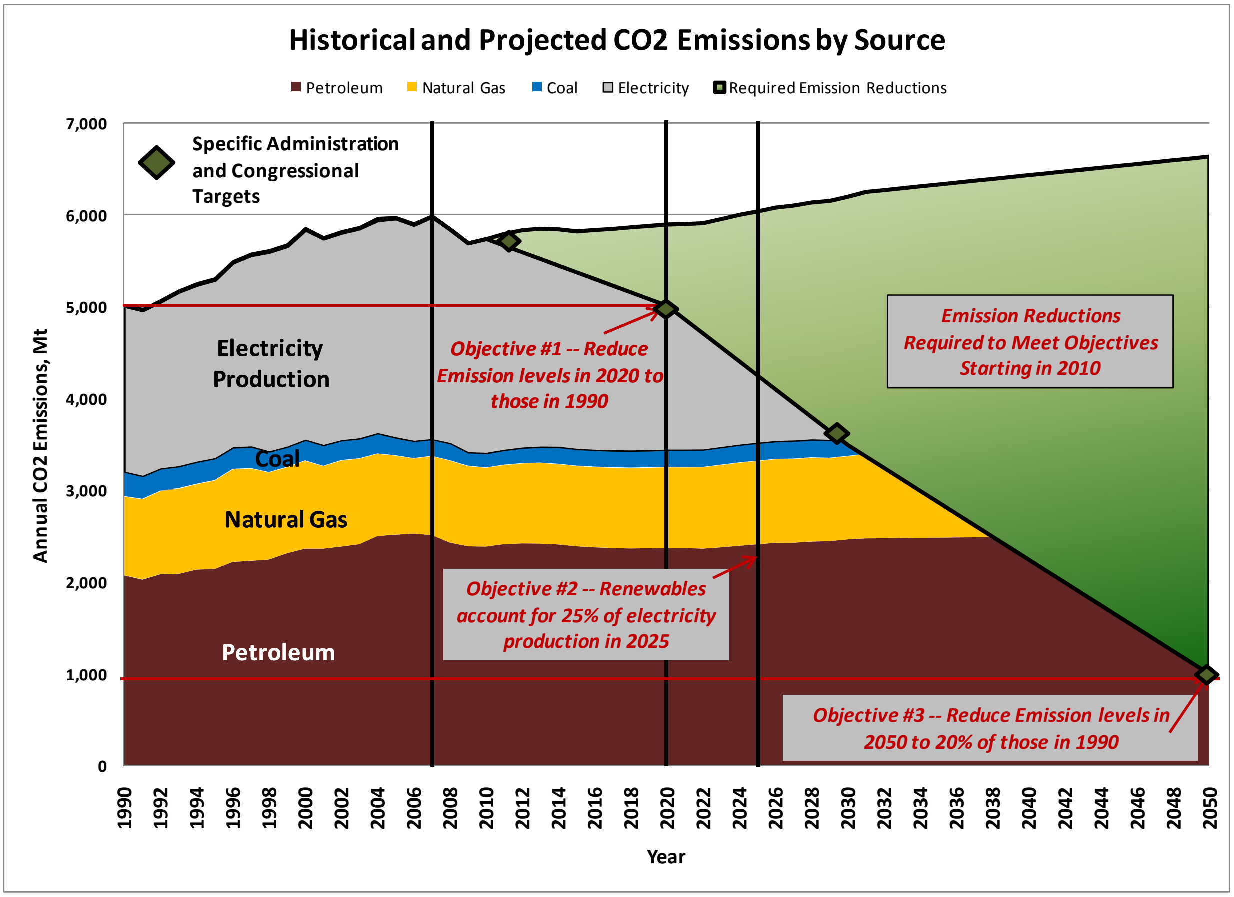


Figure 2-3. Emission Reductions Required to Meet Objectives

The reductions in emissions shown on Figure 2-3 begin in 2010. This is an aggressive assumption but is needed to improve the feasibility of meeting the objectives at the times cited. This requires that government policies, incentives and requirements be established and begin to be adopted in 2010. In fact, there are several areas where the country and industry are taking action independent of government policy that will lead to short term emissions reductions, (i.e., until the more significant initiatives evaluated herein can take effect). There is increasing emphasis on conserving energy consumption, industrial and commercial plants have initiatives to reduce their carbon footprints through shifting to less emitting sources of energy and increasing efficiency of their processes, the downturn in the economy has reduced consumption and increases in transportation fuel costs have reduced total miles driven and increased the sale of hybrid electric cars. Accordingly, some of the effort that is needed to meet the objectives is underway. However, rapid, focused and long term consistent government policies are required to achieve the full extent of the objectives.

3. MEETING THE LONG-TERM ENERGY OBJECTIVES

3.1 Long-Term Objectives

The Administration and Congressional Objectives extend over the next 4 decades. They are focused on emissions reductions to address global warming concerns. As noted previously, however, there are other challenges to our use of energy that need to be addressed to support long term secure, stable and clean energy as collateral to meeting the objectives of emissions reductions. These include:

- *Stabilizing the cost of energy* – reduce volatility in the price of energy that has been experienced because of instability in the price of oil, natural gas and electricity; this is of particular interest to the private sector
- *Ensuring the cost of energy supports growth of the economy and competitiveness internationally* – a national objective
- *Promoting security of the energy supply* – reduce reliance on foreign sources (particularly those in unstable or anti-U.S. regions of the world); primarily a national interest and of interest to selected industries; petroleum and petro-chemical industries that import a significant fraction of feedstock
- *Promoting development of the U.S. infrastructure* supporting the energy supply; primarily of national interest and to large U.S. component and system suppliers to the energy sector. This covers as a minimum the following areas:
    - Use of indigenous resources, (e.g., coal, gas, uranium)
    - Research & Development
    - Engineering
    - Equipment, component , system and material suppliers
    - Contractors.

It is of importance that long term energy strategies consider these as well as the emission reduction objectives. This will take a balanced approach that draws on the factors inherent in the technologies in the U.S. energy infrastructure addressing all objectives and balancing the effectiveness, cost and reasonableness of each strategic component. To this end, addressing transformation in the following components of energy production and consumption is the focus of the strategy discussed herein:

- Conservation and Efficiency
- Transportation
- Industrial and Commercial Processes
- Electricity Production.

The following section quantifies the specific reductions in emissions and increase in renewable electricity production that are required to meet Administration and Congressional objectives. The remaining sections outline the initiatives in each of the energy production and consumption components for reducing emissions through conservation and efficiency, increasing the percentage of renewable and nuclear based electricity production, reducing combustion of fossil fuels in transportation through improved fleet mileage and more reliance on hybrid and electric vehicles and substituting nuclear energy technologies(i.e., the Advanced Light Water Reactor (ALWR) and High Temperature Gas-cooled Reactor (HTGR)) as energy supplies in place of fossil fuels.

3.2 Cuts Needed to Meet Emission and Electricity Production Objectives

The following tables summarize the 1990 annual CO_2 emissions by fuel and sector and then lists the differentials that would be required in each of these if each were to share in the same percentage of reduction to meet the objectives. As will be shown in following sections not all of these reductions can be realized by source and sector. Certain of the sources, (e.g., electricity production) will have to absorb more of the reductions.

To meet the Administration Objectives the following reductions in emissions from those projected by AEO2009 would be required:

Objective #1 – Emissions in 2020 at the 1990 Levels

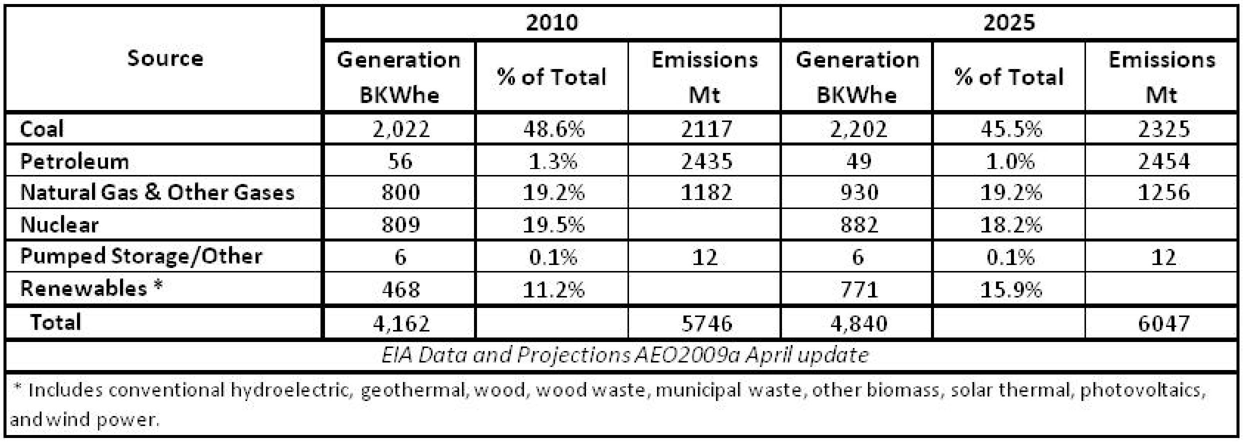
Year	Total, Mt	Emissions by Fuel, Mt annually				Emissions by Source, Mt annually			
		Natural Gas	Petroleum	Coal	Electricity	Residential	Commercial	Industrial	Transportation
1990	5,019	856	2077	265	1820	962	788	1687	1583
2020*	5,905	878	2375	186	2466	1230	1192	1557	1929
Delta	886	22	298	-79	646	268	404	-130	346

EIA Data and Projections AEO2009a April update

* These are the emissions projected by EIA in 2020 if no action is taken

Objective #2 – 25% of Electricity Production is to be by renewable sources in 2025.

EIA projects the following for 2025:



Source	2010			2025		
	Generation BKWhe	% of Total	Emissions Mt	Generation BKWhe	% of Total	Emissions Mt
Coal	2,022	48.6%	2117	2,202	45.5%	2325
Petroleum	56	1.3%	2435	49	1.0%	2454
Natural Gas & Other Gases	800	19.2%	1182	930	19.2%	1256
Nuclear	809	19.5%		882	18.2%	
Pumped Storage/Other	6	0.1%	12	6	0.1%	12
Renewables *	468	11.2%		771	15.9%	
Total	4,162		5746	4,840		6047

EIA Data and Projections AEO2009a April update

* Includes conventional hydroelectric, geothermal, wood, wood waste, municipal waste, other biomass, solar thermal, photovoltaics, and wind power.

To meet this objective renewable would have to account for 1210 BKWh of production (25% x 4840 BKWhe) This is an increase in renewable production of ~439 BKWhe; it is about three times the renewable generation projected for 2010 and an increase of ~ 57% above that currently projected by EIA for renewable production in 2025.

To meet this objective major changes are needed in the transportation sector, in electricity production and the use of natural gas.

Objective # 3 – Reduce emissions in 2050 to 20% of the 1990 levels.

Year	Total, Mt	Emissions by Fuel, Mt annually				Emissions by Source, Mt annually			
		Natural Gas	**Petroleum**	**Coal**	**Electricity**	**Residential**	**Commercial**	**Industrial**	**Transportation**
1990	5,019	856	2077	265	1820	962	788	1687	1583
2050*	6,645	966	2518	231	2930	1422	1506	1470	2247
20% of 1990	1,004	171	415	53	364	192	158	337	317
Delta	**5,641**	**795**	**2,103**	**178**	**2,566**	**1,230**	**1,348**	**1,132**	**1,930**
EIA Data and Projections AEO2009a April update extrapolated to 2050 using linear correlations									
* These are the emissions projected by EIA in 2050 if no action is taken									

The following sections describe actions that could be taken over the next four decades in each of these sectors to meet the Administration and Congressional objectives on CO_2 emissions. The impact of these initiatives on energy security through reductions in imports of foreign sources of energy is also identified.

4. EMISSIONS REDUCTION COMPONENT STRATEGIES

4.1 Conservation and Efficiency

The EIA projections on energy consumption account for Federal and State programs that address conservation and efficiency improvements with the objective of reducing the energy consumption growth rate. These are applied in the projections for the growth of energy consumption in the residential, commercial and industrial sectors. They address the use of improved building efficiencies that affect heating and cooling requirements, more efficient lighting, heating and cooling equipment, more efficient use of energy in industrial processing. The specific legislation considered at the Federal level includes:

- National Appliance Energy Conservation Act of 1987
- Energy Policy Act of 1992
- Energy Policy Act of 2005
- Energy Independence and Security Act of 2007
- Energy Improvement and Extension Act of 2008
- American Recovery and Reinvestment Act of 2009F.[b]

Specific state initiatives are included in the EIA projections geographically.

For the purposes of this study it is assumed that if the initiatives proposed herein or in the proposed Congressional legislation are taken, there will be several factors that will result in reductions in the annual growth rate of energy consumption. This is assumed to occur by increased public awareness of the need to conserve, higher energy prices and industry programs in response to government requirements for higher efficiency in energy production and consumption and reductions in GHG emissions. The EPA analyses of HR2454 [EPA 2009a & b] and S1733 [EPA 2009c] project that these effects would reduce energy consumption by ~12% below the EIA projections in 2050. This is an average annual reduction rate of 0.28% beginning in 2010, (i.e., ~50% of the annual growth rate in energy consumption predicted in [AEO2009a]). This rate of reduction is assumed herein and results in a total reduction of ~800 Mt of the emissions projected by the EIA in 2050.

Figure 4-1 shows the effect of the reductions in consumption due to Conservation and Efficiency on reducing the emissions baseline from which the remaining emissions reduction initiatives will be crafted to meet Administration and Congressional objectives.

