

Energy Alternatives and the Environment

Prepared in Support of the Proposed Final OCS Oil and Gas Leasing Program for 2012-2017

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by

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1. INTRODUCTION

The Bureau of Ocean Energy Management (BOEM) is responsible for the development of five year outer continental shelf (OCS) oil and gas leasing programs, as required by section 18 of the OCS Lands Act. As part of the process of developing a new leasing program, BOEM generates decision options and conducts a benefit-cost or “Net Benefits” analysis for each option. These are presented to the Secretary of the Interior for decision at three points in the iterative process of announcement, comment, analysis (including analysis of comments), and decision. Typically, an option is to further consider holding a set number of lease sales (auctions) in specific year(s) offering an identified portion of a planning area. If the option is selected, that program area¹ will be considered for leasing in the next stage of program development or, if selected for the final program, in the pre-sale planning process, which can take one to three years. There continues to be a “No Sale Option” for each program area.

For its Net Benefits analysis, BOEM uses its internal Offshore Environmental Cost Model (OECM) to generate monetary estimates of the environmental and social costs attributable to oil and gas exploration and production activities anticipated to result from each decision option. Moreover, the scope of study extends to cover activities associated with other sources of energy besides OCS oil and gas. When BOEM assesses a program option, OECM produces a cost estimate not only for the environmental and social costs attributable to activities anticipated to result from the sale(s) in that option but also for those attributable to the market substitutions anticipated to result from the No Sale Option; i.e., the costs associated with energy production from sources that would substitute for OCS production in the absence of anticipated production from the sale(s). The costs associated with any No Sale Option are a function of the type and scale of substitute resources predicted by a companion model, the Market Simulation Model (MarketSim).

Comments received from respondents on previous five year programs have encouraged BOEM to go beyond consideration of the program proposal and examine the full range of alternatives to OCS oil and gas production, including those that MarketSim might not represent given the current state of energy technologies and markets. Thus, in the present report BOEM explains the effects of energy alternatives on anticipated production in two ways: (1) based on the market’s response to the absence of anticipated production from the recommended option, and (2) more generally based on the potential to meet the Nation’s energy needs, both in the near- and long-term, through all available resources other than OCS oil and gas. It is important to recognize that the broader consideration of energy alternatives necessarily includes consideration of the environmental and social costs of those alternatives, just as BOEM considers the environmental and social costs of each program area option.

¹ The OCS is divided into 26 geographic “planning areas.” A program area is that portion of a planning area that remains under consideration in the program. For example, in recent programs, the Eastern Gulf of Mexico (GOM) program area has represented only a small portion of the total Eastern GOM planning area. Typically, there have been 6 to 12 program areas, some of which were entire planning areas and others only a portion thereof. The area eventually offered for lease may be reduced further in size during the pre-sale process but it cannot be increased unless and until the five year program development process has been conducted for a new or revised program.

This report presents both of these analytical approaches. First, it describes the environmental impact associated with *not* approving any of the proposed sales by (1) presenting the cost estimate associated with replacement of foregone production from the program proposal, as determined through the application of MarketSim and OECM, and (2) qualitatively highlighting other potential costs that are likely to result from not approving a new program but are not currently modeled. Second, it presents a discussion of possible near-term and longer-term substitutes for oil and gas, by use sector (transportation, electricity production, industrial, and commercial and residential). While the OCS is one source of the oil and gas utilized by the U.S. economy, it is helpful to consider the feasibility of relying on other sources to meet energy demand. The report concludes with an overview of the environmental cost considerations that would need to be taken into account in evaluating the net benefits of any transition away from production of oil and gas resources from future OCS lease sales, as well as a discussion of how policies to promote energy alternatives would impact the models used in the environmental and social cost analyses. This report provides supplemental background information to help describe the analysis of energy alternatives to OCS oil and gas. Sections of this document are also included in the Programmatic Environmental Impact Statement (EIS) (Section 4.5.7) and the Proposed Final Program decision document.

The Secretary's authority does not extend beyond management of Federal lands and the resources therein. The decision options for the OCS Oil and Gas Leasing Program for 2012-2017 were developed pursuant to the Secretary's authority and responsibilities as described in section 18 of the OCS Lands Act, as amended. The Secretary also has authority over renewable energy (e.g. wind) projects on Federal lands and has committed to promote responsible development of these projects in parallel with the development of oil and gas resources.

2. THE NO ACTION ALTERNATIVE

The National Environmental Policy Act (NEPA) requires consideration of a No Action Alternative to every major Federal action that significantly affects the environment. While adoption of a five year program is not a commitment to take any specific leasing action², an EIS is completed at this five year program stage to allow the Secretary to view future lease sale decisions together in a consistent framework. The EIS analyzes the No Action Alternative by calculating the environmental impacts that would occur in the absence of production from new lease sales. In this No Action scenario, no sales would be held in any program area.

This section presents BOEM's analysis of the energy market impacts associated with the No Action Alternative and the corresponding environmental effects associated with these impacts. With less oil and gas available from the OCS under the No Action Alternative, consumers may obtain oil and gas from other sources, substitute to other types of energy, or consume less energy overall. Similarly, energy production may shift from OCS oil and gas to onshore oil and gas, overseas oil and gas production, or domestic production of oil and gas alternatives such as coal. Each of these shifts in consumption and production relative to the program proposal (Proposed

² A separate planning and approval process occurs for each lease sale. Lease sales in previous five year programs have been altered, delayed, or cancelled.

Action in the EIS) yields environmental impacts that BOEM has evaluated and considered in developing the program.

2.1 Relationship between the No Action Alternative and No Sale Options

In the context of the five year program, the No Action Alternative is defined as the scenario in which BOEM holds no OCS oil and gas lease sales during the five year period covered by the program or, in other words, in which the No Sale Option is selected for each program area. Under this scenario, the oil and gas that would have been produced as a consequence of sales over the five year program period are not available to consumers, who must therefore obtain energy from other sources.

In the main decision documents, the analyses are presented by program area, because each decision option is specific to a program area. However, it is both cumbersome and unnecessary to use this program-area-by-program-area approach to describe the methodology for analysis of energy alternatives to OCS oil and gas. Therefore, in this document, the purpose of which is to provide background information and not to ask for a decision, BOEM will use the concept of the EIS's No Action Alternative in its explanations of the energy sources most likely to substitute for foregone OCS oil and gas production.

2.2 Methodology

The process for calculating these impacts begins with the application of MarketSim to a given exploration and development (E&D) scenario of program-initiated OCS oil and gas. In the No Action Alternative, there is no OCS activity started under the program. MarketSim is a multi-market equilibrium model that simulates, over time, the energy supply, demand, and price effects of OCS oil and gas production compared with National Energy Modeling System (NEMS) baseline projections, mostly published as the reference case of the Energy Information Administration's (EIA) *Annual Energy Outlook (AEO)*. In addition to simulating oil and natural gas markets, MarketSim includes separate modules for coal and electricity, enabling the model to capture the broad effects of an E&D scenario across individual segments of the energy market. Modeling each of these sectors, MarketSim produces an estimate of the energy market's response to the absence of production anticipated to occur as a result of a five year program.³ Three specific responses are considered important to evaluate in the absence of the E&D scenario: an increase in the quantity of oil delivered into the U.S. market via overseas tanker; the quantity of natural gas imported into the United States via tanker; and an increase in the onshore production of oil, gas, and coal within the United States. These responses are assumed to be the most significant in terms of potential environmental costs, namely (1) the impact of oil spills from incoming oil tankers; (2) the air quality impacts associated with emissions from incoming tankers carrying oil and liquefied natural gas (LNG); and (3) the incremental emissions associated with onshore oil, gas, and coal production.⁴ BOEM employed OECM to quantify

³ MarketSim models foregone production from a single program area in the same way as for the aggregated No Action Alternative.

⁴ OECM does not estimate the environmental and social costs of importing oil and gas via pipeline, although it does estimate greenhouse gas emissions.

these costs. Other potential costs may also be relevant, for example, groundwater impacts that might be associated with onshore gas production, but are not included in OECM due to the lack of credible bases for describing them as functions of specific model inputs. The methods applied by OECM to quantify the environmental costs of the No Action Alternative are described below.

2.2.1 Analysis of oil spill costs under the No Action Alternative

Since there is no oil and gas activity subsequent to lease sales under the No Action Alternative, oil spills associated with the NAA are mainly related to increased imports by tanker.⁵ The methodology for modeling oil-spill related costs under the No Action Alternative is as follows.

- OECM imports the MarketSim estimate of imported crude oil in the absence of the oil production assumed to result from a five year leasing program. Note that the relevant MarketSim output is exclusive to tankers, and thus does not need to be expressed net of imports that might arrive via pipeline.
- To assign potential costs to individual OCS planning areas, OECM makes assumptions about the geographic distribution of imported oil. As a default, OECM assumes that this distribution is proportional to the average annual fraction of total crude oil tanker trips that arrive at ports in each of the planning areas, assuming that per tanker quantities do not vary significantly among ports.⁶
- To calculate spill-related costs under the No Action Alternative, the model uses spill probability and spill-size distribution factors to determine the volume of spilled oil in each of the applicable planning areas. It then applies this volume to each of the OECM cost calculations that have a spill component in the same way it would calculate costs associated with a program scenario.
- Since OECM distinguishes between nearshore and offshore locations for its assessment of oil spill impacts, an assumption is required regarding the location of potential spills. In an effort to avoid over- or under-estimating the spill-related costs, the model assumes that spills would occur at the distance specified as the boundary between the nearshore and offshore areas.

2.2.2 Analysis of air quality costs under the No Action Alternative

OECM uses two separate approaches to estimate the air quality costs of the No Action Alternative, one approach for tanker imports of oil and natural gas and a second for increased onshore production of oil, natural gas, and coal.

- For oil and gas tanker imports, the model applies emissions factors from the literature to various tanker activities, including (1) tanker cruising, (2) unloading, (3) volatile organic compound (VOC) losses in transit for oil tankers only, and (4) ballasting for oil tankers only.

⁵ Under the No Action Alternative, there might continue to be spills from OCS wells drilled at leases issued under earlier programs, but the spill risk at older leases would be present, more or less, regardless of level of activity attributable to the new program. In principle, the NAA might slightly increase risks of oil spills at older leases to the extent that activities expand in response to the absence of new leases under the NAA and in the presence of slightly higher market prices for oil and gas.

⁶ This is based on data for the years 2004 through 2008 collected by Environmental Research Consulting.

For emissions that occur in transit such as tanker cruising and VOC losses, it is assumed that emissions are distributed across an entire planning area. In contrast, emissions released at port such as unloading and ballasting emissions are distributed across the coastal portion of each planning area. Similar to the OECM assessment of oil spill costs for tanker imports, the model assumes that the geographic distribution of tanker imports across planning areas is similar to the historical distribution.

- To estimate the air quality costs related to increased onshore production of oil, natural gas, and coal, the model follows a two-step process.
 - First, OECM estimates the emissions associated with onshore production by applying the change in onshore production projected by MarketSim to a series of emission factors specific to each fuel such as onshore oil, natural gas, and coal. This yields the change in emissions associated with onshore production.
 - Second, the model multiplies emissions resulting from oil, gas, and coal production by a series of dollar per ton values that represent the monetized costs of onshore emissions. These values were derived from outputs of the Air Pollution Emission Experiments and Policy analysis model (APEEP).⁷

2.3 Market response to the No Action Alternative

Exhibit 2.1 presents the changes in energy markets projected by MarketSim between the No Action Alternative and the five year program based on the three E&D scenarios of low, mid and high⁸ oil and gas prices examined by BOEM.⁹ As indicated in the exhibit, domestic production of both oil and gas is projected to decline overall, but onshore production in the United States is projected to increase under the No Action Alternative in comparison to all three E&D scenarios. This increase in onshore production, however, is projected to make up for only a fraction of foregone OCS production. To ensure that demands for oil and gas are met, MarketSim projects a sharp increase in oil and gas imports under the No Action Alternative, via both tanker and pipeline. The model also projects that the reduction in OCS oil and gas production under the No Action Alternative will result in an increase in domestic coal and electricity production.

Energy consumption under the No Action Alternative is projected to shift in comparison to the three E&D scenarios. More specifically, MarketSim projects that natural gas consumption will

⁷ Industrial Economics, Inc.; Applied Science Associates, Inc.; Northern Economics; and Dr. Nicholas Z. Muller. 2012. *Forecasting Environmental and Social Externalities Associated with OCS Oil and Gas Development: The Revised Offshore Environmental Cost Model (OECM)*. U.S. Department of the Interior, Bureau of Ocean Energy Management. OCS Study BOEM 2012-025.

⁸ The E&D scenarios are the forecast of activity levels anticipated to occur in each program area for the different price cases.

⁹ BOEM analyzes three flat price cases in the five year program analysis. The low-price case represents a scenario under which inflation-adjusted prices are \$60 per barrel for oil and \$4.27 per million cubic feet (mcf) for natural gas throughout the life of the program. Prices for the mid-price case are \$110 per barrel and \$7.83 per mcf. Prices for the high-price case are \$160 per barrel and \$11.39 per mcf. See the Proposed Final Program decision document for more information.

decline while domestic consumption of oil, coal, and electricity will increase. Given that domestic oil *production* declines under the No Action Alternative, the increase in oil *consumption* may be somewhat unexpected. This increase in oil consumption reflects the fact that oil and gas are substitutes within the industrial sector and, to a lesser extent, the residential and commercial sectors. The loss of a given amount of OCS production is likely to result in greater increases in natural gas prices than in oil prices, because the price of oil is largely decided in the world market while the price of natural gas is largely set in smaller regional markets. Therefore, as natural gas prices increase under the No Action Alternative compared to the E&D scenarios due to reduced OCS production, consumption of substitutes, including oil, increases. The increase in oil prices under the No Action Alternative may cause some offsetting substitution in the opposite direction, from oil to gas, but the impact of increased gas prices is the more dominant of the two effects.

EXHIBIT 2.1. PROJECTED ENERGY MARKET IMPACTS FROM 2012 THROUGH 2051 UNDER THE NO ACTION ALTERNATIVE RELATIVE TO EACH E&D SCENARIO

	DIFFERENCE BETWEEN THE NO ACTION ALTERNATIVE AND THE PROGRAM			PERCENT CHANGE FROM PROGRAM		
	Low E&D	Mid E&D	High E&D	Low E&D	Mid E&D	High E&D
OIL (billion barrels)						
U.S. Consumption	0.1	0.2	0.3	0.0%	0.1%	0.1%
U.S. Production	-3.5	-5.8	-7.9	-2.1%	-3.4%	-4.6%
Lower 48 onshore, biofuels, other	0.1	0.1	0.2	0.1%	0.1%	0.2%
Lower 48 offshore	-2.8	-4.7	-5.4	-12.2%	-18.9%	-21.1%
Alaska ¹	-0.8	-1.3	-2.7	-7.7%	-12.0%	-22.4%
Net Imports	3.5	6.0	8.1	2.3%	4.0%	5.5%
Net Imports Pipeline	0.3	0.5	0.7	1.0%	1.6%	2.2%
Net Imports Tanker	3.2	5.3	7.2	2.7%	4.5%	6.2%
GAS (trillion cubic feet)						
U.S. Consumption	-4.0	-7.6	-10.8	-0.5%	-0.9%	-1.2%
U.S. Production	-7.1	-13.7	-19.5	-1.7%	-1.7%	-2.4%
Lower 48 onshore and other	3.7	7.3	11.4	1.3%	1.2%	2.0%
Lower 48 offshore	-11.6	-19.7	-22.5	-12.0%	-18.7%	-20.9%
Alaska ¹	0.4	-2.0	-9.4	0.7%	-3.0%	-12.5%
Total Imports	2.6	4.9	7.1	2.0%	3.9%	5.7%
Imports Pipeline	2.3	4.3	6.2	2.6%	5.1%	7.6%
Imports LNG	0.3	0.6	0.9	0.7%	1.4%	2.1%
Exports	-0.6	-1.2	-1.6	-0.9%	-1.8%	-2.5%
COAL (million short tons)						
U.S. Consumption	75.2	145.5	214.7	0.1%	0.3%	0.4%
U.S. Production	73.4	142.2	209.7	0.1%	0.3%	0.4%
Net Exports	-1.8	-3.3	-5.0	-0.4%	-0.7%	-1.1%
ELECTRICITY (billion kilowatt hours)						
U.S. Consumption	141.2	265.6	388.5	0.1%	0.1%	0.1%
U.S. Production	131.1	245.2	360.2	0.1%	0.1%	0.2%
Net Imports	10.0	20.4	28.9	0.7%	1.5%	2.1%
Notes:						
1. <i>The Energy Information Administration's Annual Energy Outlook (AEO) projections do not differentiate offshore and onshore production for Alaska.</i>						

2.4 Modeled environmental impacts of the No Action Alternative

Exhibit 2.2 summarizes the environmental impacts of the No Action Alternative as estimated by OEM. ¹⁰ As indicated in the exhibit, costs associated with air pollution impacts account for the vast majority of these costs, followed by foregone recreational opportunities and ecological effects. The air pollution impacts summarized in the exhibit reflect increased emissions of several different pollutants. ¹¹ Exhibit 2.3 presents the projected increase in emissions, by pollutant, under the No Action Alternative.

EXHIBIT 2.2. QUANTIFIED ENVIRONMENTAL AND SOCIAL COSTS UNDER THE NO ACTION ALTERNATIVE (MILLIONS OF DOLLARS)

COST CATEGORY	NO ACTION ALTERNATIVE (LOW PRICE SCENARIO)	NO ACTION ALTERNATIVE (MID PRICE SCENARIO)	NO ACTION ALTERNATIVE (HIGH PRICE SCENARIO)
Recreation	218	356	4686
Air quality	12,894	22,678	28,148
Property values	0.23	0.37	0.48
Subsistence use	0.01	0.01	0.01
Commercial Fishing	0.00	0.00	0.00
Ecological impacts	10.3	16.9	22.10
Total	\$13,122.25 M	\$23,052.11 M	\$28,636.41 M

Numbers may not sum due to rounding.

¹⁰ The values in Exhibit 2.2 include reasonably foreseeable oil spill costs attributed to each cost category.

¹¹As can be seen in Exhibit 2.2, the costs associated with air quality are significantly larger than those in all of the other cost categories. For more information, see *Economic Analysis Methodology for the Five Year OCS Oil and Gas Leasing Program for 2012-2017 (BOEM-2012-022)*.

EXHIBIT 2.3. INCREMENTAL AIR EMISSIONS UNDER THE NO ACTION ALTERNATIVE
(THOUSANDS OF TONS)

	POLLUTANT	NO ACTION ALTERNATIVE (LOW PRICE SCENARIO)	NO ACTION ALTERNATIVE (MID PRICE SCENARIO)	NO ACTION ALTERNATIVE (HIGH PRICE SCENARIO)
Criteria Pollutants	NO _x	208	391	574
	SO _x	50	95	141
	PM ₁₀	187	361	540
	PM _{2.5}	2	4	5
	CO	85	163	244
	VOC	442	840	1,242
Greenhouse Gases	CO ₂	214,834	365,754	506,270
	CH ₄	147	247	340
	N ₂ O	2	4	5

2.5 Other environmental impacts of the No Action Alternative

In addition to the No Action Alternative environmental impacts quantified in OECM, the No Action Alternative may result in a range of additional environmental impacts for which sufficient data were not available for quantification. These impacts would result from alternatives to offshore oil and gas production that would take the place of production that would otherwise occur under the Five Year Program. They include, but are not limited to the following.

- ***Acid mine drainage from coal mining:*** Runoff from coal mining sites may increase the acidity of surface waters near and downstream from coal mining sites, adversely affecting habitat for aquatic organisms and limiting human recreational uses.
- ***Contamination of groundwater from oil and gas extraction:*** Accidental spills, blowouts, and/or pipeline leaks associated with terrestrial oil and gas extraction activities have the potential to result in contamination of groundwater resources. In addition, the practice of hydraulic fracturing (“fracking”) to develop terrestrial shale gas resources has raised concerns about the potential for local groundwater contamination if the chemicals and wastes associated with this process are not properly managed or if wells are not properly constructed.
- ***Water discharges from oil and gas operations:***¹² To facilitate resource extraction from subsurface formations, oil and gas producers use water to develop pressure causing oil and gas to rise to the surface (e.g., enhanced oil recovery and hydraulic fracturing). Producers must manage these waters as well as waters extracted from geologic

¹² This discussion is based on U.S. Environmental Protection Agency (EPA), 2008 Sector Performance Report. EPA 100-R-08-002, September 2008.

formations during oil/gas extraction. The environmental impacts associated with this “produced water” vary based on the geologic characteristics of the reservoir that produced the water and the separation and treatment technologies employed by producers.

- **Coal combustion impacts:** Coal consumed in place of gas under the No Action Alternative will result in environmental costs associated with diminished air quality and the disposal of coal combustion residuals. The combustion of coal in power plants or industrial boilers produces higher emissions of NO_x, SO_x, and PM than the combustion of natural gas and also results in greater CO₂ emissions.¹³ In addition, coal combustion residuals generated by power plants or coal-fired industrial boilers may pose a risk to local ground groundwater supplies when disposed in surface impoundments or landfills that are not properly maintained.

3. OIL AND GAS USES AND ALTERNATIVES: TRANSPORTATION SECTOR

Total energy use in the transportation sector has grown by an average of just over 1 percent per year over the last 20 years. As of 2010, the transportation sector accounted for an estimated 28 percent of all energy consumption in the United States, a proportion that has been slowly rising since the 1960s. The vast majority of this energy has come from oil. Nearly three fourths of all petroleum consumed in the United States in 2010, was used for transportation, with natural gas, electricity, and other alternatives playing much smaller roles.¹⁴ In this section, we discuss recent trends in the use of oil and gas in the transportation sector and the near- and long-term potential for substitutes to these energy sources. These discussions provide a current snapshot of the various Federal policies and technological advancements that are likely to affect future fuel consumption trends in the United States. BOEM welcomes comments and feedback from the other Federal agencies on our discussions of their programs and policies. In general, the information provided in these discussions supplements the analysis of the anticipated energy substitutions presented in Exhibit 2.1.