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[b] The April update of AEO2009, (i.e., AEO2009a) accounted for the provisions of the ARRA of 2009

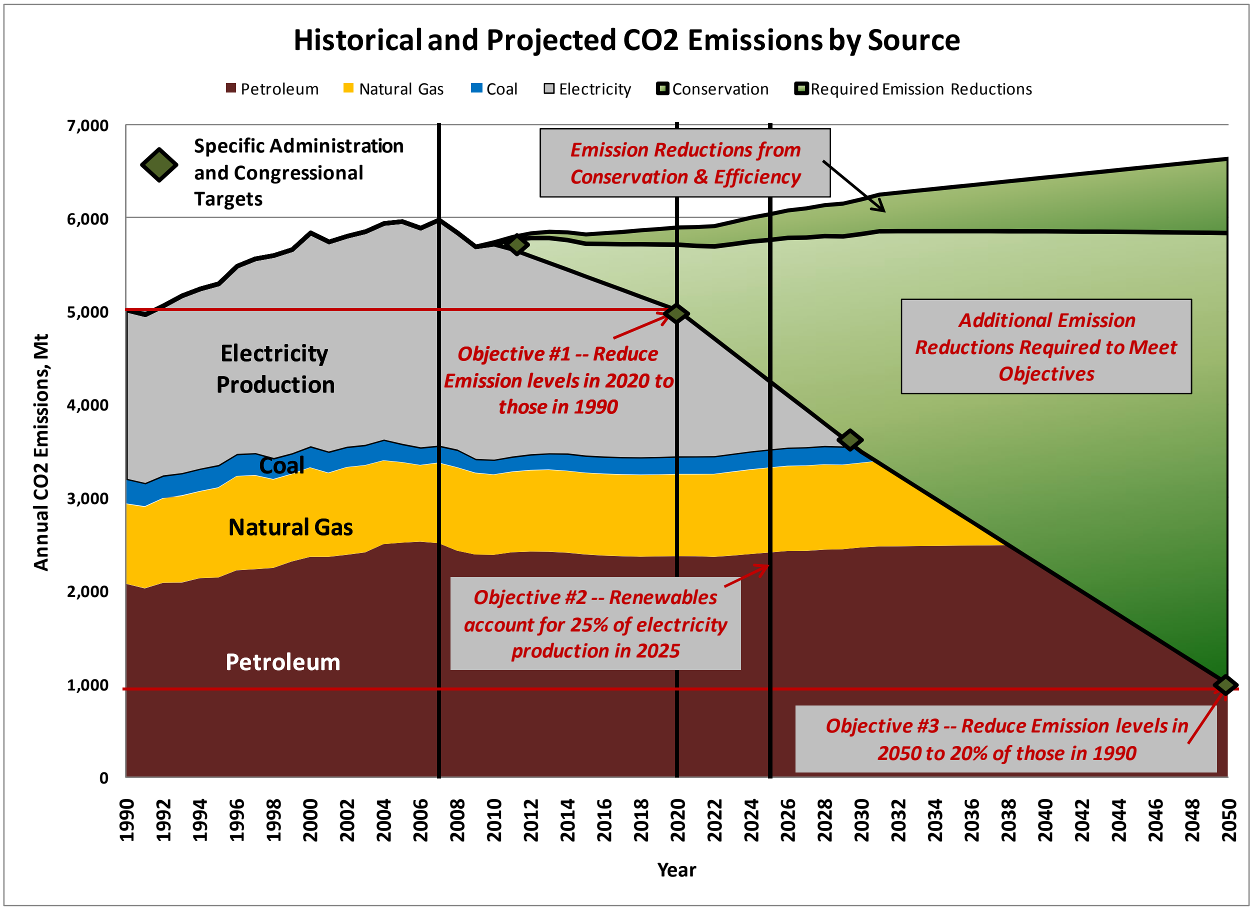

Figure 4-1. Emissions reductions from conservation and efficiency.

4.2 Transportation

The initiatives assumed to be viable in the transportation component address both energy security and CO_2 emissions by reducing the projected demand for gasoline and diesel fuels, substituting domestically produced synthetic and biofuels for imports and increasing the use of lower emitting fuels and vehicles. These initiatives include several recommended governmental programs to meet these objectives as follows:

- Support commercialization of the cellulosic process for the production of ethanol or other bio-derivative fuels, (e.g., algae) in place of production using corn. Incentives should be provided to achieve sufficient alternative bio-fuel processing to double the annual rate of their production currently projected by EIA beginning in 2010. This would provide sufficient production capacity by 2050 to supply bio-fuels in E85 FLEX vehicles and for fueling hybrid electric vehicles. Extrapolation of DOE/EIA projected miles driven by light duty vehicles from 2030 (Table 60, April 2009, [AEO2009a]) to 2050 projects that Hybrid vehicles will account for ~22% and E85 FLEX vehicles will account for ~12% of the miles driven in 2050. Electric vehicles will account for ~3% of miles driven in 2050.
- Provide incentives for production of FLEX vehicles capable of using E85 blends of ethanol (or equivalent) and gasoline and hybrid electric vehicles to achieve the maximum benefit from increased production of cellulosic ethanol and other bio-fuels on emissions and reductions in gasoline consumption.

The use of the cellulosic process for production of ethanol reduces the CO_2 emissions per mile in FLEX internal combustion engines (ICE) by ~55% compared with the emissions of corn based ethanol and ~75% when compared with the emissions from petroleum based fuels. (see Table 4-1 [DOE 2009b]) The feedstocks used in cellulosic processing or for other bio-fuels production are more varied and do not compete with the food chain as does corn based ethanol. Land availability and management may also be facilitated by use of the cellulosic process or other bio-fuel processes because of the wider variety of viable feedstocks.

Table 4-1. Life cycle emissions by vehicle type and fuel.

	Vehicle Type, gCO_2eq/mile				
			Plug-In Hybrid Electric		
Fuel Type	Conventional	Hybrid Electric	U.S. Grid	N.E. Grid	CA Grid
Gasoline					
E10	476	322	340	312	289
E85					
Corn Ethanol	389	263	302	274	250
Cellulosic Ethanol	171	116	203	175	151
Diesel					
Diesel Fuel	405	305	328	301	277
B20	334	230	279	251	227

EIA, "Light Duty Diesel Vehicles: Efficiency and Emissions Attributes and Market Issues, 2. Comparison of Light-Duty Vehicle Greenhouse Gas Emissions", Report # SR/OIAF(2009)02, February 2009

- Provide incentives for the development of bio-diesel alternatives. The use of bio-diesel as a substitute for crude oil based diesel would reduce projected emissions in 2050 by ~60Mt.
- Provide incentives to ensure the projected growth in the number of hybrid electric vehicles (HEVs) on the road assumed by the DOE-EIA.

The increase in the number of hybrid vehicles and FLEX fueled ICE vehicles on the road combined with a supply of cellulosic ethanol or other bio-fuels production and supply will result in significant reductions in life cycle emissions (~365 Mt annually in 2050, based on cellulosic ethanol when compared with corn based ethanol) and offset significant quantities of imported crude oil.

This initiative should promote increased purchase of both HEVs and plug-in hybrids. As shown in Table 4-1, however, the improvement in emission rates for plug-in hybrids currently falls below that of HEVs when cellulosic ethanol is used as an alternative fuel. This is because of the large percentage of the electricity on the U.S. grid currently supplied by coal and natural gas. Over time, however, this will change because it will be necessary to transition the electric grid to lower emitting sources of energy to reach the emission reduction goals cited previously. The reductions in emissions credited for plug-in hybrids will increase as the grid is converted to sources that do not emit GHGs. This effect has not been considered herein.

Figure 4-2 summarizes the emissions avoided by substituting cellulosic for corn based ethanol in FLEX and Hybrid vehicles and Bio-Diesel for standard diesel. It has been assumed that the use of cellulosic ethanol and bio-diesel would apply only to the increase in miles driven by hybrid, FLEX vehicles and diesel vehicles projected by EIA from 2009 through 2050.

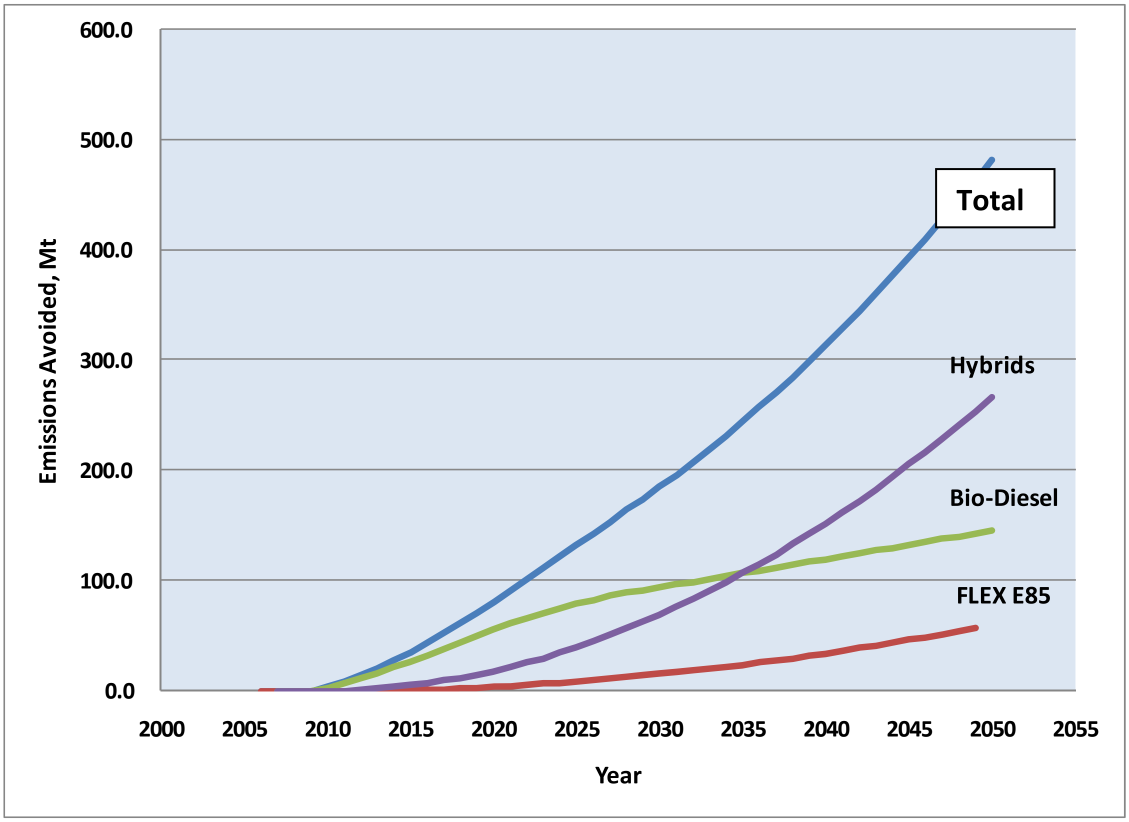

Figure 4-2. Emissions avoided by substituting cellulosic ethanol for corn ethanol and bio-diesel for conventional diesel.

- Implement the increase in fuel mileage and tailpipe emission standards for vehicle Model Years (MY) 2012 – 2016 proposed by the National Highway Transportation Safety Administration [NHTSA 2009a] and the Environmental Protection Agency [EPA2009d] in response to the Administration National Fuel Efficiency Policy [ADMIN2009b]. These would increase the average new car fleet mileage standard for internal combustion engines (ICE) to 35.5 mpg by 2016. This results in an average increase in mileage over these model years of 4.3% per annum. [NHTSA 2009a] The EPA has joined with the NHTSA to add a further initiative to apply the California tailpipe emission standards nationwide to MY2012-2016 automobiles. The EPA estimates that the combined effect of these emission standards with the revised CAFÉ standards would result in a reduction of 325 Mt of emissions in 2030 and 500 Mt in 2050. [EPA 2009c] The total emission reductions projected for these initiatives is shown in Figure 4-3. The inflection point at 2030 results from reaching the full effect of the new mileage standards. It is the point at which all cars on the road are operating at the new standard.
- The total avoided emissions per annum as a result of the sum of these initiatives is shown in Figure 4-4. As shown ~1,000 Mt of emissions would be avoided in 2050.
- These initiatives would also result in significant reductions in the consumption of gasoline and conventional diesel fuel. In [DEIS, EPA 2009c] the EPA projects that the new NHTSA CAFÉ standards and the EPA proposed reduced tailpipe emission standards would result in the fuel savings and emission reductions shown in Table 4-2 (billions of gallons) compared with consumption anticipated if no action were taken.

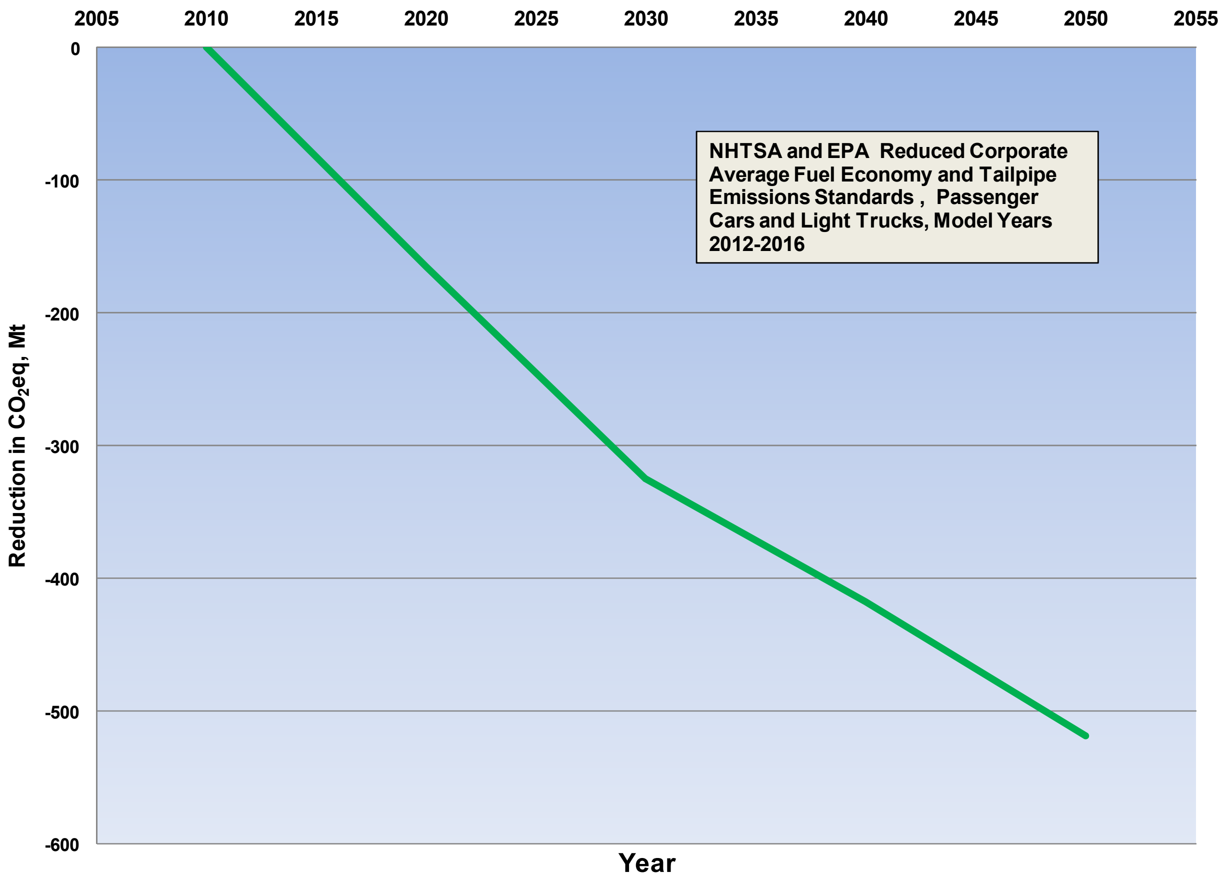

Figure 4-3. Annual emission reductions achieved from increased mileage standards.

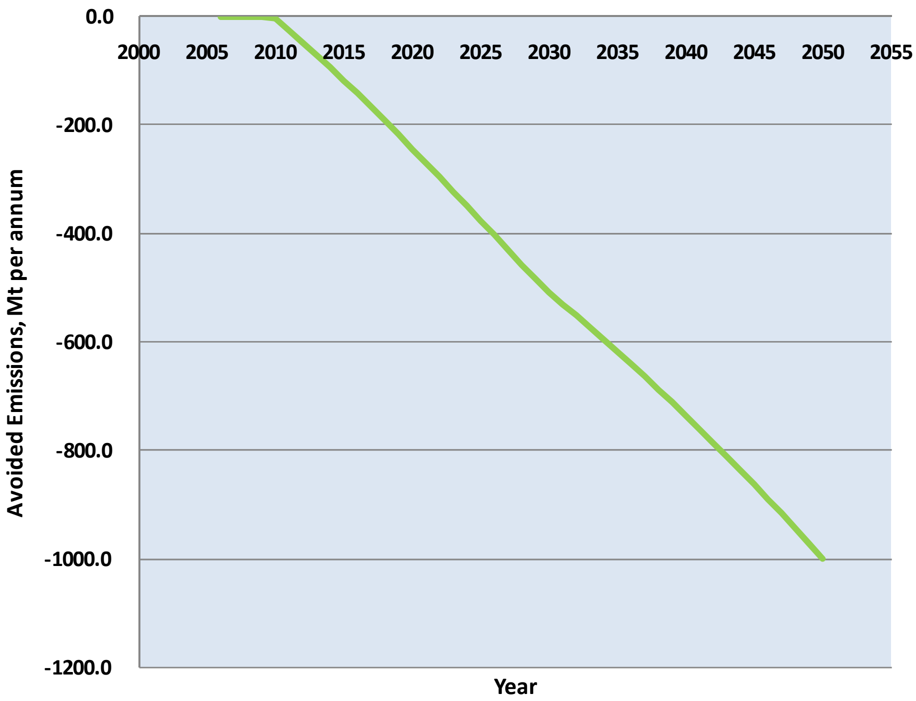

Figure 4-4. Total avoided emissions from transportation initiatives.

Table 4-2. Projected fuel savings for proposed 2012-2016 MY CAFÉ standards.

Calendar Year	**Annual GHG Reduction (CO_2 EQ Mt)**	**Fuel Savings (Million Barrels Per Day of Gasoline Equivalent)**	**Annual Fuel Savings (Billion Gallons of Gasoline Equivalent)**
2020	165.2	0.9	13.4
2030	324.6	1.7	26.2
2040	417.5	2.2	33.9
2050	518.5	2.8	42.6

Table 5.1 -- Impacts of Proposed Program on GHG Emissions and Fuel Savings [EPA DEIS 2009]

[AEO 2010, Table 11] projects the consumption of ethanol, gasoline and diesel through 2035. Figure 4-5 shows the breakdown of the consumption of liquid fuels by sector and by the type of fuel for 2009 and projected for 2030 and 2050. The 2050 data was projected by a linear extrapolation of the rate of change of EIA projections over the period 2030-2035.

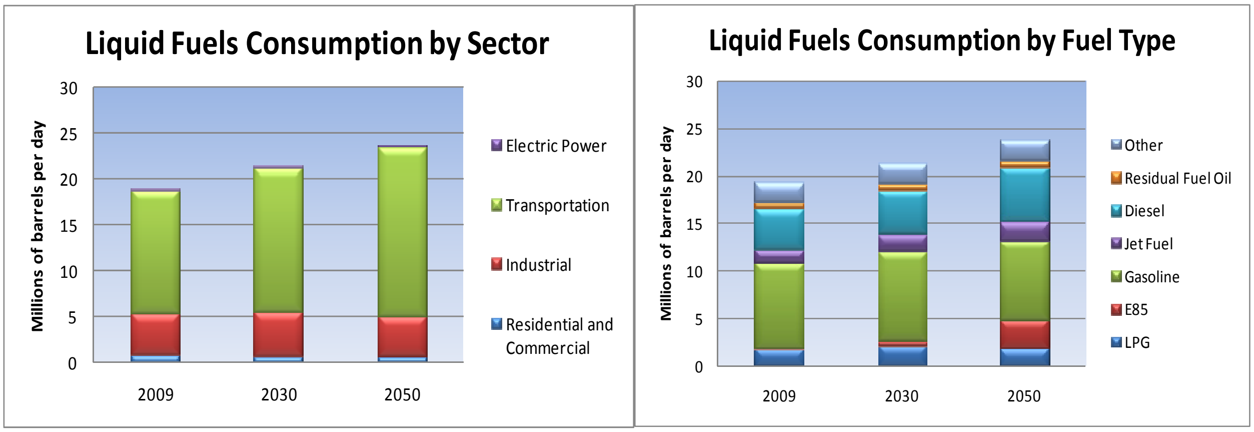

Figure 4-5. Liquid fuel consumption by sector and fuel type. [Table 11, Early Release of AEO 2010]

These projections indicate that gasoline consumption declines slightly over this 40 year period (~380 million gallons per day in 2009 to ~350 million gallons per day in 2050) even though the total consumption of liquid fuels in the transportation sector is projected to rise. This is due to the projected increase in ethanol consumption (in the form of E85) over this period (50 thousand gallons per day of E85 in 2009 to ~128 million gallons per day of E85 in 2050 or ~108 million gallons of ethanol). Since ethanol has about 70% the energy content of gasoline [GREET2007] this represents an offset of ~76 million gallons per day of gasoline consumption in 2050 [128 × 0.85 × 0.7 = 76 or 27.8 billion gallons per year]. This significant growth in ethanol consumption provides additional incentive for developing alternative methods for ethanol production such as cellulosic processes or developing equivalent bio-fuels such as algae based fuels, as substitutes for corn based ethanol. This is judged to be necessary to improve life cycle emissions of ethanol or other alternative fuels and to reduce the impact that increasing use of corn for ethanol production would have on the food chain.

Diesel consumption is also projected to increase over this period (~143 million gallons per day in 2009 to ~230 million gallons per day in 2050). Successful development of large scale production of Bio-Diesel could offset this large increase in conventional diesel consumption thereby reducing the demand for crude oil. As shown in the preceding discussion the use of bio-diesel would also result in significant reduction in emissions.

Table 4-3 summarizes the total reduction in gasoline and diesel consumption that could be affected by these initiatives and the new NHTSA CAFÉ standards. This table also presents these reductions in gasoline and conventional diesel consumption in terms of an equivalent reduction in crude oil consumption.

Table 4-3. Impact of transportation sector emission reduction initiatives on gasoline and crude oil consumption in 2050.

Gasoline and Conventional Diesel Consumption Reductions in 2050 due to use of Cellulosic Ethanol in Flex and HEVs, Bio-Diesel Development and New CAFÉ Standards		
Gasoline savings from full realization of the Proposed NHTSA CAFÉ and EPA tailpipe emissions standards	42.6	Billion gallons
Gasoline Savings from burning of E85 in FLEX and hybrid vehicles (128 million gallons per day at 70% of the energy content of gasoline.)	27.8	Billion gallons
Total gasoline savings	70.4	Billion gallons
Potential conventional diesel offset of increase in diesel consumption with bio-diesel (~87 million gallons per day)	29.3	Billion gallons
Total gasoline and diesel reduction	99.7	Billion gallons
BPD of gasoline and diesel saved	6.5	Million barrels/ day

The savings in gasoline and diesel consumption projected for 2050 is ~50% of the average consumption of gasoline and conventional diesel per day in the United States in 2009 [12.42 million bpd, AEO 2010, Table 11]. Considering that in 2009 the United States imported over 58% of its consumed crude oil (9,150,000 BPD) and a large percentage of that goes into gasoline and conventional diesel production (67% of each barrel of crude oil) this reduction in gasoline and conventional diesel consumption would have a significant impact on reducing reliance on imported oil.

Figure 4-6 shows the net impact of the Conservation & Efficiency and the Transportation initiatives on the reductions in emissions necessary to meet Administration and Congressional objectives. The next section will address how the balance of the emissions reduction can be met to meet Objective #1 in 2020 and the actions necessary to meet Objective #2 -- renewable energy supplying 25% of electricity production in 2025.

The next section discusses the elements of electricity production in the United States that are adapted to meet the specific targets for emissions reductions in 2020 and 2050.

4.3 Electricity Production

Electricity production accounts for 40% of the total emissions associated with energy production and consumption. The sources of these emissions are consolidated in coal and natural gas power stations with ~84% of the emissions coming from coal fired plants [AEO2009a]. These two sources of emissions also account for about 70% of the electricity production annually [AEO2009a]. The other 30% comes from sources that emit no or very little GHGs; nuclear at ~20% of total production and renewables including hydro-electric at ~10% of total production being the more prevalent sources [AEO2009c, AEO2009d]. An effective strategy for reducing emissions in this sector must address (1) improved efficiency in consumption of electricity, (2) more emphasis on conservation to reduce electricity consumption, and (3) substituting non-GHG sources of electricity, (e.g., nuclear, renewable sources, clean coal) for coal and natural gas sources of electricity over the next four decades.

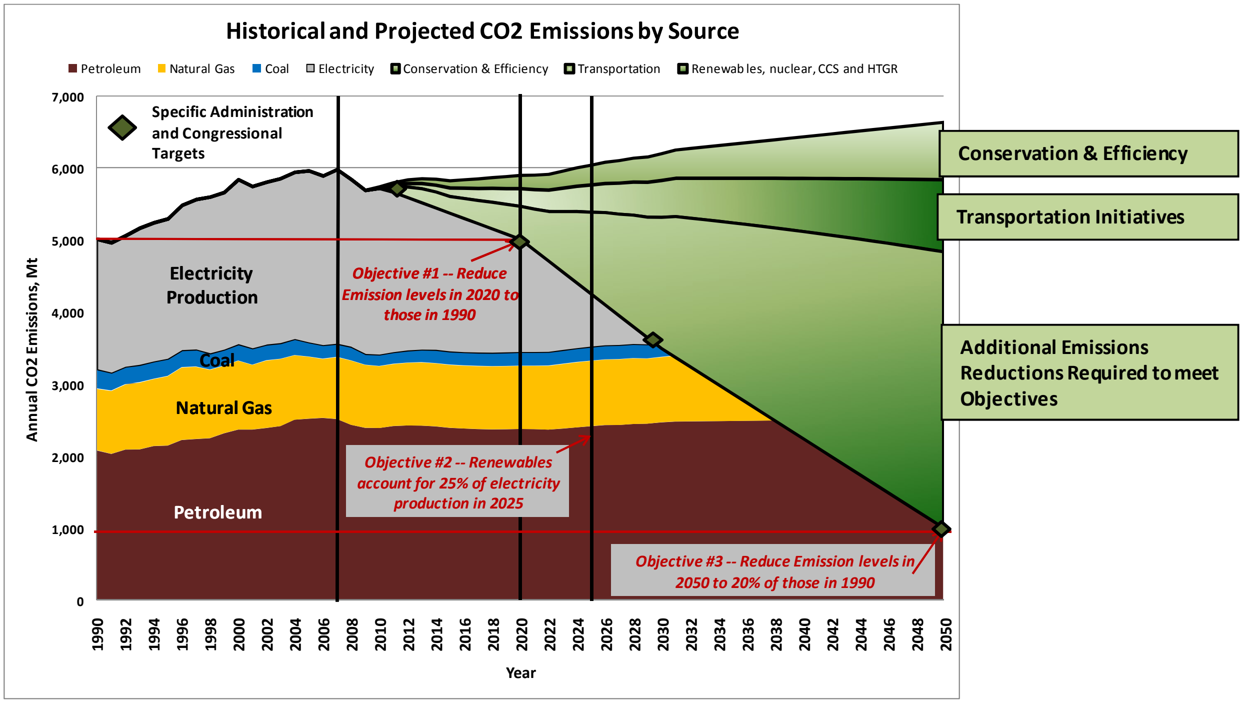

Figure 4-6. Net effect of conservation and efficiency and transportation initiatives on meeting the administration and Congressional objectives for emissions reductions.

As noted previously the 0.28% reduction in the annual growth rate of energy consumption assumed to be achievable through conservation and efficiency improvements includes reduction in electricity demand over the analysis period.

In 2008, hydro-electric accounted for about 7% of the renewable power production of electricity [AEO2009a, DOE2007]. Because most viable sites have been taken, hydro-electric production is not projected to increase materially in the future [DOE2007]. EIA projections for growth of renewable supply of electricity focus on wind as the primary growth area with solar, biomass and geothermal participating at lower rates. However, the growth rate in all renewable sources is projected at only 3.2% annually over the next 20 years [AEO2009c, AEO2009d]. This results in renewable producing ~16% of total electricity production in 2030 including hydro-electric. This does not keep pace with current projections for increasing demand for electricity over the next 20 years. The projections for the growth of nuclear power are even lower (<0.5% annually) and result in a reduction to ~18% of the total production in 2030 [AEO2009a]. Meeting the demand for increasing electricity production is assumed by the EIA to be through modest annual growth rates in coal and natural gas production [AEO2009a].

Clearly these growth rates of the nonemitting sources of electricity will not result in the emissions reductions needed to meet Administration and Congressional objectives. It also does not meet the objective of renewables accounting for 25% of electricity production in 2025. Major changes in the mix of technologies used for production of electricity are required to meet both objectives. These will include increased growth rates in renewable and nuclear power production and the introduction of clean coal power plants using carbon capture and sequestration.

Table 4-4 summarizes the pertinent characteristics of the nonemitting sources of electricity generation that are considered herein to replace coal and natural gas plants to meet emission reduction objectives. The CO_2 offset numbers and capacity factors for electricity production (in billions of kilowatt hour electric, BKwhe) are based on historical and projected EIA data on emissions and electricity production for coal and natural gas plants [AEO2009a]. They are consistent with the attributes described in Table 4-5.

Table 4-4. Characteristics of nonemitting sources of electricity production.