3.1 Current use of oil and gas

3.1.1 Ground travel

Oil is the dominant energy source for ground travel, which consumed approximately 136 billion gallons of motor gasoline and 42 billion gallons of diesel fuel in 2010. Growth in consumption was slow but steady during the mid-2000s economic expansion, averaging about one percent per year from 2003 to 2007.¹⁵ However, motor gasoline use fell by about three percent from 2007 to

¹³ For detailed emissions data for power plants, see U.S. EPA’s eGRID2010 database, <http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html>

¹⁴ U.S. DOE, Energy Information Administration (EIA). *Annual Energy Review 2010*. DOE/EIA-0384(2010), October 19, 2011. <http://www.eia.doe.gov/aer/>

¹⁵ U.S. DOE, EIA. *Alternatives to Traditional Transportation Fuels 2007*. DOE/EIA-0585(2007), April 2009. http://www.eia.doe.gov/cneaf/alternate/page/atftables/afv_atf.html

2008, the first time that total annual consumption has fallen since the 1988-to-1991 period. Consumption remained flat from 2008 to 2010.¹⁶

This mid-2000s growth trend was attributable to several factors. Growth in the U.S. population, averaging just under one percent per year, resulted in approximately three million potential new vehicle drivers annually.¹⁷ Meanwhile the number of highway vehicles grew even faster, at a rate of nearly four million vehicles per year from 2003 to 2007. At the end of 2007, 254 million registered highway vehicles were in use in the United States, one for every 1.19 people. The growth in the number of vehicles has been realized entirely in the light truck segment, as the number of passenger cars has remained more or less constant.¹⁸ The subsequent flat growth in fuel consumption follows the general trend of fuel consumption declining during periods of economic recession and/or high gasoline prices.

After 20 years of steady increase, the average number of miles driven per vehicle peaked at 12,211 per year in 1998 and stayed more or less at that level until 2007 when it began to decline.¹⁹ The average fuel efficiency of all vehicles on the road improved only minimally over that time period. The trend towards increased efficiency will accelerate in the future, as the fuel efficiency of *new* vehicles has been increasing in recent years. New fuel efficiency and greenhouse gas pollution standards, announced in July 2011, will increase the minimum fleetwide average for manufacturers of cars and light trucks to 54.5 miles per gallon (MPG) for model years 2017 through 2025, which is expected to reduce oil consumption by almost 34 billion gallons per year by 2025.²⁰ In addition, the new Heavy-Duty National Program, recently announced by the U.S. Environmental Protection Agency (EPA) and Department of Transportation (DOT) will reduce fuel consumption by large trucks and buses, further reducing overall ground transportation fuel use.²¹

¹⁶ U.S. DOE, EIA. *Annual Energy Review 2010*.

Table 5.14c: Heat Content of Petroleum Consumption: Transportation and Electric Power Sectors, 1949-2010. DOE/EIA-0384(2010), October 19, 2011. <http://www.eia.doe.gov/aer/>

¹⁷ U.S. Census Bureau, Population Division. Annual Estimates of the Resident Population for the United States, Regions, States, and Puerto Rico: April 1, 2000 to July 1, 2009. NST-EST2009-01, December 2009. <http://www.census.gov/popest/states/NST-ann-est.html>

¹⁸ U.S. Department of Transportation (DOT), Bureau of Transportation Statistics. National Transportation Statistics 2009. Table 1-11. Number of U.S. Aircraft, Vehicles, Vessels, and Other Conveyances. June 2009. http://www.bts.gov/publications/national_transportation_statistics/

¹⁹ U.S. DOE, EIA. *Annual Energy Review 2010*. Table 2.8: Motor Vehicle Mileage, Fuel Consumption, and Fuel Rates, 1949-2008. DOE/EIA-0384(2010), October 19, 2011. <http://www.eia.doe.gov/aer/>

²⁰ U.S. EPA. 2011 News Releases: President Obama Announces Historic 54.5 MPG Fuel Efficiency Standard. July 2011. <http://yosemite.epa.gov/opa/admpress.nsf/1e5ab1124055f3b28525781f0042ed40/0019c092ccae8ac2852578dc0056ded0!OpenDocument>

²¹ U.S. EPA. Regulatory Announcement: EPA and NHTSA Adopt First-Ever Program to Reduce Greenhouse Gas Emissions and Improve Fuel Efficiency of Medium- and Heavy Duty Vehicles. August 2011. <http://www.epa.gov/otaq/climate/documents/420f11031.pdf>

The use of natural gas as a vehicle fuel in both compressed and liquid forms has increased in recent years, with an average annual growth rate of 8.3 percent from 2006 to 2010²². However, natural gas still represents a small fraction of total vehicle fuel consumption, at just over 225 million gallons of gasoline-equivalent in 2009, or slightly more than one percent of total vehicle fuel use.²³ In 2009, approximately 117,000 natural gas-fueled vehicles were in use, many of which were buses and other fleet vehicles.²⁴

Ethanol, as a gasoline additive, makes up the majority of alternative fuel currently in use. Consumption increased from 2.8 billion gallons gasoline-equivalent in 2005 to 7.3 billion gallons in 2009. As a primary fuel (i.e., in a blend that is at least 85 percent ethanol), ethanol consumption increased from 38 million gallons of gasoline-equivalent in 2005 to just over 71 million gallons in 2009. Biodiesel use rose even more quickly over that period, but remains relatively modest overall at 325 million gasoline-equivalent gallons. Electricity, hydrogen, and other fuels contributed very little. Electricity use for vehicle transportation actually declined slightly over this period.²⁵

Exhibit 3.1 summarizes the trends in the consumption of vehicle fuels and in the number of alternative fuel vehicles in recent years.

3.1.2 Air travel

Certificated U.S. air carriers used 17.3 billion gallons of fuel in 2010, 6.4 percent of the total energy consumed by the U.S. transportation sector.²⁶ Until 2007, fuel use for air travel was rising faster than use for ground travel. Total consumption rose by 4.6 percent per year from 2003 to 2007 before falling in 2008 through 2010,²⁷ indicating a strong linkage to larger economic factors. Petroleum-derived, kerosene-style jet fuel accounts for nearly all of the fuel used for air travel.

²² U.S. DOE, EIA. *Annual Energy Review 2010*. Table 6.5 Natural Gas Consumption by Sector, Selected Years, 1949-2010. DOE/EIA-0384(2010), October 11, 2010. <http://www.eia.doe.gov/aer/>.

²³ U.S. DOE, EIA. *Alternatives to Traditional Transportation Fuels 2009*. DOE/EIA (2009), April 2011. http://www.eia.gov/renewable/alternative_transport_vehicles/pdf/afv-atf2009.pdf

²⁴ Ibid.

²⁵ Ibid.

²⁶ U.S. DOT, Bureau of Transportation Statistics. *National Transportation Statistics*. Table 4-21: Energy Intensity of Certificated Air Carriers, All Services. January 2011. http://www.bts.gov/publications/national_transportation_statistics/

²⁷ Ibid.

EXHIBIT 3.1 ESTIMATED CONSUMPTION OF VEHICLE FUELS AND NUMBER OF ALTERNATIVE FUELED-VEHICLES IN THE U.S., 2009

FUEL	CONSUMPTION (1000 GASOLINE-EQUIVALENT GALLONS)			ALTERNATIVE-FUEL VEHICLES, 2009
	2005	2009	PERCENT ANNUAL GROWTH	
Ethanol in Gasohol	2,765,663	7,343,133	27.65%	
Biodiesel	93,281	325,102	36.63%	
Natural Gas (CNG and LNG)	189,287	225,175	4.44%	117,446
Ethanol, 85 percent (E85)	38,074	71,213	16.95%	504,297
Electricity	5,219	4,956	-1.28%	57,185
Hydrogen	25	140	53.83%	
Total Alternative Fuels	3,091,549	7,969,719	26.71%	

Source: U.S. DOE, EIA. Alternatives to Traditional Transportation Fuels 2009. DOE/EIA (2011), April 2011.

As with ground travel, fuel use for air travel is influenced by a number of factors, the trends for several of which are summarized in Exhibit 3.2. The increase through 2007 in total fuel use was attributable to an increase in aircraft-miles; that is, more planes are logging more miles in the air. This was coupled with a steady increase in passenger-miles, which increased at a rate well above population growth (i.e., the average person is flying more). Meanwhile, the number of seats per aircraft has exhibited a long downward trend since the 1980s, suggesting a shift to smaller planes. This would in and of itself lead to an increase in fuel use, but there also was an increase in load factor, or the proportion of seats in use, which rose to a high of 80 percent in 2007. The net effect, coupled with some modest engineering improvements, was a nine percent increase in seat miles per gallon from 2003 to 2008, a critical measure of efficiency. More directly, energy efficiency, as measured by Btu per passenger mile, fell by 16 percent over that same period. In short, during this period, we see a combination of factors similar to ground travel. Efficiency improvements in the design and use of vehicles are occurring in parallel to an increase in overall travel, while playing a mitigating role in total fuel use.²⁸ However, after 2007, load factors and seat miles per gallon continued to climb and passenger miles traveled decreased, leading to reductions in fuel use during this period.

²⁸ Ibid.

EXHIBIT 3.2 ENERGY INTENSITY OF AIR CARRIERS, 1980-2010

	1980	1990	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Aircraft-miles (millions)													
Domestic operations	2,523	3,963	5,089	5,110	5,230	5,896	6,366	6,529	6,423	6,534	6,247	5,757	5,807
International operations	401	760	1,385	1,373	1,348	1,426	1,592	1,723	1,798	1,881	1,895	1,778	1,859
Total	2,924	4,723	6,474	6,483	6,578	7,322	7,958	8,252	8,221	8,415	8,142	7,535	7,666
Percent annual change	4.69%	6.42%	6.69%	0.14%	1.47%	11.31%	8.69%	3.69%	-0.38%	2.36%	-3.24%	-7.46%	1.74%
Available seat-miles (millions)													
Domestic operations	346,028	563,065	702,693	684,279	670,963	685,283	736,888	744,058	730,996	747,064	717,502	669,856	678,040
International operations	86,507	170,310	266,449	256,312	235,746	235,508	263,304	285,258	296,520	313,015	323,312	305,431	313,848
Total	432,535	733,375	969,142	940,591	906,709	920,791	1,000,192	1,029,316	1,027,516	1,060,079	1,040,814	975,287	991,888
Percent annual change	7.38%	6.01%	4.43%	-2.95%	-3.60%	1.55%	8.62%	2.91%	-0.17%	3.17%	-1.82%	-6.30%	1.70%
Passenger-miles (millions)													
Domestic operations	200,289	340,231	500,440	473,627	472,361	498,181	548,594	573,627	577,582	595,331	570,922	541,646	555,642
International operations	54,363	117,695	200,370	184,944	178,232	175,996	203,748	221,490	232,518	246,675	252,844	238,336	253,394
Total	254,652	457,926	700,810	658,571	650,593	674,177	752,342	795,117	810,100	842,006	823,766	779,982	809,036
Percent annual change	9.36%	6.36%	6.36%	-6.03%	-1.21%	3.63%	11.59%	5.69%	1.88%	3.94%	-2.17%	-5.32%	3.72%
Fuel consumed (million gallons)													
Domestic operations	8,519	12,323	14,865	13,868	12,922	13,082	14,091	13,976	13,694	13,682	12,686	11,339	11,256
International operations	1,747	3,909	5,508	5,336	5,079	5,219	5,592	5,975	6,018	6,205	6,187	5,721	6,028
Total	10,267	16,232	20,373	19,204	18,001	18,301	19,683	19,951	19,712	19,887	18,873	17,060	17,284
Percent annual change	1.55%	5.19%	3.06%	-5.74%	-6.26%	1.67%	7.55%	1.36%	-1.20%	0.89%	-5.10%	-9.61%	1.31%

	1980	1990	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Seats per aircraft													
Domestic operations	137.1	142.1	138.1	133.9	128.3	116.2	115.8	114	113.8	114.3	114.9	116.4	116.8
International operations	215.7	224.1	192.4	186.7	174.8	165.1	165.3	165.5	164.9	166.4	170.6	171.8	168.8
Percent annual change	5.67%	-1.82%	-1.72%	-3.00%	-5.46%	-7.19%	-0.07%	-0.57%	-0.29%	0.72%	1.71%	0.95%	-0.90%
Seat-miles per gallon													
Domestic operations	41	46	47.3	49.3	51.9	52.4	52.3	53.2	53.4	54.6	56.6	59.1	60.2
International operations	50	44	48.4	48	46.4	45.1	47.1	47.7	49.3	50.4	52.3	53.4	52.1
Percent annual change	9.35%	1.23%	1.38%	1.67%	1.03%	-0.81%	1.95%	1.51%	1.78%	2.24%	3.71%	3.31%	-0.18%
Energy intensity (Btu/passenger-mile)													
Domestic operations	5,742	4,890	4,010	3,953	3,693	3,545	3,467	3,289	3,201	3,103	3,000	2,826	2,735
International operations	4,339	4,484	3,711	3,895	3,847	4,003	3,705	3,642	3,494	3,396	3,303	3,241	3,211
Percent annual change	-12.51%	-2.55%	-3.10%	1.64%	-3.92%	0.11%	-4.98%	-3.36%	-3.40%	-2.93%	-3.02%	-3.74%	-1.99%
Load factor (percent)													
Domestic operations	58.0	60.4	71.2	69.2	70.4	72.7	74.4	77.1	79	79.7	79.6	80.9	81.9
International operations	62.8	69.1	75.2	72.2	75.6	74.7	77.4	77.6	78.4	78.8	78.2	78	80.7
Percent annual change	4.50%	1.36%	1.81%	-3.42%	3.25%	0.96%	2.99%	1.91%	1.75%	0.70%	-0.44%	0.70%	2.33%

Source: U.S. DOT, Bureau of Transportation Statistics. National Transportation Statistics 2011. Table 4-21: Energy Intensity of Certificated Air Carriers, All Services. January 2011. http://www.bts.gov/publications/national_transportation_statistics/

3.1.3 Marine travel

Marine travel accounts for a relatively small proportion of total oil consumption in the transportation sector and, as with air travel, does not consume any natural gas. Total fuel consumption for marine travel was about 997 trillion Btu in 2009, roughly three-fifths the amount used by air travel and four percent of the total for the sector. Marine travel employs a mix of fuels. Residual fuel oil makes up about 70 percent of oil use, while distillate/diesel fuel oil and gasoline each account for about 15 percent. This mix has remained generally consistent over time.²⁹

As summarized in Exhibit 3.3, total oil consumption for marine travel has shown no clear trend over time, with periods of sharp declines following years of growth, and vice versa. After dropping by nearly 30 percent from 2000 to 2003, fuel use increased nearly as dramatically to reach comparable levels by 2007. Consumption decreased from 2007 to 2009. Like other fuels, general consumption trends follow the general economic trend.

3.1.4 Rail travel

Similar to marine travel, rail travel comprises a small proportion of total oil consumption and virtually no natural gas consumption. Total oil use was 454 trillion Btu in 2009. The overwhelming majority of this was for freight, rather than passenger, transport. Distillate and diesel are the primary fuels used with electricity accounting for only two trillion Btu out of the total.³⁰ Following a low of 414 trillion Btu in 1990, oil consumption for rail transportation grew steadily to 594 trillion Btu in 2006, before falling to 454 trillion Btu in 2009.³¹

²⁹ U.S. DOT, Bureau of Transportation Statistics. National Transportation Statistics 2011. Table 4-6: Energy Consumption by Mode of Transportation (Trillion Btu). October 2011.
http://www.bts.gov/publications/national_transportation_statistics/

³⁰ Ibid.

³¹ Ibid.

EXHIBIT 3.3 ENERGY CONSUMPTION FOR MARINE TRAVEL, 1980-2009 (TRILLION BTU)

	1980	1985	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Residual fuel oil	1,340	687	947	881	960	810	726	580	702	775	861	947	758	680
Distillate / diesel fuel oil	205	236	286	324	314	284	288	307	297	278	264	267	165	176
Gasoline	132	132	163	133	141	124	135	138	126	158	155	153	142	141
Total	1,677	1,054	1,396	1,338	1,415	1,218	1,149	1,025	1,125	1,211	1,280	1,367	1,065	997
Percent annual change	14.52%	-8.86%	5.77%	-0.84%	5.05%	-13.92%	-5.67%	-10.79%	9.76%	7.64%	5.70%	6.80%	-22.09%	-6.38%

Source: U.S. DOT, Bureau of Transportation Statistics. National Transportation Statistics 2011. Table 4-6: Energy Consumption by Mode of Transportation (Trillion Btu). October 2011. http://www.bts.gov/publications/national_transportation_statistics/

3.2 Near-term market analysis of substitutes

This section analyzes the near-term potential for substitution away from oil and gas in the transportation sector, either through efficiency measures or through the use of alternative fuel sources. Due to the nature of the equipment involved, the focus is solely on ground transportation. Options for oil and gas substitutes in air travel will be discussed in the longer-term analysis in section 3.3. Due to their relatively small contributions to oil and gas consumption, we do not consider substitution in the marine or rail travel sectors, except insofar as rail-based mass transit could provide a substitute for automobiles in the longer term.

With the exception of flex-fuel vehicles, which operate using either gasoline or ethanol without any modifications, and the capacity of diesel vehicles to use biodiesel with relatively modest engine adjustments, most automobiles are locked into using the single-fuel type for which they were originally designed. This means that, barring a major shift in driving patterns, the potential for changes in oil and gas consumption for transportation will be determined by changes in the composition of the vehicle fleet. Based on sales and registration data, the average lifespan of a passenger vehicle is approximately 14 years. Recent data suggest this may be on an upward trend, but since new vehicle sales are generally tied to the health of the overall economy, these data are not sufficient to indicate a long-term trend.^{32,33} With a 14-year average lifespan, we can expect roughly 82 million vehicles, mostly from the late 1990s and early 2000s, to be retired in the next five years. Around 83.7 million new vehicles will replace them, assuming population growth and vehicle ownership per capita trends continue. We will use these rough estimates to establish the magnitude of the impact of various oil and gas substituting technologies below. It is important to note that in the following section and throughout this analysis, efficiency is considered a ‘substitute’ energy source. Thus, much of the potential for a shift away from oil and gas use relies on technologies that continue to use these fuels, albeit in smaller quantities per vehicle mile traveled.

3.2.1 More efficient vehicles

3.2.1.1 Fuel efficiency improvements

Based on recent trends, it is possible to develop a rough estimate of the number of new vehicles expected to come into use over the next five years. Since 2000, U.S. population has grown by an average of just under one percent per year. Over that timeframe, passenger cars and light trucks per capita has fallen by 0.7 percent annually. Considering these forces together, one can expect a net addition of 1.7 million new cars and trucks from 2011 to 2015. However, this does not tell the whole story. After accounting for 82 million vehicle retirements over that time, assuming an

³² U.S. DOT, Bureau of Transportation Statistics. National Transportation Statistics 2009. Table 1-11: Number of U.S. Aircraft, Vehicles, Vessels, and Other Conveyances. June 2009.
http://www.bts.gov/publications/national_transportation_statistics/

³³ U.S. DOT, Bureau of Transportation Statistics. National Transportation Statistics 2009. Table 1-17: New and Used Passenger Car Sales and Leases (Thousands of vehicles). June 2009.
http://www.bts.gov/publications/national_transportation_statistics/

average lifespan of 14 years, we can assume that 83.7 million new cars and trucks will be purchased over that time, of which about half will be trucks and half passenger cars.

In the near term, efficiency of the U.S. vehicle fleet is likely to be determined more by stricter regulatory requirements than by a demand pull from consumers for yet-more efficient vehicles. The corporate average fuel economy (CAFE) standards through model year 2010 stood at 27.5 MPG for passenger cars and 23.1 MPG for light trucks. Building on requirements in the 2007 Energy Policy Act, EPA and DOT have jointly established stricter targets, setting a schedule that steadily raises the requirements to an end point equivalent to of 35.7 MPG for cars and 28.6 MPG for light trucks for model year 2012-2016 vehicles. The new vehicles subject to these limits will replace older, retired vehicles manufactured in the late 1990s and early 2000s, whose fuel efficiency was about eight MPG lower on average. This is equivalent to a 23 percent savings in fuel use for passenger cars, or a 28 percent savings for light trucks. If we hold the number of miles driven per vehicle steady at the relatively high 2007 levels, we can expect to be close to an upper bound of expected total savings of 12.3 billion gallons of gasoline per year by 2015, as a result of the stricter vehicle standards. Recently announced stricter fuel efficiency and greenhouse gas pollution standards for model years 2017-2025 require 54.5 MPG fleetwide average and have been estimated to reduce oil consumption by 2.2 million barrels per day or approximately 33 billion gallons per year by 2025.³⁴

3.2.1.2 Hybrid vehicles

Hybrid-electric vehicles are by now a familiar presence on U.S. roads. Powered by gasoline, hybrid vehicles can produce significant efficiency gains by using ‘regenerative braking,’ recapturing the energy given off when a car brakes by charging a supplemental electric battery. However, by 2010, following the economic downturn that began in 2008, the sale of hybrids in the U.S. market had dropped by more than 20 percent from its 2007 peak.³⁵ Plug-in hybrids, whose batteries can be charged through electrical grid connections, entered the U.S. passenger vehicle market in 2010.

Hybrids attract attention because of their high fuel efficiency. However, it is important to note, that these gains are not necessarily additional to the savings noted above under fuel efficiency and greenhouse gas pollution standards, since hybrids would constitute a portion of the efficiency gains required under those regulations. Hybrids may be a promising technology for manufacturers to achieve fuel efficiency and greenhouse gas pollution standards. For instance, the Toyota Prius, by far the most popular hybrid in the United States, gets an EPA estimated average 50 MPG.³⁶ This compares favorably to a number of important benchmarks, including

³⁴ U.S.EPA. 2011. News Releases: President Obama Announces Historic 54.5 MPG Fuel Efficiency Standard. July 2011.
<http://yosemite.epa.gov/opa/admpress.nsf/1e5ab1124055f3b28525781f0042ed40/0019c092ccae8ac2852578dc0056ded0!OpenDocument>

³⁵ U.S. DOT, Bureau of Transportation Statistics. National Transportation Statistics 2011. Table 1-19: Sales of Hybrid Vehicles in the United States. October 2011.
http://www.bts.gov/publications/national_transportation_statistics/

³⁶ http://www.fueleconomy.gov/FEG/bymodel/2012_Toyota_Prius.shtml

the 2008 average passenger car efficiency of 22.6 MPG, the average new car efficiency of 32.6, and the 2010 CAFE standard of 27.5 MPG.³⁷ Of course, not all hybrids match the Prius for fuel efficiency, particularly some of the hybrid sport utility vehicles on the market. Perhaps a more useful point of comparison would be the Toyota Camry hybrid, which, at 41 MPG, represents a 46 percent improvement over the conventional Camry.³⁸ Projecting this 46 percent improvement to all hybrid vehicles implies an upper bound for total oil savings of about 240 gallons per vehicle per year, based on 2008 average consumption of 522 gallons per passenger vehicle.³⁹

3.2.1.3 Electric and plug-in hybrid vehicles

All-electric vehicles, rather than using gasoline, typically run on batteries, which need to be charged on a regular basis. Most users charge electric cars every night through a connection to the electric grid or an off-grid power source. Instead of an internal combustion engine, such vehicles make use of an electric motor. Many of the mechanical parts of a conventional engine are thus eliminated or replaced with electronic components. On a daily basis, the operating cost of an electric vehicle is generally lower than a typical vehicle, due to reduced fuel and maintenance costs. At present, however, the adoption of such vehicles is hindered by their limited range and by the current state of battery technology, among other factors. Many electric vehicles can travel only 50 to 100 miles on a single charge and the batteries used are heavy, expensive, and need to be replaced every few years. Plug-in hybrids, which do not face the same range limitations, are more likely to be widely adopted by consumers over the near term, especially as battery technology improves and costs decrease.