				Annual		
Source	Thermal Rating, Mwt	Elec Rating, Mwe	Cap Factor	Total Annual Electricity Production per Unit, BKWhe	Mt of CO_2 Emissions Avoided by Offsetting Coal Usage	Mt of CO_2 Emissions Avoided by Offsetting NG Usage
Wind[c]	N/A	5	0.4	0.013	0.012	0.005
LWR[d]	3,600	1,200	0.92	9.650	9.352	3.843
HTGR[e]	600	252	0.92	2.027	1.964	0.807
Coal CCS[f]	2,408	800	0.74	5.158	4.999	2.054

Table 4-5. Characteristics of conventional coal and natural gas plants.

Attribute	Average Net Efficiency	Lbs CO_2 emitted/MMBtu
Coal plants	33.3%	213
Natural Gas plants	44.6%	117

Table 4-6 is the source of the capacity factors used for this analysis:

Table 4-6. Summary of capacity factors for electricity production.

Nuclear	91.8%
Coal	73.6%
Natural Gas/Combined Cycle	42.0%[g]
Other Renewables	40.1%
Hydroelectric	36.3%
Petroleum	13.4%
Natural Gas/Other Types	11.4%
Sources: Energy Information Administration, Form EIA-860, "Annual Electric Generator Report;" Form EIA-923, "Power Plant Operations Report."	

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c. For the purposes of this analysis it is assumed that deployment of wind turbines will predominate the application of renewables and that the deployment will include 90% land based and 10% offshore based.

d. Nuclear light water reactor; the capacity factor is representative of the current fleet of 104 reactors.

e. High Temperature Gas Reactor; the capacity factor is assumed to be the same as the LWR.

f. Coal plant with carbon capture and sequestration; the capacity factor is assumed to be the same as current coal plants.

g. This has been the historical capacity factor for natural gas plants because they have been traditionally used in peaking service; not base loaded. If governmental policies result in costs for carbon emissions the use of natural gas plants for base loaded service will increase. Under those circumstances a capacity factor of 85% is assumed. [King 2008]

Note that the capacity factor for Other Renewables includes the composite for wind, solar, wood and wood products, biomass and geothermal. The capacity factors for the individual components vary considerably. The average capacity factor used for analysis of renewable production is 40%. This is the capacity factor cited by AEO2009 for the 2008 mix of renewable energy sources.

4.4 Renewable Electricity Production

4.4.1 Renewable Production to 2025

The growth rate of renewable capacity on the grid will need to increase significantly to meet the Administration objectives for renewable production accounting for 25% of total production, including hydro-electric, by 2025. As shown above in the discussion on Objective #2, this requires an increase of 535 billion kilowatt hours of renewable production over that projected by [, AEO2009c, AEO2009d] for 2025.

For the purposes of this analysis the following will be assumed:

- The current EIA projected growth rate for renewable production over the period 2010 through 2025 (~3.4% annually) will need to almost double to ~6.5% annually to achieve the objective of 25% of total production by renewable in 2025 (See Figure 4-7). As shown in the figure the rate of increase in renewable generation predicted by the EIA over the next two years would need to be sustained through 2025 to meet the Administration Objective #2. It is understood that the Congressional Bills have provisions that make reductions in consumption equivalent to an increase in renewable production. The EPA assessment of HR2454 [EPA2009a, EPA2009b] predicts a very modest increase in renewable electricity production over this period because of the predictions in reduced consumption described in a preceding section. For the purposes of the analyses herein, however, both reductions in consumption & efficiency and increases in renewable electricity production in accordance with Objective #2 will be accounted for.

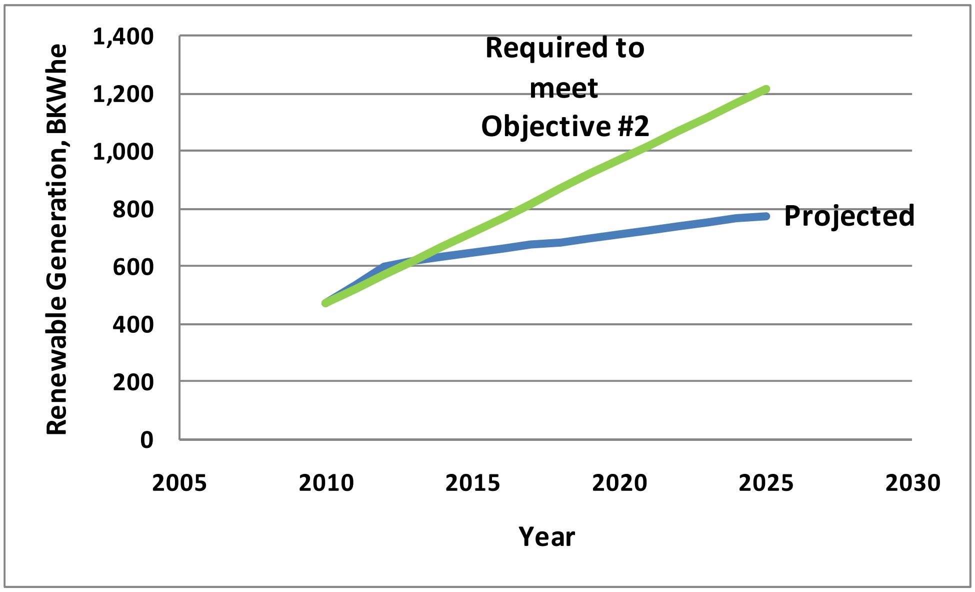


Figure 4-7. Growth in renewable electricity production required to meet Objective #2 compared with AEO2009a projections of renewable generation growth.

Table 4-7 summarizes the share of renewable electricity production predicted by EIA in 2010 and 2025. As shown in the table, EIA predicts that renewable electricity generation includes hydro, wind and other technologies such as solar, biomass, geothermal. In this mix wind and biomass are predicted to provide a significant share of generation in 2025 with biomass predicted to have approximately the same share of generation as wind. The other technologies other than hydro do not have a significant share. It is noted that the specific generation by hydro is not predicted to increase significantly 2010 to 2025 so its share of generation in 2025 is reduced. This is attributed to a lack of new technically and economically viable sites for new hydro plants.

From an electricity generation perspective biomass is not currently a large source. Biomass is described as an emissions neutral source of energy for electricity production. However, recent evaluations [Searchinger2009] show that the premise that biomass is emissions neutral may not be correct.

Table 4-7. Summary of renewable electricity generation by technology in 2010 and 2025.

	2010		2025	
Renewable Generation Technology	Generation BKWhe	% of Total	Generation BKWhe	% of Total
Conventional Hydropower	270	57.8%	299	38.8%
Geothermal	18	3.8%	22	2.8%
Biogenic Municipal Waste	22	4.8%	24	3.2%
Wood and Other Biomass	41	8.8%	197	25.5%
Solar Thermal	0.99	0.2%	2	0.3%
Solar Photovoltaic 5/	3	0.7%	19	2.5%
Wind	112	24.0%	207	26.8%
Offshore Wind	0.00	0.0%	0.75	0.1%
Total	468		771	
[AEO2009d Table 10.1 Renewable Energy Generation by Fuel]				

It is not possible to identify with any certainty what strategy or technology will prevail in adding renewable generation. However, the majority of renewable additions over the last decade in the United States have been in wind turbines. More information is also currently available on the capacity factors, size and costs for construction and operation of wind turbines than for other renewables. As noted there is also uncertainty in the environmental benefit of biomass generation. Accordingly, for the purposes of the analyses herein, the increase in renewable generation will be accounted in terms of additions of wind turbines. Use of wind as a surrogate for renewable energy growth herein is used simply to illustrate the magnitude of the effort required in this area to support meeting objectives.

It is assumed that technical advancements in the design of wind turbines will result in an average power rating per turbine of 5 MWe. The current average size of commercial wind turbines is in the range of 1 to 2 MWe with 3 MWe turbines likely available in the next generation. The actual size of the wind turbines that will be available over the next 15 years cannot be predicted with reasonable certainty. The only use of this assumed size of turbines is in assessing how many would be required to meet the objectives. Clearly the actual number of turbines and their size will be diverse over the next four decades. This does not affect the conclusions, however, on the total capacity additions that will be required to meet the emissions reductions objectives no matter what the technology.

For emission offset purposes it will be assumed that the increase in renewable generation offsets the equivalent amount of generation from conventional coal plants rather than from natural gas fueled plants.

This is the most likely outcome since experience has shown that some cycleable backup capacity is required on the grid to accommodate the fluctuating nature of renewable generation, particularly wind turbine generation [Parsons2008, IEA2009, Benitez2007, FERC2005]. Natural gas combustion turbines are better suited for this purpose than coal plants. The current prices for natural gas also make them competitive with coal plants [DOE2009d].

The average capacity factor used for analysis of renewable production is 40%. This is the capacity factor cited by AEO2009 for the 2008 mix of renewable energy sources, [Table 4, AEO2009c].

At this average capacity factor the required growth rate requires the addition of about 125 Gwe of renewable capacity over the next 15 years or ~8,300 Mwe per year above the 65% increase in renewable capacity projected by DOE-EIA (771 BKWhe in 2025 versus 468 BKWhe renewable production in 2010; an increase of 90 GWe capacity at a capacity factor of 40%). At 5 MWe per turbine this is equivalent to adding ~25,000 wind turbines over the next 15 years. About 8,900 MWe of wind turbine capacity was added in 2008 due to favorable governmental tax and production credits. The projections for 2009 are lower due to expiration of these credits. Some form of government incentives will be necessary to achieve the growth rates in all forms of renewable power needed.

This increase in renewable power on the grid results in avoiding ~426 Mt of CO_2 emissions annually in 2025; assuming the renewable power offsets the equivalent amount of coal based power.

4.4.2 Renewable Production Through 2050

It is assumed that renewable generation is maintained at 25% of total generation through the end of the analyses in 2050.

It is assumed that the percentage of renewable generation on the grid is limited to this value because of the uncertainty in how much penetration of renewable energy, particularly wind turbines, is acceptable to ensure grid stability and reliability and is economically viable. The latter is of concern because of the relative low capacity factor achieved with wind turbines in certain areas of the country.

NREL/CP-500-43540 [Parsons2008] summarizes the results of 18 case studies on the costs of wind integration internationally under a National Renewable Energy Laboratory (NREL) contract. This summary concluded, in part, that:

> "The capacity value of wind power can be up to 40% of installed capacity if wind power production at the times of high load is high, and down to 5% in higher penetrations and if local wind characteristics correlate negatively with the system load profile." In other words the viability of wind as an economic and reliable source of power is very sensitive to location and power demand profile.
>
> "Integration costs of wind power need to be compared to something meaningful, like production costs or market value of wind power, or integration costs of other production forms. There is also benefit when adding wind power to power systems; it reduces the total operating costs and emissions as wind replaces fossil fuels." [Note that the latter part of this statement on operating costs is contradictory to a previous conclusion that "From the investigated studies, system operating cost increases amounted to about 1 to 4 euros/Mwh"]. The study also concluded that "the cost of grid reinforcements due to wind power is dependent on where the wind power plants are located relative to load and grid infrastructure. The grid reinforcement costs from investigated studies varied from 35 to 160 euros/Kw [of installed capacity]."

Finally, the study concluded that “For high penetration levels of wind power, optimization of the integrated system should be explored. Modifications to system configuration and operational practices to accommodate high wind penetration may be required. For high penetration, there will be need for increased generation flexibility, transmission to neighboring areas, demand side management, or storage, (e.g., pumped hydro, thermal, or batteries of electric cars).”

Benitez, et.al. [Benitez2007] studied the addition of wind power at two different sites to the Alberta, Canada grid and concluded:

> When wind power is added to an electrical grid consisting of thermal and hydropower plants, it increases system variability and results in a need for additional peak-load, gas-fired generators. [This cost needs to be included in the evaluation of the economics of the application.]

There are several studies on the combination of compressed air storage with wind turbines to provide a means for smoothing out production. These use a combination of wind power to compress and store air which is then released and heated in a conventional gas turbine to produce electrical power. It appears that the benefit of this arrangement is a lessening of the natural gas required for the combustion turbine, reducing emissions and potentially reducing costs, depending on the cost of natural gas [IOWA 2006, WIKI2010].

The evaluation performed in this paper does not attempt to address these issues or quantify the costs or uncertainties associated with use of renewable for high percentages of electricity production

Table 4-8 summarizes the build out required in renewable energy supplies over the next four decades and the impact on emission reductions and the percent of electricity production by renewable required to meet the Objective #2 that 25% of total electricity production in 2025 be by renewable technologies. Figure 4-8 shows the annual reductions in emissions for this build out.

The required increase in the on-line renewable power generation is significant. Whether this rate of growth is achievable or desirable, particularly for the higher penetration considering the potential for unsuitable influence on the electric grid and the cost impact on electrical power, depends on the overall strategy, incentives and provisions of the government program for emissions reductions. Such growth in the renewable energy penetration would require significant increases in the industries supporting equipment manufacture, installation and operation and in the transmissions and grid control systems. The latter will be necessary to move the power from the locations best suited for production, (e.g., high and sustained wind locations) to the consumers. The analyses herein have not attempted to scope the costs of these electric power transmission and distribution infrastructure upgrades.

Table 4-8. Summary of the renewable initiative.

Energy Initiative	**Renewable Initiative**				
	2010	**2020**	**2025**	**2030**	**2050**
EIA Projected Generation, BKWhe	468	708	771	797	903
Delta Generation, BKWhe	0	255	439	466	572
Revised Production, BKWhe	468	963	1210	1264	1474
% of Total Production	11.2%	21.1%	25.0%	25.0%	25.0%
Delta Capacity, Gwe	0	73	125	133	163
Number of Plants (5 Mwe/plant)	0	14,564	25,069	26,612	32,623
Delta Avoided Emissions, Mt	0	247	426	452	554
EIA Data and Projections Table 85 AEO2009a April update extrapolated to 2050 using linear correlations					

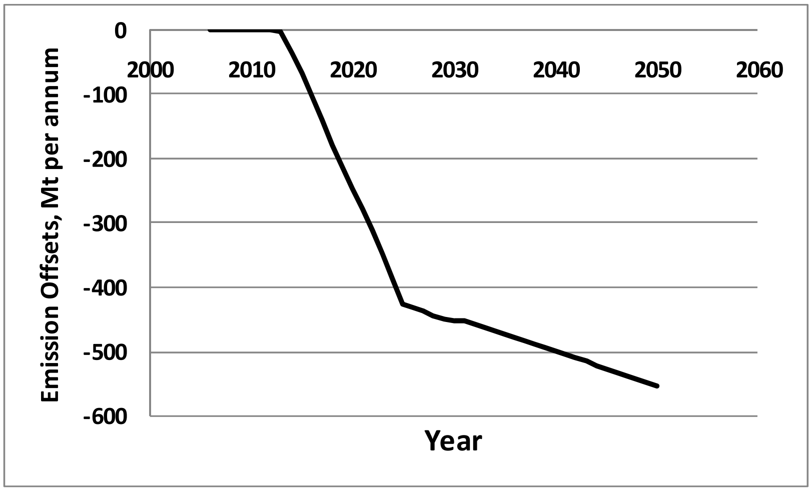


Figure 4-8. Emissions avoided by replacing coal generated electricity with renewable technologies.

The combination of Conservation & Efficiency, Transportation initiatives and the Renewable scenarios through 2050 result in subtotal reductions in annual emission rates as shown in Table 4-9.

Table 4-9. Total avoided annual emissions in 2050 for transportation and renewable sectors.

Sector	Avoided Annual Emissions in 2050	Sub Totals by Scenario	Balance to 5,640 Mt Reduction
Conservation & Efficiency	800	800	4,840
Transportation	1000	1,800	3,840
Renewable Additions	560	2,340	3,280

The balance can be made up by a combination of advanced LWR nuclear plants (ALWR), High Temperature Gas Reactor (HTGR) plants and Coal plants with carbon capture and sequestration (Coal CCS) as summarized in the following sections.

Figure 4-9 shows the combined impact of Conservation & Efficiency, the Transportation Sector initiatives and the Renewable Energy Sector initiatives as increments to achieving Objective #1 emissions by 2020 and achieving Objective #2 (25% of total electricity production by renewables in 2025). Note that this figure only extends to 2025 (not to 2050) to emphasize the 2025 renewable objective.

As seen on this figure the combination of Conservation & Efficiency, the Transportation initiatives and Renewable Energy sector initiatives are not sufficient to meet the required emission reductions of Objective #1, reducing projected emissions in 2020 to 1990 levels. It is also not considered reasonable to increase the rates of growth in these sectors beyond the levels already assumed. The balance of the required emission reductions (~235 Mt in 2020) are assumed to come from increasing the growth of electric power generation using advanced light water nuclear reactor technology.

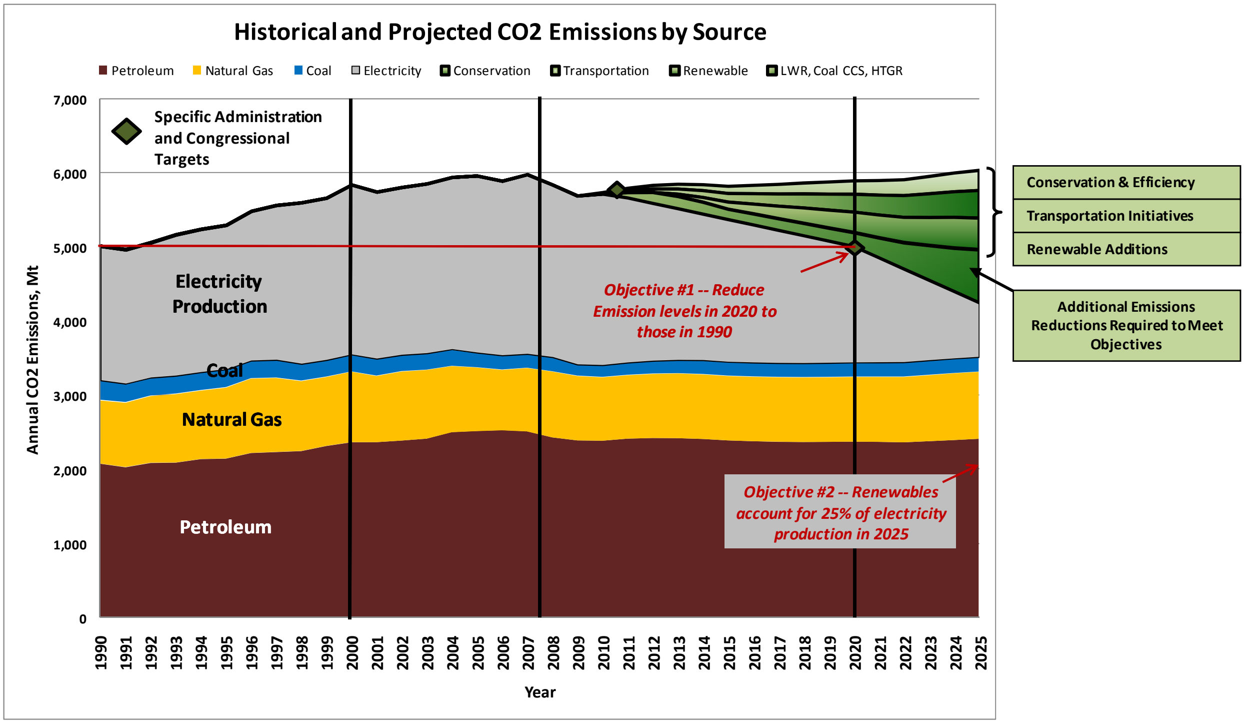


Figure 4-9. Impact of conservation, transportation and renewable initiatives on meeting emissions Objective #1 and renewable production Objective #2.

4.5 Electricity Production using Nuclear Power through 2020

Advanced nuclear plant technology is available and can begin to be deployed with construction started in 2010 or 2011 with the required incentives. The incentives require executing the licensing and financing incentives that were initiated in the government's [NP2010, EPACT2005] programs. These incentives protect the initial installations of the advanced nuclear technology from significant delays due to the licensing process, (so-called standby support) and provide financial guarantees, (e.g., loan guarantees, construction and production tax incentives) that will provide sources of financing for these projects and covering the initial startup costs. Much of the licensing for the advanced nuclear plant designs has been completed as part of the design certification process initiated in these programs. Several utilities have selected sites and designs for new installations. As of December 31, 2008 there were 31 applications for licenses by the NRC [DOE2008]. Once the licenses are granted government support will be required to initiate deployment.

To achieve the total emissions reductions of Objective #1 an additional ~235 Mt annual emission reduction is required in 2020. Table 4-4 and Table 4-6 summarize characteristics of the several technologies that are used in the United States for the production of electricity that are used in this paper to develop the strategy for substituting non-GHG emitting sources of electricity for current GHG emitting sources, (e.g., replacing a coal based plant with wind turbines as described in the preceding section). Using the data in this table a reference advanced light water reactor (ALWR) can offset ~9.4Mt of annual CO_2 emissions from the reference coal fired plant and ~3.8 Mt from the reference natural gas plant. Assuming that the addition of nuclear capacity results in retirement of 75% of the equivalent coal production and 25% of the equivalent natural gas production, one nuclear plant will offset ~8 Mt of CO_2 emissions annually. Accordingly, 30 new nuclear plants will need to be built by 2020 or ~3 per year to achieve the emissions reductions required to meet Objective #1.

It is judged that if the incentives summarized above are provided in 2010 by the government for the first few plants, this build out rate is reasonable. As noted there are currently 31 license applications pending for advanced nuclear plants. To also put this build rate in perspective it is informative to examine the current activity in building nuclear plants internationally. China currently has 24 LWR nuclear plants in some phase of construction and commissioning. Several nuclear power plants are being built in Russia, India and Finland. The build out rate of 30 new nuclear plants over the next ten years is, therefore, not unprecedented.

Accordingly, the balance of the deficit in emission reductions in 2020 shown in Figure 4-9 above is assumed to be made up by deployment of these additional nuclear plants over the next ten years.

4.6 Use of Nuclear Energy in the Industrial and Commercial Sectors

The industrial and commercial sectors burn significant quantities of gas, (e.g., natural gas) in crude oil refining, petro-chemical processes, fertilizer production, etc. and for the generation of steam, electricity and hydrogen. The combustion of gases is the primary source of the emissions from this sector and in combination with the residential sector account for ~34% of energy consumption. Not only does combustion of natural gas add to the carbon footprint of the processes but the price of natural gas has fluctuated widely over the last several years adding uncertainty to the cost of the processes. Additionally, natural gas has benefit as a feedstock, (e.g., in petro-chemical processing). Using the gas as an energy source is a poor use of this limited resource.

The high temperature gas reactor (HTGR) is a non-GHG emitting alternative to the burning of natural gas and other fossil fuels in industrial and commercial processes. The DOE initiated the Next Generation Nuclear Plant Project (NGNP) in FY-06 as an outcome of the 2005 Energy Policy Act. This Project has the objective of commercializing the HTGR technology. The HTGR is a helium cooled, graphite moderated reactor that can operate at temperatures up to 950°C. Because it operates at a much higher temperature than an LWR (typically operating temperatures of a light water reactor (LWR) are in the range of 300°C) it can be used in commercial applications other than for generation of electricity; the principal application of LWRs to-date. These applications include supplying process heat and energy in the forms of steam, electricity and high temperature gas to a wide variety of industrial processes including, for example, petro-chemical and chemical processing, fertilizer production, and crude oil refining. In addition to supplying process heat and energy the HTGR can be used to produce hydrogen and oxygen which can be used in combination with steam and electricity from the HTGR plant to produce, for example, synthetic transportation fuels, chemical feedstock, ammonia, from coal and natural gas. Studies performed to the date of this writing and discussions with potential end users have investigated the characteristics of the HTGR that best fit these applications. [NGNP2007, NGNP2009] These studies have concluded that reactor module sizes in the range 200 to 600 MWt operating in the temperature range of 700 to 800°C can satisfy most of the energy needs of these applications.

The following discusses assumptions on specific applications of this technology that are judged technically and economically viable for substitution of natural gas firing in Co-generation and Heat Supply processes.

4.6.1 Supplying Process Heat and Energy to Industrial Processes

In most applications supplying heat and energy to an industrial process multiple HTGR modules would be deployed with an average plant at a total rating of 2,000 to 2,400 MWt containing 4 to 10 modules depending on the rating of each module. These plants would be used to supply steam, electricity and hot fluids to the process. Based on the current NGNP schedule the first-of-a-kind (FOAK) commercial module could be operating in 2022. It is anticipated that multiple modules will be deployed in this initial application and, when shown to be successful, in many other similar applications. Based on scoping estimates it is judged that there are 150 refineries, 100 petro-chemical plants, 100+ ammonia and ammonia derivative plants, and many other industrial plants for which the HTGR technology could be used to supply energy needs. [MPR 2008a & b]

The HTGR technology also provides a non-GHG source of energy for extraction and processing of unconventional sources of hydrocarbons such as from the oil sands of Alberta, Canada and from Oil Shale which is prevalent in the United States and Canada. Conventional processes for extraction and processing from these sources use natural gas as the energy source with significant CO_2 emissions. This is a poor use for a limited natural resource. Studies have shown that the HTGR technology is a viable substitute for natural gas firing in these applications technically and economically. Based on this work less than twenty 600 Mwt HTGR modules would be required to supply steam to Steam Assisted Gravity Drainage systems to extract 1 million barrels of bitumen per day from Canadian Oil Sands. [INL 2009b]

Figure 4-10 illustrates the potential end users of this technology and the number of plants available for use. For this study we have assumed that about 250 plants using on average four 600 MWth modules could be deployed in the U.S. within the petro-chemical, petroleum refining, fertilizer/ammonia manufacturing plants and for extraction of nonconventional hydrocarbons from oil shale. These would be used as substitutes for natural gas firing in the production of steam, electricity and heat in the form of hot gas and hydrogen. This would take place in the period 2022 through 2050; requiring the building of about 10 plants per year on average. Substituting this build out of HTGR plants for gas fired plants would avoid ~835 Mt of CO_2 emissions in 2050. (Note this does not include deployment of plants in Canada for extraction and upgrading Bitumen from oil sands.)

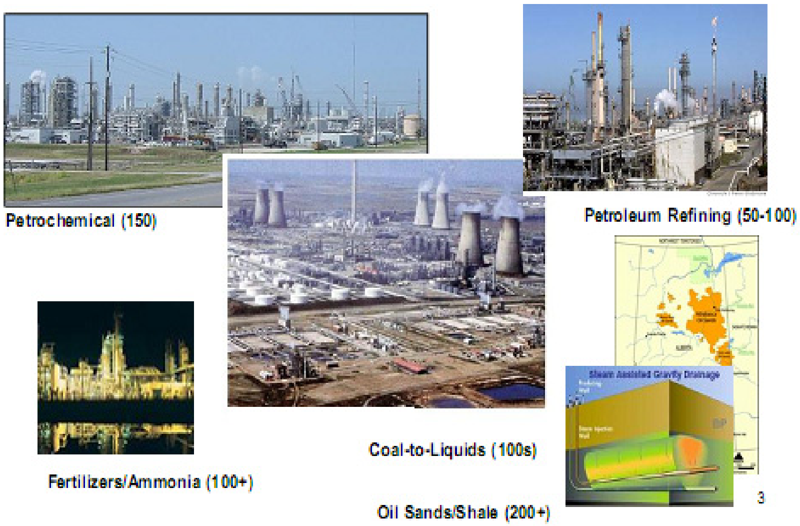
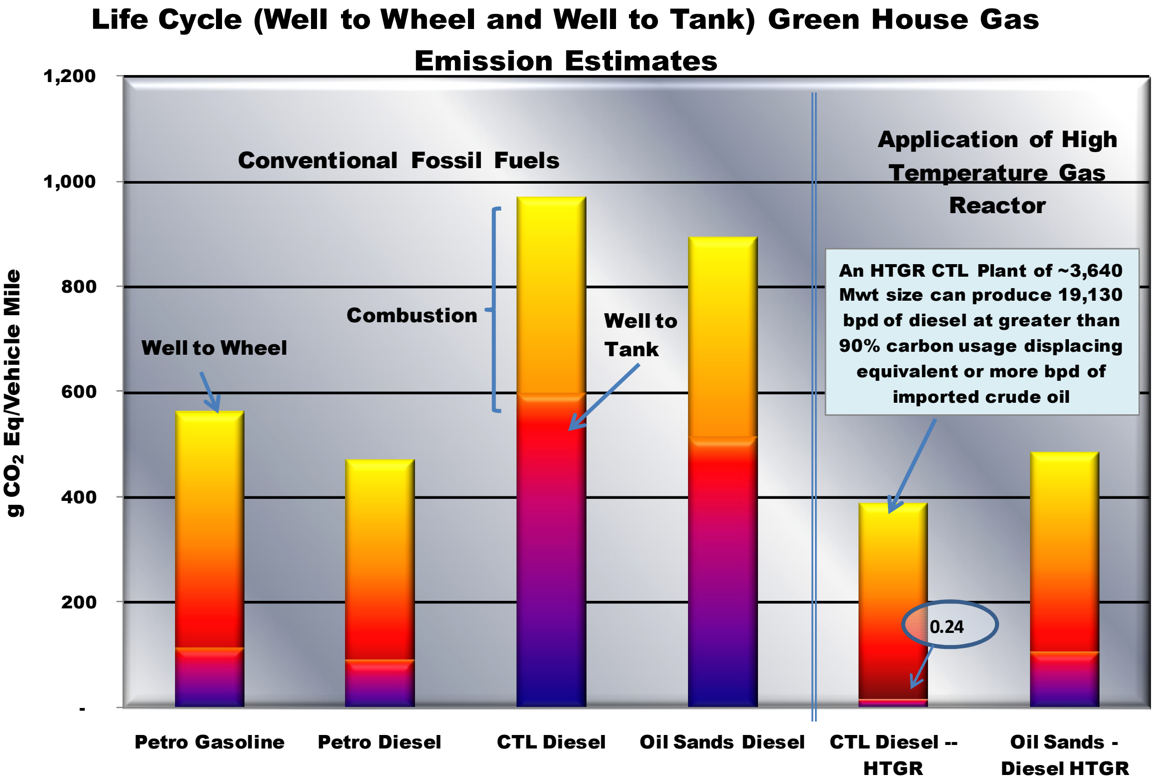


Figure 4-10. Potential end users of HTGR and the number of plants available for use.