President Obama has proposed aggressive policies to promote electric cars in the United States with the goal of one million electric vehicles by 2015.⁴⁰ Certain automakers are investing heavily in electric cars. In particular, Nissan began selling its first all-electric car, the Leaf, in late 2010 in the United States, Japan and Europe.⁴¹ Chevrolet also released the Volt in late 2010, which is an all-electric car with a range-extending gasoline generator.⁴² Ford will begin selling an electric version of the Focus starting in 2012, with initial production goals of 5,000 to

³⁷ U.S. DOT, Bureau of Transportation Statistics. National Transportation Statistics 2011. Table 4-23. Average Fuel Efficiency of U.S. Passenger Cars and Light Trucks. October 2011. http://www.bts.gov/publications/national_transportation_statistics/

³⁸ http://www.fueleconomy.gov/FEG/bymodel/2012_Toyota_Camry.shtml. Calculation is a comparison of the 2012 Camry Hybrid LE 4 cylinder model to the non-hybrid 4 cylinder Camry.

³⁹ U.S. DOE, EIA. *Annual Energy Review 2010*. Table 2.8: Motor Vehicle Mileage, Fuel Consumption, and Fuel Economy, 1949-2008. DOE/EIA-0384(2010), October, 2011. <http://www.eia.doe.gov/aer/>. Calculation assumes a 46 percent decrease in average passenger vehicle fuel consumption.

⁴⁰ U.S. DOE. Analysis Shows Significant Advances in Electric Vehicle Deployment. February 8, 2011. http://apps1.eere.energy.gov/news/daily.cfm/hp_news_id=290

⁴¹ Reuters. "Nissan Unveils Electric Car, to Be Available Next Year." New York Times. August 2, 2009.

⁴² Chevrolet. Somebody has to be first. November 17, 2011. <http://www.chevrolet.com/volt-electric-car/>

10,000 vehicles per year.⁴³ The electric sports car manufacturer, Tesla, is planning greater production capacity for its new Model S, projecting 20,000 vehicles per year in 2012.⁴⁴ Other manufacturers have all-electric vehicles in the development phase or for sale in countries other than the United States.

President Obama's objective of at least one million electric vehicles by 2015 would represent approximately 0.7 percent of the total U.S. vehicle fleet. Consequently, the near-term impact of all-electric vehicles on oil consumption may be modest, especially since the early adopters of these vehicles are likely to be drivers who travel relatively short distances.⁴⁵ As in the case of pure hybrid gains, the efficiency gains may not necessarily be greater than the fuel efficiency and greenhouse gas pollution standards, but electric cars may be the technology chosen to achieve the fuel efficiency and greenhouse gas pollution standards.

It is important to note the environmental consequences of shifting from gasoline to electricity as a fuel source for vehicles. In simple terms of energy used, due to efficiency gains allowed by design differences, electric vehicles represent a significant improvement over gasoline vehicles. The Nissan Leaf, with a 24 kWh battery, can travel 73 miles on a single charge, with a fuel economy equivalent to 99 MPG of gasoline.⁴⁶ Electric vehicles, therefore, produce environmental benefits by eliminating fossil fuel combustion and the associated tailpipe emissions of SO₂, NO_x, particulate matter, and greenhouse gases. However, these benefits are offset by increased emissions from electricity generation at power plants. The extent of these offsetting impacts will be determined by the electricity fuel sources used, which varies in different regions across the country. In the Pacific Northwest, which has a high proportion of hydropower, the net impact of electric vehicles may be positive. However, in areas where coal (which is more greenhouse gas-intensive than oil and can emit high levels of SO₂, NO_x, and particulate matter) is the dominant fuel source, the overall effect may be modestly beneficial or harmful. Areas in the immediate vicinity of coal-fired power plants may incur substantially worse air and water quality. Similarly, replacing oil fuel in cars with electricity from nuclear power plants could lead to increased production of radioactive waste, which if improperly transported or disposed could pose serious health hazards. The substitution of renewable energy as a source of baseload power (e.g., through the development of utility-scale wind, solar, biomass, and geothermal resources), would mitigate the negative impact of increased reliance on electric vehicles.

⁴³ Jim Motavalli. "New York Auto Show: Ford, Microsoft and E.V.'s." New York Times online, Wheels blog. March 31, 2010. <http://wheels.blogs.nytimes.com/2010/03/31/new-york-auto-show-ford-microsoft-and-e-v-s/?ref=automobiles>

⁴⁴ Matt Nauman. "Tesla to Build Electric-car Factory in San Jose." San Jose Mercury News. October 10, 2008.

⁴⁵ U.S. DOT, Bureau of Transportation Statistics. National Transportation Statistics 2011. Table 4-11 Passenger Car and Motorcycle Fuel Consumption and Travel. http://www.bts.gov/publications/national_transportation_statistics/

⁴⁶ <http://www.fueleconomy.gov/feg/evsbs.shtml>

3.2.2 Ethanol vehicles

Ethanol is a form of alcohol, of the type found in alcoholic beverages. As a hydrocarbon, it can also be used as an energy carrier and it has been used as a fuel source or additive for vehicles for several years. Most ethanol used for fuel in the United States is derived from corn, although in other countries, such as Brazil, sugar cane is a more popular and more efficient feedstock.

In the United States, ethanol is used primarily as an additive to gasoline. Several states mandate or subsidize ethanol blends in the range of 5 to 15 percent. Less frequently, ethanol is used as the primary fuel, either as an 85/15 blend with gasoline or in pure (neat) form. While all gasoline-powered vehicles can use ethanol in small amounts, higher concentrations require modifications. Flex-fuel vehicles can use any mixture of gasoline and ethanol or, in some cases, natural gas. Nearly eight million flex-fuel vehicles are currently in use in the United States. However, many owners may be unaware that their vehicle has this capability.⁴⁷

In the near term, ethanol use is likely to be determined largely by policy requirements. Most notably, the Renewable Fuel Standard, as revised through the Energy Independence and Security Act of 2007, requires an increase from nine billion gallons of ethanol and other renewable fuels in 2008 to 36 billion in 2022. EPA has established interim targets of 12.95 billion gallons in 2010 and 20.5 billion gallons in 2015,⁴⁸ more than 10 percent of 2008 levels of total oil consumption for transportation. Assuming this goal remains in force, the 7.5 billion gallon increase in biofuels over this time period should offset about five billion gallons of gasoline per year by 2015, taking into account ethanol's considerably lower energy density as compared to gasoline.⁴⁹

The impacts on land use and food prices from such a large increase in corn production for ethanol may be significant. These will be considered below, when we evaluate the longer-term potential for oil and gas substitutes in the transportation sector.

3.2.3 Public transportation

For people living in urban areas, public transportation can provide a substitute for automobiles, especially for purposes of commuting to work or school. While many people live in areas that are not well served by public transportation, or do not have public transportation options that meet their particular needs, for others it is a viable option even within the existing transportation infrastructure. Upwards of 65 million people live in the 10 urban areas with the highest transit usage. Many more live in other transit-served areas. As of December 31, 2009, 7,200 separate public transportation service systems were operating in the United States. Of this total,

⁴⁷ Flexible Fuel Vehicles. U.S. DOE, Office of Energy Efficiency and Renewable Energy. February 24, 2010. http://www.afdc.energy.gov/afdc/vehicles/flexible_fuel.html

⁴⁸ EPA Finalizes Regulations for the National Renewable Fuel Standard Program for 2010 and Beyond. U.S.EPA, Office of Transportation and Air Quality. February 2010. <http://www.epa.gov/otaq/renewablefuels/420f10007.pdf>

⁴⁹ Bioenergy Conversion Factors. U.S. DOE, Oak Ridge National Laboratory. N.d. http://bioenergy.ornl.gov/papers/misc/energy_conv.html

approximately 5,200 were classified as paratransit, or transportation for elderly and disabled persons that does not follow fixed routes or schedules.⁵⁰

Due in part to high oil prices, transit usage reached an all-time high in 2008, with ridership declining slightly in 2009.⁵¹ Seventy percent of trips taken on public transportation were for travel to work or school. A similar proportion of riders used public transportation five or more days per week. However, only about five percent of workers nationwide used public transportation to commute to work on a regular basis.⁵² We conclude that the greatest potential for increased use of public transportation exists among commuters who currently drive to work.

The extent of oil and gas savings from using public transportation instead of automobiles is dependent on a number of factors, including but not limited to, the mode of public transportation used and its fuel source, the distances involved, and the fuel use characteristics of users' automobiles. In general, it is safe to conclude that due to the inherent efficiencies in transporting large numbers of people at once, public transportation usage reduces oil and gas consumption, even for those modes of travel such as most buses that rely on fossil fuels. The American Public Transportation Association (APTA) cites data from two major reports on the topic, showing that for a typical year, using public transportation produced direct energy savings equivalent to 420 million gallons of gasoline, plus an additional 340 million gallons from avoided congestion. An even larger amount, 3.4 billion gallons, was saved due to reduced travel distances caused by public transportation-related location decisions.⁵³

It is difficult to estimate the extent to which increased reliance on public transportation in place of automobiles could reduce consumption of oil and gas in the near term. Aggregated data on the utilization rate of the Nation's public transportation infrastructure, that is, the proportion of the capacity in place that is already being used, the complement to which is the proportion that could be used to accommodate increased ridership without requiring additional investment, are not readily available. Nor is it clear how many Americans who do not currently use public transportation on a regular basis could choose to do so without moving or changing their place of work.

One method to estimate the benefits of increased public transportation on energy use is to assume a continuation of the growth trend in transit use from 2004 to 2008. In 2009 growth did not continue, but it is not clear if this is a change in trend or a short term dip.⁵⁴ APTA cites the

⁵⁰ APTA. 2011 Public Transportation Fact Book. April 2011.
<http://www.apta.com/RESOURCES/STATISTICS/Pages/transitstats.aspx>

⁵¹ Ibid.

⁵² Ibid.

⁵³ Note that this is energy savings, not oil savings. Public transportation vehicles powered by electricity would be using some electricity generated from oil and gas, but would also presumably be relying on large amounts of coal, hydropower, and nuclear power as their underlying primary energy sources. Thus, the oil and gas savings of public transportation are likely to be even larger than these numbers would suggest.

⁵⁴ Ibid.

U.S. Census Bureau's American Community Survey, which reports that 4.57 percent of workers used public transportation as their primary means of travel to work in 2004, rising to 5.01 percent by 2008.⁵⁵ This translates into an increase of about 0.11 percent of the overall working population per year. Data from the intervening years show that the increase was essentially linear. If this trend were to continue, 5.78 percent of all workers would be relying primarily on public transportation by 2015. Accounting for population growth of about one percent per year, this rate of increase would imply an additional 1.7 million regular public transportation users by 2015 over 2008 levels, an increase equivalent to 23.5 percent of 2008 transit-using commuters. If we assume that non-school and work trips remain constant, that would translate into a 16.5 percent increase in total transit trips. Based on the nationwide totals highlighted above, such an increase would produce an incremental energy savings of 125 million gallons of gasoline equivalent, assuming there are no new indirect savings from location decisions in this timeframe.

3.3 Long-term market analysis of substitutes

This section analyzes the long-term potential for substitution away from fossil fuels. The focus is primarily on ground transportation, which could demonstrate lower fuel consumption through efficiency improvements, a shift toward greater use of public transportation, or use of alternative fuels. This section also includes a discussion on the potential for oil substitution in air travel through both efficiency improvements and fuel switching.

3.3.1 More efficient vehicles

As noted above, automobiles in the United States currently have a lifespan of about 14 years. While some individual vehicles will remain in use for a longer period of time, we assume that the Nation's fleet will have turned over nearly in its entirety within 20 years. As of 2009, more than 254 million highway vehicles were registered in the United States, of which 194 million were light duty vehicles and 7.9 million were motorcycles. The remainder comprise other vehicle types, primarily trucks, vans, and larger SUVs. Population growth may add more vehicles, outpacing any decrease in vehicles per capita.⁵⁶ As recognized in the new fuel efficiency and greenhouse gas pollution standards, there is huge potential for oil reductions through efficiency improvements in the Nation's automobiles. As mentioned previously, the fuel efficiency and greenhouse gas pollution standards may create incentives for the deployment of the following technologies. Since natural gas currently accounts for such a small proportion of fuel used for transportation, we do not consider it further.

3.3.1.1 Hybrid vehicles

Hybrid vehicles are already fairly well-established, with all of the major automakers now mass-producing hybrid models. While hybrids will remain somewhat more expensive than conventional cars in terms of the upfront cost, the premium will likely fall as technology

⁵⁵ Ibid.

⁵⁶ U.S. DOT, Bureau of Transportation Statistics. National Transportation Statistics 2011. Table 1-11: Number of U.S. Aircraft, Vehicles, Vessels, and Other Conveyances. January, 2012.
http://www.bts.gov/publications/national_transportation_statistics/

improves and manufacturers continue to scale up production. With sufficiently strong tax incentives or other forms of policy support, hybrids theoretically could replace conventional automobiles entirely.

The calculations performed earlier can be repeated to illustrate the potential scale of the impacts such a shift would entail. If population growth continues at its current pace, there will be about 393 million people in the United States in 2035, likely translating into roughly 300 million vehicles. Projecting a 46 percent savings per vehicle, based on the hybrid and traditional Toyota Camry models, would imply a total savings of 72 billion gallons of gasoline, more than one-fourth of total current consumption for ground transportation. While this is a very rough, illustrative figure, it nonetheless shows that hybrid vehicles have the potential to offset a significant fraction of oil use. Other types of fuel efficiency improvements, such as switching from trucks to cars or using more lightweight materials, would offer additional gains.

3.3.1.2 Electric and plug-in hybrid vehicles

The key to future rates of adoption of electric vehicles and plug-in hybrids are the batteries used to replace, in whole or in part, the gasoline-powered combustion engine. Both plug-in hybrids and electric vehicles currently use lithium-ion batteries. Most conventional hybrids use nickel-metal hydride technology, but are expected to switch over to lithium-ion batteries as well.⁵⁷ Within the broad characterization of lithium ion batteries are several different subtypes, each of which can be evaluated on six basic criteria: energy storage capacity, power, safety, performance, life span, and cost. Significantly, none of the battery types currently in use performs well across all six criteria. As a result, despite expected improvements in the years to come, the Boston Consulting Group concluded that technology and prices challenges remain as the industry continues to mature.⁵⁸

Similarly, a report from the National Research Council (NRC) explored the prospects for plug-in hybrid vehicles by 2030. NRC estimates that under optimistic assumptions the maximum number of plug-in electric vehicles on the road at that time would be 40 million. Cost and convenience factors suggest that 13 million may be more likely. NRC did not anticipate significant cost improvements in lithium-ion batteries in the foreseeable future.⁵⁹

Given this outlook, the impact of plug-in hybrid and electric vehicles is likely to be comparatively modest, even over a fairly long 25-year horizon. Plug-in hybrids use 20 to 55 percent less gasoline than traditional hybrids, depending on the mix of electricity and gasoline used.⁶⁰ Electric vehicles, of course, use no oil at all. The existence of 40 million plug-in

⁵⁷ Pike Research. Electric Vehicle Batteries – Lithium Ion batteries for Plug-in Hybrid and Battery Electric Vehicles: Market Analysis and Forecast. 2009. <http://www.pikeresearch.com/research/electric-vehicle-batteries>

⁵⁸ The Boston Consulting Group. Batteries for Electric Cars: Challenges, Opportunities, and the Outlook to 2020. January 2010. <http://www.bcg.com/documents/file36615.pdf>

⁵⁹ National Research Council of the National Academies. Transitions to Alternative Transportation Technologies— Plug-in Hybrid Electric Vehicles. 2010. http://www.nap.edu/catalog.php?record_id=12826

⁶⁰ Ibid.

hybrids, matching the high estimate from NRC, would imply a savings of about 12 billion gallons of gasoline per year. While the NRC report did not consider all-electric vehicles, a similar number of electric vehicles, a very aggressive assumption, would save about 22 billion gallons of gasoline per year. The more likely figure of 13 million vehicles would produce savings of four to seven billion gallons.

3.3.2 Ethanol vehicles

Perhaps the single most important factor influencing the long-term adoption of ethanol is the cost of producing cellulosic ethanol. Unlike traditional corn- or sugar-based ethanol, which is derived from starch, cellulosic ethanol uses cellulose as its basis, a structural component of plant cell walls and the most common organic compound on earth. A cost-effective method to produce cellulosic ethanol would allow for the use of a wide variety of feedstocks, including inedible crop residues and plants that grow on marginal agricultural land with little or no active cultivation. This in turn would enable far greater use of ethanol as a substitute for petroleum-based fuel.

At this time, cellulosic ethanol production is too expensive to justify large-scale use, due largely to the cost of producing enzymes to convert cellulose into a useable form. However, many observers expect significant cost reductions in the coming years. An early bellwether may be Novozymes, the world's largest manufacturer of industrial enzymes, which announced in February 2010, that it was launching a line of enzymes that it expects will lower overall production costs to under \$2 a gallon, a cost that is in line with those for corn-based ethanol and gasoline.^{61,62} In April 2011, construction started on a plant expected to produce 13 million gallons of cellulosic ethanol annually.⁶³

If ethanol production costs fall below those of petroleum, further policy support may be unnecessary, as ethanol may become the preferred transportation fuel. Failing this, however, energy policy could play a major role in determining future levels of ethanol use. As noted above, the Energy Independence and Security Act mandates the use of 36 billion gallons of ethanol in 2022, of which 16 billion is intended to be cellulosic ethanol.⁶⁴

Another important consideration is the availability of sufficient agricultural capacity to support substantially greater reliance on biofuels without causing an unacceptable rise in the price of

⁶¹ Leber, Jessica. Economics Improve for First Commercial Cellulose Ethanol Plants. ClimateWire. February 16, 2010. <http://www.nytimes.com/cwire/2010/02/16/16climatewire-economics-improve-for-first-commercial-cellu-93478.html>

⁶² Motavalli, Jim. Cellulosic Ethanol's Time May Finally Have Come. BNET. March 11, 2010. <http://www.bnet.com/blog/electric-cars/cellulosic-ethanol-8217s-time-may-finally-have-come/1475>

⁶³ Novozymes Bioenergy. Novozymes partner to open world's largest cellulosic ethanol plant in 2012. 9 <http://novozymes.com/en/news/news-archive/Pages/novozymes-partner-to-open-largest-cellulosic-ethanol-plant-in-2012.aspx>

⁶⁴ EPA Finalizes Regulations for the National Renewable Fuel Standard Program for 2010 and Beyond. U.S. EPA, Office of Transportation and Air Quality. February 2010. <http://www.epa.gov/otaq/renewablefuels/420f10007.pdf>

basic foods due to upward pressure on demand for agricultural land. A 2005 joint report by DOE and the U.S. Department of Agriculture (DOE/USDA) examined the feasibility of displacing 30 percent of the country's petroleum consumption with biomass-based energy, which the authors estimated would require dry biomass potential of about one billion tons per year. That report identified the potential for 368 million dry tons biomass potential per year from forestlands and 998 million dry tons biomass potential from agricultural lands, with "relatively modest changes in land use and agricultural and forestry practices." Agricultural biomass would comprise a mix of crop residues, grains for biofuels, process residues, and dedicated perennial crops. Not all of this would be suitable for conversion to liquid fuels for transportation. Nonetheless, the report makes clear that the country has the productive capacity to meet a portion, but not all, of its transportation fuel demand from biofuels.⁶⁵ In addition to estimating the potential capacity of biofuels, a follow up report has estimated capacity at different price ranges, which broadens the potential capacity range from well below to well above the 2005 estimate.⁶⁶

The DOE/USDA 2005 study cited above noted several potential environmental impacts from increased use of forest and agricultural land for biofuel production.

- Increased logging could result in greater soil erosion and elevated levels of sediment in surface waters.
- Removing crop residues could reduce soil quality, increase erosion, and release carbon from the soil into the atmosphere.
- In addition, removing the nutrients embodied in crop residues could lead to increased fertilizer use, leading to increased nutrients in water runoff and greater use of fossil fuels for fertilizer manufacture.⁶⁷

Furthermore, agriculture is relatively fuel-intensive. Reliance on petroleum to power machinery and equipment and to manufacture fertilizers and other inputs could offset much of the potential for biofuels to reduce overall petroleum consumption. Cellulosic ethanol is expected to have a more favorable life-cycle profile than corn ethanol, but it will nonetheless be unable to reduce petroleum consumption on a one-to-one basis.

Overall, if cellulosic ethanol becomes cost-competitive with other liquid fuel sources and/or it is given sufficiently strong policy support, it may displace a significant amount of petroleum in the long term, possibly approaching 30 percent of total consumption.

⁶⁵ DOE/USDA. Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply. April 2005. http://www1.eere.energy.gov/biomass/pdfs/final_billionton_vision_report2.pdf

⁶⁶ DOE/USDA. U.S. Billion-ton Update: Biomass as Feedstock for a Bioenergy and Bioproducts Industry: August 2011. http://www1.eere.energy.gov/biomass/pdfs/billion_ton_update.pdf

⁶⁷ Ibid.

3.3.3 Public transportation

In the short term, cities that have established public transportation systems could see increased ridership on their existing routes. To expand the impact of public transportation over the longer term, cities could build new mass transit systems or expand existing systems, thereby allowing residents to reduce their use of gasoline-fueled automobiles. While no firm rules exist regarding the time needed to develop new systems, anecdotal information from cities that have recently created or expanded their transit networks is instructive.