4.6.2 Biomass/Coal to Synthetic Liquid Fuels (BTL/CTL)

The HTGR technology is also applicable to production of synthetic hydrocarbons from coal and biomass which can be made into transportation fuels and feedstock, (e.g., for petrochemical plants). These synthetic hydrocarbons are produced using traditional coal and biomass to synthetic fuel processes but with the HTGR supplying the energy, hydrogen and oxygen. Because the HTGR does not emit any CO_2, a process optimized for use of the HTGR energy improves the efficiency of carbon transfer from the coal and biomass to the production fuels from a typical conventional plant conversion rate of ~30% to over 90% resulting in essentially no carbon footprint [INL2009b]. This provides a mechanism for clean production of synthetic fuels from indigenous resources of coal and biomass reducing emissions from refining of crude oil and improving energy security by reducing the need to import crude oil. This is also a long term solution to the production of transportation fuels as the indigenous sources of crude oil are expended [INL2009c].

Figure 4-11 compares the life cycle emissions for transportation fuels derived from traditional refining of crude oil, from conventional coal to liquid (CTL) processes and from oil sands using traditional fossil fuel based technologies with the use of HTGR technology for extraction from oil sands and for coal to liquid processes. As shown, the HTGR technology provides significant benefits in life cycle emissions reductions for these processes. "Well to tank" emission levels using the HTGR technology are several orders of magnitude less than conventional CTL processes and conventional oil sands extractions. (Emissions from combustion of the transportation fuels are similar for conventional and coal to liquid fuels.) This use of HTGR technology in the coal to liquids process also has emission levels several factors lower than those produced by conventional production and refining of crude oil.



Data for processing using conventional fossil fuels was obtained from DOE/NETL -2009/1346, DOE/NETL-2007/1260 & 1298, DOE/NETL-2001, data for the HTGR was developed by INL and contractors for the NGNP Project
Source file "Nuclear-Fuels Hybrid Calculation R04_09_09", Chart Revision 0, 4/9/09

Figure 4-11. Comparison of life-cycle emissions for several processes.

At the time of this writing there is limited production of synthetic fuels from coal and biomass in the U.S although several studies by the DOE NETL [NETL2007a,b,c, NETL2008] and others [Agrawal2007, NATLACAD] have shown the potential benefit in energy security in developing this technology. For this study we are assuming that aggressive action by the government to support development of this technology would result in the building of 24 – 100,000 barrels per day CTL plants[h] (~22—600 MWth HTGR modules per plant) in the 2022 – 2050 time frame; less than one plant per year on average. Governmental action in support of this activity is desirable since, as will be shown below, this activity will not only reduce emissions but will also reduce the need to import crude oil and will utilize our most abundant form of energy, (i.e., coal) more effectively and with essentially no effect on the environment.

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[h] The specific characteristics of the CTL plant used in this study are based on recent INL work on applying the HTGR technology to this type of plant [INL2009b].

4.6.3 Benefits of the Full Deployment of the HTGR Technology

Table 4-10 summarizes the potential build out of HTGRs for both co-generation, oils sands recovery and BTL/CTL synthetic fuel production over the period 2022-2050 and the reductions in annual emissions in 2050 from deployment of these reactors assumed for this study. In 2050 a total of ~920 Mt of CO_2 emissions are avoided per year. Note that the calculation of the reductions in CO_2 emissions for deployed HTGR CTL plants was made in comparison with conventional crude oil refining. In comparison with a conventional CTL plant the reductions would be ~800 Mt per annum instead of 82 Mt per annum.

Table 4-10. Deployment of HTGRs (all numbers are accumulative in time).

HTGR Process Heat & Energy	**2010**	**2020**	**2025**	**2030**	**2040**	**2050**
Number of plants	0	0	35	80	169	258
New Capacity, GWt	0	0	84	192	406	619
Avoided emissions, Mt	0	0	115	259	548	836
HTGR CTL Plants						
Number of Plants	0	0	3	7	16	24
New Capacity, GWt	0	0	40	92	211	317
Avoided emissions, Mt	0	0	11	25	54	82

Clearly an aggressive application of HTGR technology is assumed. The ~250 plants assumed for supplying process heat and energy to industrial processes is not large compared with the number of natural gas fired plants that are currently in service in the US supplying energy to these plants. However, the applications to BTL/CTL would represent a departure from current practice; there is not currently a large use of CTL in the U.S. However, such deployment of these BTL/CTL plants would result in a significant reduction in the need to import oil, make productive use of one of our most abundant forms of energy, (e.g., coal) and provide a market for coal as its use is reduced for the production of electricity.

This level of deployment of HTGR plants will require a consolidated effort to reduce the emissions from burning of natural gas in these processes; to improve the environment and to make this important natural resource available for more productive purposes. Achieving this will require a significant increase in the industrial infrastructure for supply of large vessels, reactor fuel, pumps, valves, piping, the engineering, procurement and construction organizations required to design and build the plants and companies to operate them. As discussed more below, this would increase jobs and provide a solid manufacturing and operating base to the U.S. economy.

Reductions in Imports of Crude Oil

The assumed deployment of the HTGRs in BTL/CTL plants results in a production capacity in 2050 of ~2.4 million BPD of synthetic fuels. This production rate is ~25% of the rate at which the U.S. imported crude oil in 2008 (~9.75 million barrels per day [EIA 2010, Table 11]). The use of this quantity of synthetic fuels to replace crude based gasoline, LPG, diesel and/or naphtha (a feedstock for petro-chemical processes and gasoline production) production would have a large impact on reducing the need to import crude oil. This combined with the reductions in reliance on conventional gasoline and diesel cited in the preceding discussion of the transportation initiative would reduce the need to import crude oil in 2050 significantly, if at all.

Figure 4-12 shows the sum of all of the initiatives through deployment of the HTGR technology relative to meeting the final Objective #3 – Reduce emissions to 20% of 1990 levels in 2050. A balance of ~2370 Mt of CO_2 emission reductions are required to meet the objective. This can be achieved through deployment of a mix of Coal CCS and LWR Advanced Nuclear plants as discussed in the next section.

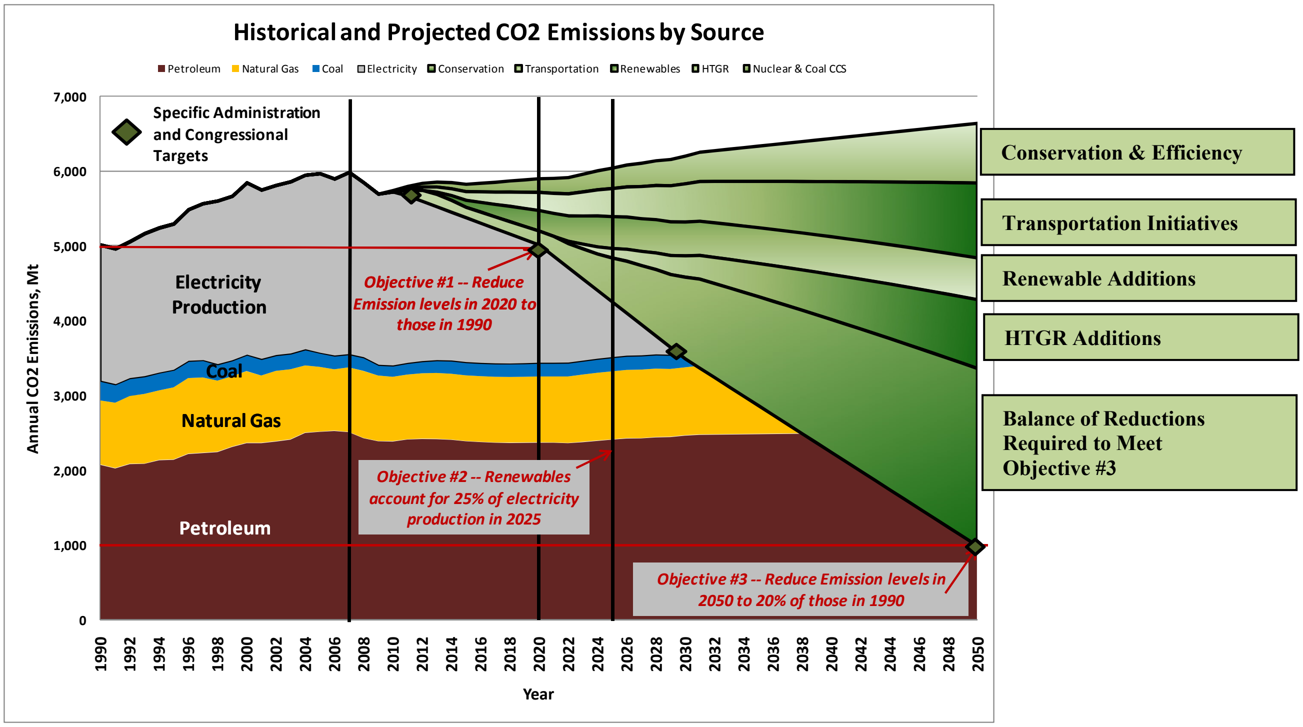

Figure 4-12. Summary of the impact of initiatives through HTGR Deployment on reducing emissions.

4.7 Deployment of Nuclear and Coal CCS Plants Through 2050

4.7.1 Deployment of Coal Plants with Carbon Capture and Sequestration (CCS)

No coal plants with CCS have been deployed as yet at the time of this writing. EPRI [EPRI2008] examined the status of development of these plants and concluded that the earliest one of these would be on-line was in 2020. EPRI stated that there is considerable uncertainty in whether this date would be met so the EPRI analyses were performed assuming the technology would not be available until 2030. For the purposes of this paper it is assumed that these plants will be available by 2020. This will require emphasis on development requiring government support for the initial construction. Provisions for such government support are included in HR2454 and S-1733 bills pending in Congress. Other alternative applications of coal for electricity production, such as oxygen fired plants[i] and Integrated Gasification Combined Cycle (IGCC) plants may also be available.

It is assumed that ~4.5% of the electricity production in 2050 will be satisfied by deployment of some form of lower emitting coal plants such as Coal CCS plants with the characteristics summarized in Table 4-4. This relative low level of deployment reflects the uncertainty in the technical and economic viability of these alternatives. The following table summarizes the results for deployment of Coal CCS plants for this assumption.

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[i] A significant amount of oxygen is produced in nuclear hydrogen production plants that could be used to supply an oxygen fired coal plant if contiguous location of these plants was practical.

Table 4-11. Deployment of Coal CCS plants.

Energy Initiative	Renewable Scenario 2				
	2016	2020	2025	2030	2050
% of Production	0.0%	0.7%	1.5%	2.3%	4.5%
Delta Production, Bkwhe	0	31	72	119	268
Projected Total Prod, Bkwhe	0	31	72	119	268
Delta Capacity, Mwe	0	4,800	11,200	18,400	41,600
Number of Plant	0	6	14	23	52
Delta avoided emissions	0	(35)	(73)	(117)	(262)

The ~260 Mt of emissions avoided through deployment of these plants obtains a balance of ~2100 Mt that will be achieved through deployment of additional ALWRs

4.7.2 Deployment of Additional Advanced Light Water Reactors

Table 4-12 summarizes the required deployment of Advanced Light Water Reactors (ALWR) to meet both Objective #1 in 2020 and #3 in 2050. This shows that an addition of ~300 GWe of nuclear power is required to that projected to be in place by the EIA in 2050.

Table 4-12. Deployment of LWRs.

Energy Initiative	Year				
	2016	2020	2025	2030	2050
% of Production	23%	23%	31%	40%	58%
Delta Production, Bkwhe	164	174	598	1,129	2,461
Projected Total Prod, Bkwhe	997	1,050	1,480	2,019	3,417
Delta Capacity, Mwe	20,400	21,600	74,400	140,400	306,000
Number of Plant	17	18	62	117	255
Delta avoided emissions	(147)	(151)	(513)	(972)	(2,105)

The substitutions of Renewable, Nuclear ALWR and Coal CCS plants for coal and natural gas plants on the grid over the period 2010 – 2050 assumed in this paper results in ~12% of the electricity production projected for 2050 using conventional coal (~2%) and conventional natural gas (~10%) plants. As stated in the preceding discussion on renewable electricity production, it is judged that some fossil based cycleable electricity production capacity will be necessary to stabilize the grid with the 25% of production using renewable technologies required to meet Objective #2. There is not sufficient experience nor analysis available at the time of this writing on the effect of this much renewable production on grid stability. The 12% of fossil power that is retained on the grid in 2050 will accommodate fluctuations in availability at a little less than half of the total renewable production assumed. (Note that about 5% of this renewable production is hydro-based. This leaves about 20% that has a fluctuating power characteristic. The hydro-based power can also be cycled to assist in stabilizing the grid.) Over the next several decades as more renewable comes on line and as the coal and natural gas plants are retired and replaced with nuclear and coal CCS plants the requirements for cycleable power generation will become evident and the mix of power technologies adjusted to ensure that the grid remains stable.

The build out of ALWR plants assumed herein is significantly greater than that projected by EIA; (increases as a percent of total production about 2 times current EIA projections). On economic and emission reduction bases, substitution of ALWRs for conventional coal and natural gas fired electric power production plants is the most cost-effective of the other nonemitting alternatives (see Table 5-2). The assumption is equivalent to a three-fold increase in the number of LWR plants on-line over the next four decades with a total of ~350 plants. Note there are currently 104 commercial nuclear plants operating in the United States. This build out is judged to be achievable considering the first deployment of almost 125 plants in the first couple of decades of deploying the current fleet of plants and the advancement in technology for design, construction and operation of the current ALWRs. As noted previously there are over 30 plants in the early process of getting a license to construct and operate in the United States. What is required is completing the government commitment to support the licensing and construction of the first few plants under the NP2010 and EPAct 2005 programs to demonstrate the viability of this power production alternative. [As this paper was being finalized the government announced issue of loan guarantees for two nuclear plants as part of these programs.] This build out of LWRs will also re-vitalize the industries that support design, construction and operation of these plants adding jobs and strengthening the manufacturing sector of the U.S. economy.