- Houston voters approved a transit referendum involving light rail in 1988, but due to opposition by key lawmakers, it was not until March 2001, that construction started on the city's METRORail system. It opened in January 2004.
- The Metro Light Rail system in Phoenix was created in the city's 2000 Regional Transit Plan. Construction began in March 2005, and the system started operations in December 2008.
- Denver has had light rail since 1994, but recently completed a major expansion. A 1995 congestion study ultimately led to a major highway and light rail expansion project known as T-REX. Construction began in October 2001, and was completed in November 2006.

These experiences suggest that a 10 to 15- year time horizon generally should be sufficient for large cities to create or expand light rail systems. Bus-based systems presumably could be implemented in a much shorter timeframe.

It is difficult to predict which cities that currently lack light rail or tram service would be most likely to add such systems, but the most populous metropolitan areas that do not currently have light rail or tram service would seem to be likely targets. These include Austin and San Antonio, Texas; Cincinnati and Columbus, Ohio; Kansas City, Missouri; Las Vegas, Nevada; and Orlando, Florida.

These metropolitan areas had an estimated combined population of 13.8 million as of July 2009, approximately 4.5 percent of the U.S. population.⁶⁸ The extent to which new public transit networks in these or other cities could reduce automobile use would depend on the extent of the systems, the frequency of service, and residents' driving habits. To illustrate the potential magnitude of the effect, however, if 10 percent of the residents of those cities switched from automobiles to public transit for commuting purposes, it would mean an 18.7 percent increase in total nationwide transit use. This would save the energy equivalent of approximately 142 million gallons of gasoline or about one percent of current consumption for ground-based travel.⁶⁹ It is important to note, however, that by influencing patterns of urban development, the development

⁶⁸ U.S. Census Bureau. Annual Estimates of the Population of Metropolitan and Micropolitan Statistical Areas: April 1, 2000 to July 1, 2009. March 2010. <http://www.census.gov/popest/metro/CBSA-est2009-annual.html>

⁶⁹ This estimate relies on the same assumptions used in section 3.2.3 to estimate the impact of a nationwide increase in public transit use from 2010 to 2015.

of light rail systems could have a substantially greater impact over the span of decades. The APTA study cited above estimates that the indirect oil savings from public transportation due to location effects were more than four times greater than the direct savings from substituting for individual automobile trips.⁷⁰

3.3.4 Hydrogen and fuel cell vehicles

The advantages of hydrogen gas as a transportation fuel include its abundance as an element, its density as an energy carrier, and its lack of harmful emissions. However, since its gas form is too rare to be collected, it must be created from water, making hydrogen more like a battery than a traditional fuel. In vehicles, hydrogen gas can be used in two different ways, for burning in an internal combustion engine or as a chemical reaction in a fuel cell. The focus of this section is on the latter, which has the potential for greater efficiency. Fuel cells work by separating a chemical fuel, such as hydrogen, into negatively charged electrons and positively charged ions. The electrons are forced through a wire to create an electrical current that powers the vehicle. The electrons then are reunited with the ions and oxygen to form pure water. Since there are no moving parts, fuel cells are reliable and can remain operational for a long time.

Although hydrogen is one of the most abundant elements on earth, it occurs only rarely in pure elemental form. Hydrogen for fuel must be gathered from another source. Currently, 95 percent of the hydrogen used in the United States is produced through steam reforming of natural gas, in which high-pressure steam reacts with methane to produce hydrogen, carbon monoxide, and a small amount of carbon dioxide.⁷¹ A potentially more environmentally friendly but expensive alternative is to split water molecules into hydrogen and oxygen through the process of hydrolysis. Since hydrolysis is powered by electricity, renewable power sources, such as wind or solar, theoretically could be used to produce the hydrogen needed to fuel vehicles.

All of the technology needed for hydrogen-powered, fuel cell-operated cars already is in existence, but not at a stage that would permit cost-effective, widespread commercial deployment. Key areas of ongoing research include the materials and manufacturing process for fuel cells, in particular, reducing the amount of platinum used. Sufficient progress appears to be occurring for Toyota to expect to market a mid-size hydrogen sedan in 2015.⁷² However, some analysts argue that automakers will need to realize further cost reductions to make hydrogen vehicles cost-competitive with current offerings.⁷³ Another area of ongoing research concerns development of more efficient means of producing hydrogen through hydrolysis or from other

⁷⁰ APTA. 2010 Public Transportation Fact Book. April 2010.
<http://www.apta.com/RESOURCES/STATISTICS/Pages/transitstats.aspx>

⁷¹ U.S. DOE, Office of Energy Efficiency and Renewable Energy. Natural Gas Reforming. December 15, 2008.
http://www1.eere.energy.gov/hydrogenandfuelcells/production/natural_gas.html

⁷² Mukai, Anna and Yuki Hagiwara. Toyota to Unveil Hydrogen-Fueled Sedan. November 15, 2011.
<http://www.businessweek.com/news/2011-11-15/toyota-to-unveil-hydrogen-fueled-sedan-aqua-compact-hybrid-car.html>

⁷³ Ohnsman, Alan. Toyota Targets \$50,000 Price for First Hydrogen Car. Bloomberg. May 6, 2010.
<http://www.businessweek.com/news/2010-05-06/toyota-targets-50-000-price-for-first-hydrogen-car-update2-.html>

non-fossil fuel sources, which would ultimately be more environmentally beneficial than production from natural gas.

Another critical issue is the “chicken-and-egg” problem inherent in deploying hydrogen fuel on a wide scale. Widespread adoption of hydrogen vehicles will necessitate significant investments in infrastructure to make the fuel as widely available as gasoline is at present. However, it will be difficult to justify investment on the scale required until there are enough hydrogen-fueled cars on the road to create sufficient demand to support the industry. So long as there is a sufficient supply of petroleum or biofuels that can use existing infrastructure to meet the needs of the Nation’s vehicle fleet, this will likely be more cost effective than the full cost of the transition to a hydrogen system. Well-timed policy support likely would be necessary to establish an adequate hydrogen fueling infrastructure and a smooth transition.

The California Fuel Cell Partnership estimates that if fuel cell vehicles are introduced into the market on a limited scale over the next decade as expected, they could be widely available by 2030. Due to the significant lag in vehicle turnover, it would likely be another 10 to 20 years before hydrogen could replace oil as the dominant transportation fuel. Some analysts argue that hydrogen has the potential to replace almost all of the petroleum used by the transportation sector, but over a long time horizon.⁷⁴

3.3.5 More efficient planes

As noted above, air travel has grown significantly more fuel-efficient over time. This trend is expected to continue into the future, due in part to engineering changes and in part to operational improvements. A recent National Aeronautical and Space Administration (NASA) and Boeing report forecasts that efficiency gains of 15 to 20 percent are possible in the medium term.⁷⁵ Meanwhile, member airlines of the International Air Transport Association, including American, Continental, Delta, United, and US Airways, have set a voluntary goal of a 25 percent improvement in fuel consumption per *revenue-ton-mile* by 2020 compared to 2005 levels.⁷⁶ If successful, a 25 percent fuel savings would reduce 4.7 billion gallons of fuel annually by 2020, based on 2008 levels of consumption. However, if passenger-miles traveled continue to grow at the three percent annual rate seen over the last five years, and if revenues rise accordingly, the reduction would be 6.4 billion gallons, equivalent to about 2.5 percent of total U.S. transportation fuel use in 2010.

3.3.6 Alternative-fuel planes

In a 2006 NASA Technical Memorandum, Daggett et al. explore the potential for alternative fuels in the aviation sector. The authors found that biofuel could be blended into jet fuel in small

⁷⁴ National Renewable Energy Laboratory. “Validation of Hydrogen Fuel Cell Vehicle and Infrastructure Technology.” October 2007. <http://www.afdc.energy.gov/afdc/pdfs/42284.pdf>

⁷⁵ Daggett, D. et al. “Alternative Fuels and Their Potential Impact on Aviation.” NASA Technical Memorandum 2006-214365, October 2006. <http://gltrs.grc.nasa.gov/reports/2006/TM-2006-214365.pdf>

⁷⁶ International Air Transport Association. “Fuel Efficiency.” N.d. http://www.iata.org/whatwedo/environment/Pages/fuel_efficiency.aspx

quantities of 5 to 20 percent without requiring any engine modifications. An additional fuel processing step may be required to make the fuel compatible with the sector's exacting specifications. They go on to note that "[f]or biofuels to be viable in the commercial aviation industry, significant technical and logistical hurdles need to be overcome. However, the task is not insurmountable and no single issue makes biofuel unfit for aviation use." In fact, on November 7, 2011, in an effort to demonstrate technical viability, United became the first U.S. airline to fly commercial passengers on a plane fueled with a blend of biofuel and traditional jet fuel.⁷⁷ Other potential fuel sources, such as hydrogen or ethanol, are less suited to aviation, because the added weight of storage tanks for hydrogen or the weight and volume of ethanol fuel creates significant energy efficiency penalties.⁷⁸

As with biofuel use for ground vehicles, supply is likely to pose a bigger constraint than demand in the aviation sector. At 20 percent of current levels of fuel use, the upper limit suggested for blending with jet fuel as currently formulated, jet travel could consume as much as 2.2 billion gallons of biofuel. Soybeans, the major domestic biofuel crop, yields about 60 gallons of fuel per acre, meaning about 37 million acres would be required, an area the size of Illinois.

In light of the limits on available supply for biofuels, Daggett et al. conclude that it may be more efficient to concentrate use of this fuel source in the much larger ground transportation sector. They suggest that in the long term, the most attractive option for alternative jet fuel may be synthetic fuel produced from coal or natural gas.⁷⁹ However, to make this path environmentally preferable, at least with regard to greenhouse gas emissions, processing plants involved would need to utilize carbon sequestration, a technology that has not yet been widely adopted.

In summary, our review of potential sources of oil and gas savings from the transportation sector highlights the following.

- The ground transportation sector accounted for about 168 billion gallons of gasoline and diesel fuel use in 2009. Air travel consumed roughly 13 billion gallons of fuel, while marine travel used approximately seven billion gallons. Natural gas did not play a significant role as a transportation fuel.
- In the near term, major sources of potential fuel savings include more efficient gasoline-powered automobiles and substitution of biofuels for gasoline in automobiles. Depending on assumptions, these two sources could save approximately 17 billion gallons of gasoline per year by 2015, or about 10 percent of the total for ground transportation.
- The potential for oil savings is greater in the long term. Most notably, cellulosic ethanol could displace as much as 30 percent of total oil consumption. Hybrid and electric

⁷⁷ "United Airlines Flies First U.S. Commercial Advanced Biofuel Flight." November 7, 2011. <http://www.united.com/press/detail/0,7056,69232,00.html>

⁷⁸ Daggett, D. et al. "Alternative Fuels and Their Potential Impact on Aviation." NASA Technical Memorandum 2006-214365, October 2006. <http://gltrs.grc.nasa.gov/reports/2006/TM-2006-214365.pdf>

⁷⁹ Ibid.

vehicles, increased use of public transportation, and more efficient planes could generate oil savings as well, albeit in more modest amounts, likely on the order of 9 to 14 billion gallons of gasoline equivalent. Finally, if adopted on a wide scale, hydrogen fuel could replace substantially all of the petroleum used by the transportation sector, but only over a very long time horizon.