4.7.3 Final State to Meet Emission Objectives

Figure 4-13 summarizes the complete deployment of actions to address the Administration and Congressional emissions reduction initiatives for the two Renewable Energy Addition scenarios.

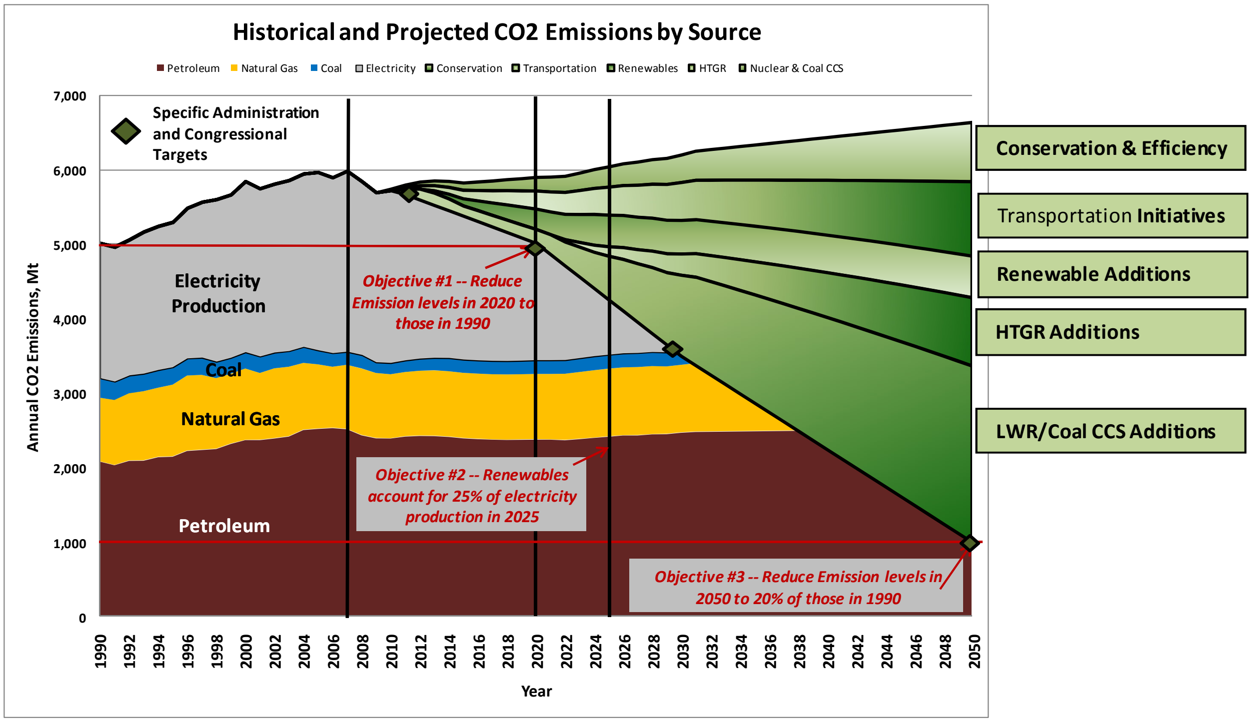


Figure 4-13. Summary of the impact of all initiatives on reducing emissions.

4.8 Additional Considerations

4.8.1 Infrastructure, Supply of Engineering, Materials and Equipment

This report has focused on estimating the contributions of the various ways that CO_2 emissions can be reduced and in the process of reducing emissions how these changes can improve energy security, reduce price volatility and provide more efficient use of limited natural resources. Naturally, though, there will be additional consequences of these changes at the scale proposed. Some of them are reviewed here.

The preceding chapters have discussed the various kinds of energy facilities required under this report's scenarios for the future. Not included is the support infrastructure for designing, constructing and operating those plants. Also not included for renewable energy are the power transmission lines needed to carry electricity from areas with good wind resources, solar potential or geothermal deposits to where the demand is. It will also be necessary to install pipelines to move synthetic fuels from coal-to-liquids plants, and other pipelines to carry captured carbon dioxide to ultimate sequestration sites. In addition, the bridges, highways, and railroads serving new power plant sites must be sufficient both to support the weight of units transported in as well as have sufficient capacity that delivery of components or construction materials can be done without creating delays for all traffic on the roads or railroads.

Achieving the objectives of the Administration and Congress for CO_2 emissions reductions will require significant capital investment for design and construction work over the next four decades. Because the general types of systems to be built will be known well before their construction is committed, there is a great opportunity for a concerted program of research and development in manufacturing and construction to facilitate this construction, speeding its completion and holding down the overall costs. For example, an effort to improve the materials and practices used for large construction projects or to improve the factory-based manufacturing of wind turbines, composite-based vehicles, or components of carbon-capture systems could lead to large cost savings in the next 40 years.

Designing and building these facilities will require a large number of engineers of many types. A study on the manpower needs implied by the facilities discussed in this report would allow universities to plan for their education. A federally funded program of manufacturing and construction R&D (which would tend to flow into many engineering departments) would assure that the faculties are available to teach these new engineers.

It is judged the required increases in engineering, manufacturing, equipment supply, construction and plant operating infrastructure to meet the emissions reduction objectives will need to be U.S. based to ensure availability of the necessary equipment, materials and resources necessary to complete this work. Similar build-outs will be taking place internationally as the economies and needs for additional power demands are met in the major developing countries, (e.g., China, India). This international build out will not necessarily include emissions reduction objectives but will take resources from the build out effort in the United States. This possibility presents an opportunity for the United States to use the resourcefulness it has demonstrated in the past to develop and implement viable solutions to major problems such as material supply, (e.g., developing and substituting composite materials for scarce metals), engineering, (e.g., improving designs to use modular construction, promote easier and more efficient operation), and fabrication, manufacturing and construction methods to reduce time and cost for constructing the plant. As shown below the total costs estimated for the completion of these initiatives are a reasonable fraction of the U.S. GDP so will add significant numbers of jobs and stimulation to the production sector of the economy. About 8 million man years of effort is estimated required to complete the infrastructure changes over the 40 year period of this strategy. On average this would require an additional labor force over the 40 year period of about 200,000. About 350,000 permanent jobs would also be developed in the production portion of the revised energy infrastructure. An additional several hundred thousand jobs would be required to support continued operation, maintenance and upgrade of the revised energy infrastructure.

The United States has the capabilities and has shown the ability to address these needs with innovation and economy. Consistent and focused attention to addressing these needs domestically could make the United States a principal competitive supplier of the technologies, engineering, equipment and construction methodologies internationally. Such an effort could spread to and reinvigorate the broader manufacturing industry in the United States potentially promoting a material shift toward a production oriented economy in the United States away from the services economy that has dominated the last few decades.

4.8.2 Capital Markets

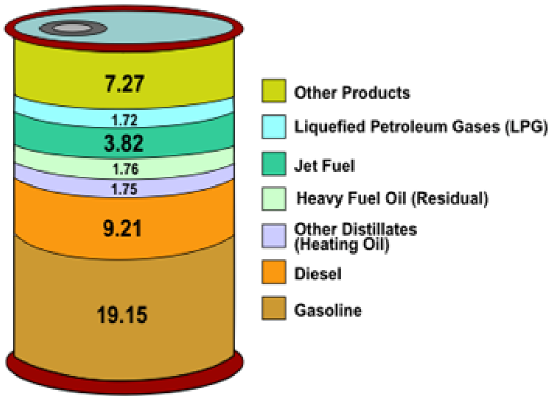
Completion of any strategy to realize the objectives of this energy infrastructure transformation will require substantial capital investment. The government will need to institute programs with the objective of transforming the energy infrastructure, likely with the focus of reducing emitting technologies in the United States, and provide tax incentives and loan guarantees across the full range of energy production and consumption sectors to ensure the availability of the needed capital. The government support, however, will not be sufficient for the long term if the strategies are not economically viable. The investors and the owner/operators must achieve acceptable returns on capital or the capital markets will dry up. The investment will be from the private sector, but will require substantial government support to ensure the availability of capital. A following section discusses the estimated cost for implementation of the strategies evaluated herein and the expected effect on the cost of energy when implemented.

4.8.3 Stabilizing Energy Costs

Full implementation of this strategy will promote stability in the cost of energy by transferring the sources of energy from imports to indigenous resources and by insulating the prices of energy from the large fluctuations in the prices of crude oil and natural gas that have characterized these dominant sources of the U.S. energy portfolio. This stability will come with an increase in the overall average price of energy. However, the stability in prices will support better predictions of industrial, commercial and residential energy costs supporting a more stable economy. A following section provides an estimate of the average increase in energy costs for the energy transformation scenario evaluated.

4.8.4 Reductions in Crude Oil Imports Improves Energy Security and Energy Price Stability

As noted in the discussions of the Transportation Sector initiatives and HTGR application to clean production of synthetic transportation fuels, a benefit of these proposed changes is the reduction in imported petroleum. In 2050 the Transportation Initiatives would reduce gasoline consumption by ~4.8 million barrels per day from that currently projected by DOE-EIA or ~50 % of total gasoline consumption in 2009. The Synthetic fuels production using HTGR would produce an additional 2.4 million barrels per day (bpd) of synthetic fuels; ~25% of the crude oil imported in 2008. As shown in the figure from the EIA [DOE2008], a typical 42 gallon barrel of crude oil produces 9.21 gallons of diesel and 19.15 gallons of gasoline. Synthetic fuels could also be used for heating oil and jet fuel. Accordingly, the reductions in gasoline consumption and the significant production of synthetic fuels using the



HTGR would have impact on reducing the United States import of crude oil. To put this in perspective, the EIA predicts for 2030 that the United States will produce 10.06 million barrels per day of conventional and 2.43 million bpd of unconventional (biomass, oil sands, oil shale, etc) crude oil or crude oil equivalent against a consumption of 20.92 million bpd, for a net import of 8.43 million bpd. The ~7.2 million bpd of reduction in consumption of gasoline and diesel in 2050 could more than eliminate imports and the consequent concerns about security of supply. The reduction in imports would also support more stability in the price of transportation fuels since the cost of coal used for synthetic fuel production has been relatively steady for decades. This would provide a market for coal that is no longer in use to produce electricity as a result of the Electricity Energy sector initiatives for replacing coal fired plants with non-GHG emitting plants.

5. COSTS

5.1 Capital Expenditures

A rough order of magnitude estimate of the costs for implementation of the emissions reduction initiatives was made using cost data from [AEO2009e, NEI2009, NGNP2007]. This cost data is summarized in Table 5-1. The data for the existing coal and conventional combined cycle plants are representative of average costs for these plants.

The construction costs for new plants, (e.g., coal w/CCS, Advanced Nuclear, Wind (land based 90% and off-shore 10%), and HTGR) were applied to the number of plants estimated to be required to meet the Administration and Congressional objectives for each renewable scenario. Figure 5-1 shows the estimated accumulative investment required for the strategies developed herein. The estimates are in \$2007 consistent with Table 5-2. Note that these cost estimates do not include any costs for the transportation initiatives nor for the infrastructure costs discussed in the preceding section. The infrastructure costs will add several billion dollars to the cost estimates.

The total required expenditures will be about \$3.85 T, and the expenditure by year will be ~ \$100B per annum, which is about 0.5% of the GDP projected by DOE-EIA for 2030 [AEO2009a], (~\$20,000B in \$2000). As noted in the prior section sustaining this expenditure rate will require that the investment provide a market return. This will result in an increase in the cost of energy as these investments are made. The next section estimates the increase for each scenario.

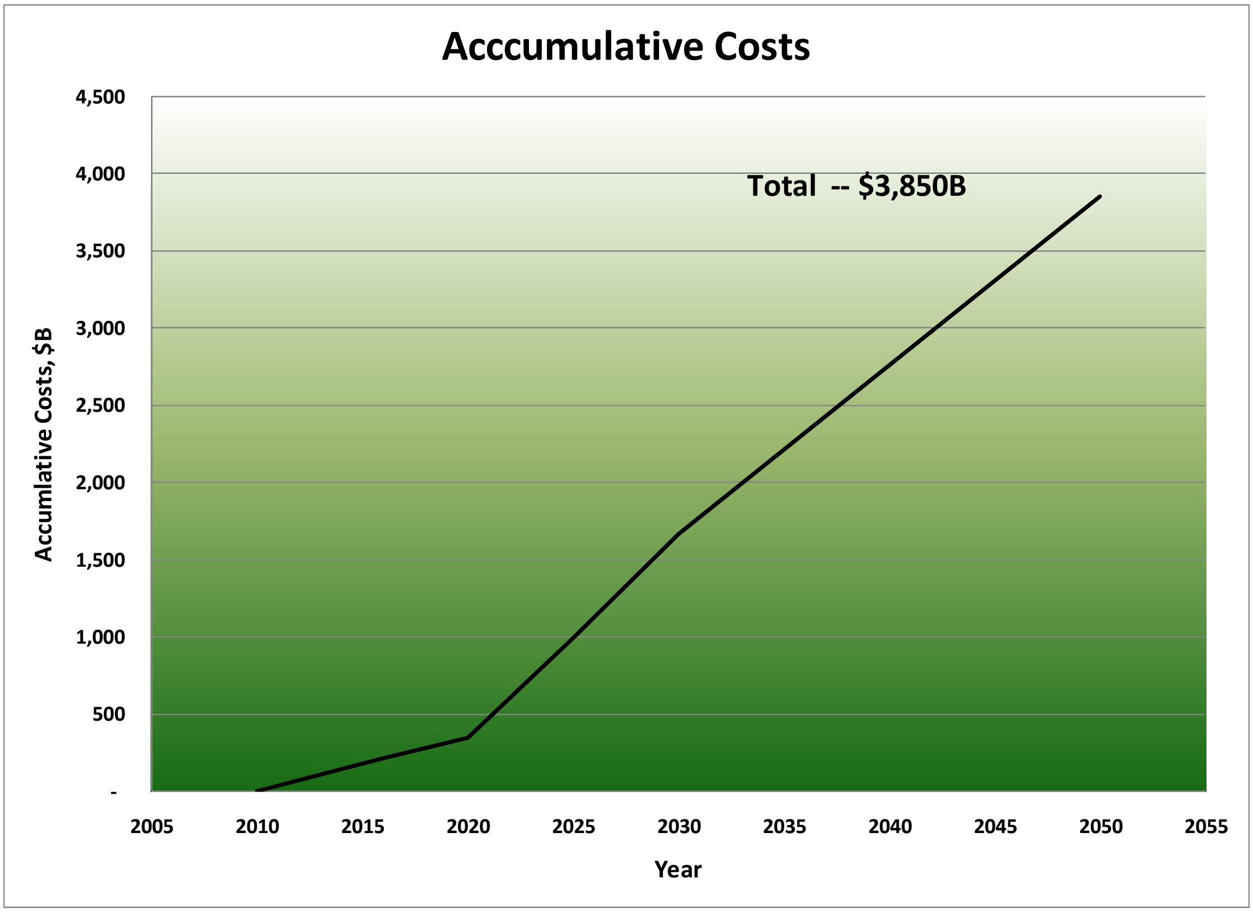
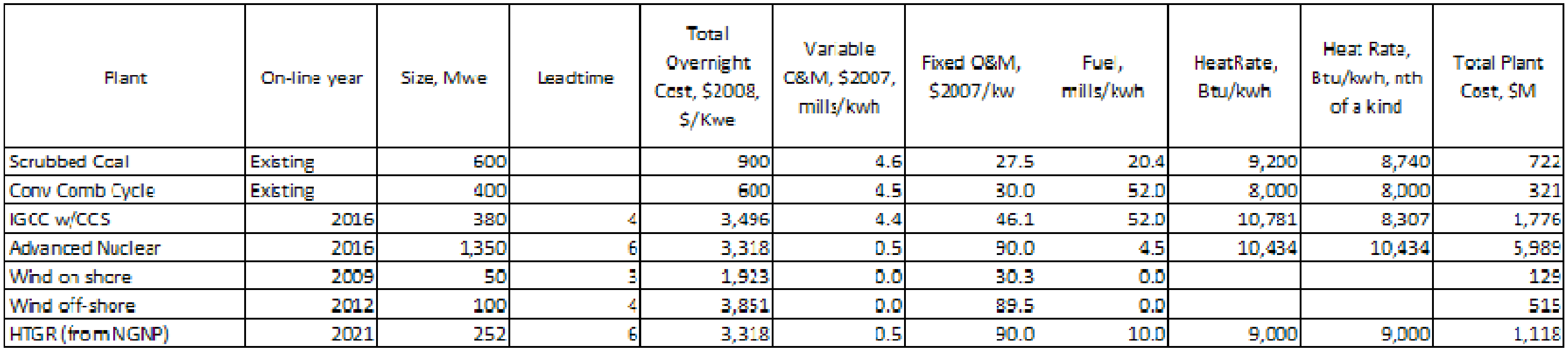


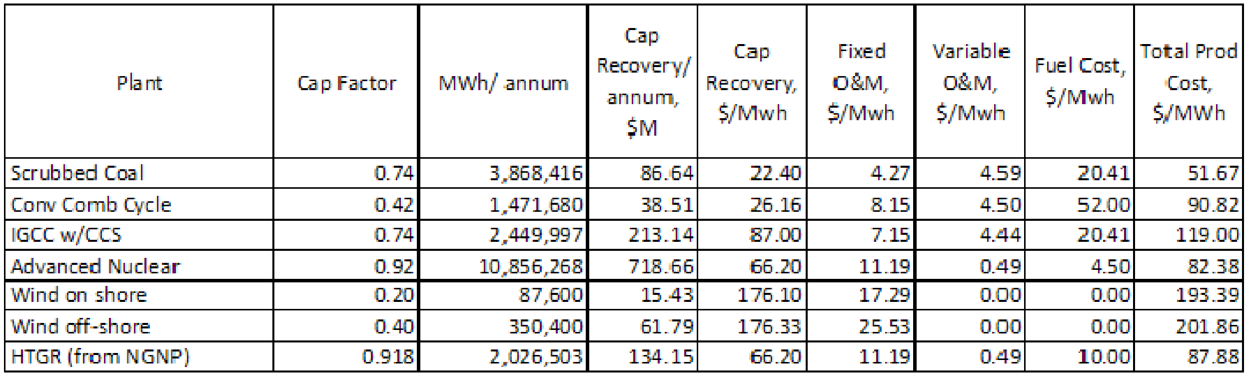
Figure 5-1. Estimate of accumulative costs for each scenario.

Table 5-1. Power plant cost factors.



Plant	On-line year	Size, Mwe	Leadtime	Total Overnight Cost, $2008, $/Kwe	Variable C&M, $2007, mills/kwh	Fixed O&M, $2007/kw	Fuel, mills/kwh	HeatRate, Btu/kwh	Heat Rate, Btu/kwh, nth of a kind	Total Plant Cost, $M
Scrubbed Coal	Existing	600		900	4.6	27.5	20.4	9,200	8,740	722
Conv Comb Cycle	Existing	400		600	4.5	30.0	52.0	8,000	8,000	321
IGCC w/CCS	2016	380	4	3,496	4.4	46.1	52.0	10,781	8,307	1,776
Advanced Nuclear	2016	1,350	6	3,318	0.5	90.0	4.5	10,434	10,434	5,989
Wind on shore	2009	50	3	1,923	0.0	30.3	0.0			129
Wind off-shore	2012	100	4	3,851	0.0	89.5	0.0			515
HTGR (from NGNP)	2021	252	6	3,318	0.5	90.0	10.0	9,000	9,000	1,118

Table 5-2. Estimate of production costs for several electric power plants.



Plant	Cap Factor	MWh/ annum	Cap Recovery/ annum, $M	Cap Recovery, $/Mwh	Fixed O&M, $/Mwh	Variable O&M, $/Mwh	Fuel Cost, $/Mwh	Total Prod Cost, $/MWh
Scrubbed Coal	0.74	3,868,416	86.64	22.40	4.27	4.59	20.41	51.67
Conv Comb Cycle	0.42	1,471,680	38.51	26.16	8.15	4.50	52.00	90.82
IGCC w/CCS	0.74	2,449,997	213.14	87.00	7.15	4.44	20.41	119.00
Advanced Nuclear	0.92	10,856,268	718.66	66.20	11.19	0.49	4.50	82.38
Wind on shore	0.20	87,600	15.43	176.10	17.29	0.00	0.00	193.39
Wind off-shore	0.40	350,400	61.79	176.33	25.53	0.00	0.00	201.86
HTGR (from NGNP)	0.918	2,026,503	134.15	66.20	11.19	0.49	10.00	87.88

It should be noted that these costs are not compared against costs that would be expended to sustain the energy supply in each of these sectors over the next four decades. Based on the low growth rate that is projected in the energy sectors and the age of plants in the electricity sector this is not considered a major factor. This factor can be included in refinement of these analyses, if warranted. In any event whether it is in like-for-like replacement or replacements and upgrades to achieve a transformation of the energy infrastructure a significant expenditure is required.

5.2 Estimate of Increased Cost of Energy

The capital and operating costs including fuel from Table 5-1 were used to develop a levelized production cost per MWh for each of the processes used in the evaluation. The portion of the capital cost attributable to the production cost was calculated assuming a 33.7% factor applied to the Overnight Cost that covers Owners Cost and Interest During Construction and a 12% Capital Recovery Factor. Table 5-2 summarizes the results.

Figure 5-2 shows the projected cost of electricity over the next four decades for the recommended strategies for replacing current coal and natural gas plants with nonemitting sources of electricity production and the deployment of HTGR plants in co-generation and synthetic fuel production applications. The increase (~54% over the 4 decade period) is judged to be representative of the increase in the cost of energy in general. (Note that the EPA estimate of HR2454 projects the same increase in the real cost of energy over the same period for the provisions of that bill (EPA2009a, EPA2009b].)

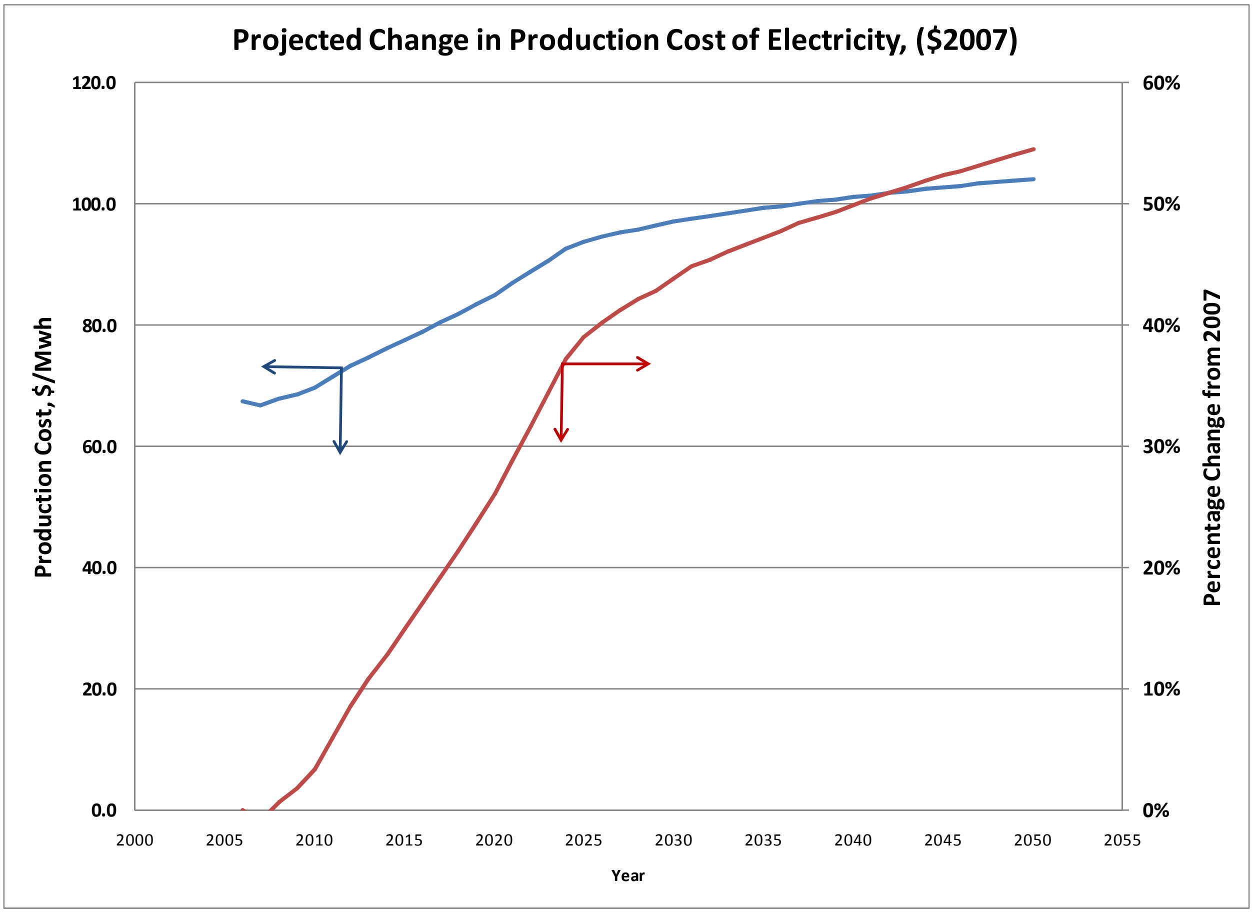


Figure 5-2. Projected change in the cost of electricity production.

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Appendix A

Summary of Administration and Congressional Objectives for Reducing Greenhouse Gas Emissions

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1. OBJECTIVES

1.1 Administration Objectives

The current Administration has proposed the following as national objectives in addressing the issue of climate change:

- **Objective #1[j] -- by 2020**

  "… reduce [carbon] emissions to 1990 levels"

  AEO2009 reports that in 1990 there were 5019 Million Metric tons [shortened to Mt for convenience] of CO_2 emissions attributable to energy production and consumption[k] and that if no action is taken the emissions in 2020 are projected to be 5905 Mt. To meet Objective #1 the emissions in 2020 will have to be reduced by ~900 Mt.

- **Objective # 2 – by 2025**

  "… 25 percent of electricity consumed in the United States is derived from clean, sustainable energy sources, like solar, wind and geothermal"

  AEO2009 reports that 15.9% of electricity production in 2025 is projected to be from renewable sources. EIA includes hydro-electric as a renewable source of electricity and this accounts for about 7% of the production in 2025. An additional ~10% of renewable production will need to be added to the production mix in 2025 to meet this initiative. Hydro-electric production is not projected to grow significantly in the future since most viable sites have already been developed. Accordingly, the increase in renewable will come from nonhydro-electric sources such as wind, solar, wood, biomass, geothermal.

- **Objective #3 – by 2050**

  "… reduce carbon emissions by the amount scientists say is necessary: 80 percent below 1990 levels"

  80% below 1990 levels is an annual emission rate of ~1005 Mt. Extension of the AEO 2009FlF emission projections predicts that CO2 emission levels will be at 6645 Mt in 2050 if no action is taken to reduce them. Accordingly CO2 emissions will need to be reduced by 5640 Mt to meet Objective #3.

The Administration also has an initiative to improve the new car gas mileage as a measure to reduce emissions in the transportation sector as follows:

- Increase vehicle mileage by ~5% per year to achieve an average new car fleet mileage of 35.5 mpg by 2016

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[j] The objectives have been numbered for convenient reference herein. These objectives were not numbered in the referenced policy paper.

[k] The figures following each objective show the impact of the objective statement on current projections by DOE EIA in the referenced Annual Energy Outlook 2009 data

[l] T*he DOE-EIA Annual Energy Outlook for 2009 provides projections to 2030, the 2050 value is based on extrapolation of the average rate of change projected by AEO2009 over the period 2010 to 2030.*

- The current CAFÉ requirements on new car fleet mileage are at 27.5 mpg.

1.2 Congressional Objectives

At the time of this writing a Congressional bill HR 2454 has been passed and a similar bill S1733 is being debated in the Senate. Both of these bills have similar objectives. Since it has been passed, the following summarizes the objectives of HR2454:

- Cap emissions [assumed to be GHG emissions] at 2005 levels beginning in 2012
- Require a reduction of 17 percent below the 2005 baseline by 2020
- By 2030 emissions must fall by 42 percent below the baseline and by 2050 by 83 percent.
- Utilities shall get 15 percent of their power from renewable sources by 2020

This bill also proposes a cap and trade program on GHG emissions with wide-spread allowance allocations and domestic and international offsets with extensive rebates of governmental and energy supplier revenues from allowances to protect consumers from higher energy costs associated with these emissions reductions.

The objectives of HR2454 generally align with the Administration objectives.

Several assessments of the costs of this bill to the government and the consumer have been performed. Two of these by the Congressional Budget Office and the U.S. Environmental Protection Agency are compared to the strategy discussed herein in a companion paper.