4. OIL AND GAS USES AND ALTERNATIVES: ELECTRICITY GENERATION SECTOR

Petroleum plays a very modest role in electricity generation and the proportion of U.S. electricity generation from oil-fired power plants has been on a steep decline since the late 1970s. For natural gas, the converse is true. Gas-fueled electricity generation has increased steadily from 1996 to 2010, nearly doubling from 1996 to 2010.⁸⁰ The electricity generation sector is second only to industrial use in terms of overall consumption of natural gas. This section analyzes the use of oil and gas for electricity generation, beginning with an examination of recent trends and current use of oil and gas in the sector, and continuing with a discussion of the near- and long-term potential for substitutes. A particular focus is on the circumstances under which these fuels are used for electricity generation and how this affects the ability of renewable energy sources to serve as substitutes.

4.1 Current use of oil and gas

Electricity generation consumed 65 million barrels of petroleum in 2010, or about 2.7 billion gallons. This translates into total primary energy use of about 376 trillion Btu.⁸¹ This represents a steep decline from 2005, when electricity production consumed more than three times as much. Prior to that, oil consumption had remained at approximately the same level since the mid-1980s. Oil consumption in the electricity generation sector peaked in 1977 at 3,900 trillion Btu, more than ten times the current level.⁸²

Within the electricity generation sector, petroleum is used primarily to fuel ‘peaker’ plants, facilities that stand idle most of the time and are used only at times of very high demand. Generally, such plants are relatively cheap to build but expensive to operate, as the per-unit fuel costs are more expensive than other plants. Thus, they are used only when all other options have been exhausted. As a result, oil provides the fuel for only a small fraction of electricity generated in the United States. Petroleum was used to produce 37 million megawatt (MW) hours of electricity in 2010, less than one percent of the 4,127 million megawatt-hour (MWh) total.

⁸⁰ U.S. DOE, EIA. *Annual Energy Review 2010*. Table 6.5: Natural Gas Consumption by Sector, Selected Years, 1949-2008. DOE/EIA-0384(2010), October 19, 2011. <http://www.eia.doe.gov/aer/>

⁸¹ U.S. DOE, EIA. *Electric Power Annual with Data for 2010*. November 09, 2011. Table ES1: Summary Statistics for the United States. http://www.eia.doe.gov/cneaf/electricity/epa/epa_sum.html

⁸² U.S. DOE, EIA. *Annual Energy Review 2008*. Table 5.14c: Heat Content of Petroleum Consumption: Transportation and Electric Power Sectors, 1949-2008. DOE/EIA-0384 (2008), June 26, 2009. <http://www.eia.doe.gov/aer/>

This was far less than the generation provided by coal, natural gas, nuclear, hydroelectric, or even biomass and wind resources.⁸³

Since most petroleum-fired plants are used relatively infrequently, these plants contribute a larger proportion of generating *capacity* to the total than they do actual generation. In 2010, oil-fired plants accounted for 57,647 MW of net summer generating capacity, or 5.3 percent of total U.S. capacity. This figure has remained fairly steady since 2002, despite the significant drop in petroleum-fueled electricity generation over that time period, during which overall peak electricity demand increased.^{84,85} For peaking power plants in particular, this indicates that there may not be a strong correlation over the short run between available capacity and actual use. Thus, oil price changes may be reflected to some degree in electricity generation, but it will take a longer time and a more sustained price change, before total capacity of oil-fired plants similarly is affected.

The use of oil predominantly as a peak fuel means that most oil-fired plants are relatively small and a relatively high number of them are in use. In 2010, 3,779 petroleum-fired generating stations were available, with an average capacity of 16.5 MW. By comparison, 1,396 coal-fired plants were in operation, with an average generating capacity of almost 250 MW.

EXHIBIT 4.1 ELECTRIC UTILITIES GENERATING CAPACITY AND NET GENERATION

ENERGY SOURCE	GENERATORS	GENERATING CAPACITY (MEGAWATTS)	NET GENERATION (THOUSAND MEGAWATT-HOURS)	PERCENT OF NET GENERATION
Coal	1,396	342,296	1,847,290	45
Gas	5,529	467,214	987,697	24
Nuclear	104	106,731	806,968	20
Hydroelectric	4,020	78,204	260,203	6
Other renewable	3015	56993	169,761	4
Petroleum	3,779	62,504	37,061	1
Total	17,843	1,113,942	4,127,648 ¹	100%

Source: U.S. DOE, EIA. Electric Power Annual with Data for 2011. DOE/EIA-0348, November, 2011.

¹. Total includes sources not represented in table.

⁸³ U.S. DOE, EIA. Electric Power Annual with Data for 2010. November 9, 2011. Table ES1: Summary Statistics for the United States. http://www.eia.doe.gov/cneaf/electricity/epa/epa_sum.html

⁸⁴ U.S. DOE, EIA. Electric Power Annual with Data for 2008. January 21, 2010. Table ES1: Summary Statistics for the United States. http://www.eia.doe.gov/cneaf/electricity/epa/epa_sum.html

⁸⁵ U.S. DOE, EIA. Electric Power Annual with Data for 2006. July 7, 2008. Table ES1: Summary Statistics for the United States. http://tonto.eia.gov/reports/reportsD_archived.cfm?title=Electric%20Power%20Annual

Compared to petroleum, much larger quantities of natural gas are used for electricity generation. In 2010, 7,680 billion cubic feet of natural gas or 7,893 trillion Btu, were consumed in electricity generation, an energy content more than 20 times greater than that supplied by petroleum. Natural gas use rose sharply during the economic expansion years, growing by an average of 6.3 percent annually from 2003 to 2008. While that rate may seem modest, it was five times greater than the overall increase in electricity generation. After dipping in 2008, it grew substantially through 2010. Only coal supplied a larger share of the Nation's electricity in 2010.⁸⁶

In terms of nameplate generating capacity, natural gas ranks as the largest component of the electricity generation sector, with 467,214 MW in 2010, or about 40 percent of the total. Growth in gas-fired capacity has outpaced overall capacity expansion in recent years, 2.2 percent versus 1.3 percent per year. Notably, gas generation expanded much more rapidly in the early years of the last decade than in later years, growing more than 16 percent per year from 1999 to 2003. This was largely in response to the relative flexibility of natural gas power plants, which can be used for baseload, intermediate, or peak generation and the comparatively favorable environmental profile of such plants compared to coal or nuclear power. As of 2010, 5,529 gas-fired generators were in operation in the United States., with an average capacity of approximately 85 MW.⁸⁷

Electricity generation is somewhat more efficient using natural gas than oil. This is partially due to the nature of the combustion engines used for each fuel. Since natural gas engines are more expensive and run more frequently, there is a greater incentive for efficient combustion. However, efficiency has also been rising in recent years as the result of greater use of natural gas combined-cycle plants. In a combined-cycle plant, exhaust gases from the gas turbine are used to heat steam which is used to turn a second turbine, thereby capturing the waste heat from the first cycle. As these secondary steam turbines are installed in new gas power plants or placed into existing ones, the efficiency of gas-fired electricity generation should continue to improve.

4.2 Near-term market analysis of substitutes

A significant proportion of oil- and gas-fired generation does have the capability to switch between the two fossil fuels. As of 2010, 26 percent or 124,412 MW of capacity with natural gas listed as the primary fuel was capable of switching to petroleum liquids and 41 percent or 22,296 MW of capacity with oil listed as the primary fuel was capable of switching to natural gas.^{88,89} However, this report is not concerned with substitutions between oil and gas but rather switches from oil and gas to other energy sources. Although no comprehensive data exist, it seems logical to assume that a similar proportion of oil and gas plants would be capable of using

⁸⁶ U.S. DOE, EIA. Electric Power Annual with Data for 2010. November, 2011. Table ES1: Summary Statistics for the United States. http://www.eia.doe.gov/cneaf/electricity/epa/epa_sum.html

⁸⁷ Ibid.

⁸⁸ U.S. DOE, EIA. Electric Power Annual with Data for 2010. November, 2011. Table 1.7: Fuel Switching Capacity of Generators Reporting Natural Gas as the Primary Fuel, by Producer Type, 2008. http://www.eia.doe.gov/cneaf/electricity/epa/epa_sum.html

⁸⁹ Ibid.

biofuels, which can be refined to meet specifications similar to those of many petroleum products. In the near term, however, the increasing demand for biofuels in the transportation sector put in place by the Renewable Fuels Standard suggests that there will be relatively little additional biofuel supply available for use by power plants. It seems likely then that there is little if any near-term potential for cost-effective substitution away from oil and gas among existing power plants.

With existing generating plants excluded, we must then consider how the composition of the electricity generation sector as a whole could change in the near term. Power plants are long-lived assets, meaning that reactions to market or policy signals necessarily will be somewhat delayed. Using data from 2004 to 2008, approximately four to six percent of all petroleum-fired generators were retired each year, implying an expected lifespan of about 20 years. For natural gas-fired generators, the retirement rate was somewhat lower, implying an expected lifespan of 23 years.⁹⁰ This is consistent with a general rule of thumb that fossil fuel plants can run for about 25 years before needing to replace generators and other key equipment. Therefore, we can assume that only those gas plants that were built in the late 1980s to early 1990s likely will be retired over the next few years. If recent trends continue, approximately 500 MW of oil-fired capacity and 2,100 MW of gas-fired capacity will be retired every year, or 2,500 MW and 10,500 MW respectively over a five-year period.⁹¹ These retirements most likely will be balanced at least in part by new capacity additions of the same type. Nonetheless, these figures give an idea of the scope of potential near-term substitution away from oil and gas. If market conditions changed such that oil or gas became more expensive, this is the maximum amount of generation we could expect to be displaced by alternatives.⁹²

However, as noted above, different fuel sources are useful for electricity generation in varying contexts. This means that certain renewable electricity sources may not be direct substitutes for oil- and/or gas-fired generation. Biomass, geothermal and nuclear power generally are used as baseload power, making them poor substitutes for oil, and of limited usefulness in replacing natural gas, which, while sometimes employed for baseload generation, is more commonly used as intermediate or peak power. Hydroelectric power mostly is used for baseload generation as well, although it is more flexible and can be ramped up and down more easily. However, with most potential large hydroelectric sites already developed, there is relatively limited potential for additional domestic capacity. A Navigant Consulting study, based on an earlier DOE report, estimated a maximum technical capacity of about 84,000 MW of additional hydroelectric power, of which 22,000 MW could realistically be developed by 2025. This would constitute an

⁹⁰ U.S. DOE, EIA. Electric Power Annual with Data for 2008. January 21, 2010. Table 1.5: Capacity Additions, Retirements and Changes by Energy Source, 2008. http://www.eia.doe.gov/cneaf/electricity/epa/epa_sum.html

⁹¹ Ibid.

⁹² This considers replacement of retiring units only, not new capacity. Based on trends from 2004 to 2008, retirements of petroleum generation are likely to outpace new additions in the near future, while new natural gas generation will outpace retirements by more than 10,000 MW per year. U.S. DOE, EIA. Electric Power Annual with Data for 2008. January 21, 2010. Table 1.5: Capacity Additions, Retirements and Changes by Energy Source, 2008. http://www.eia.doe.gov/cneaf/electricity/epa/epa_sum.html. It is doubtful that new renewables could displace this generation on top of the replacement of retiring units discussed here.

increase of approximately 30 percent over 2010 levels, but would still leave hydropower at less than 10 percent of total electricity generation.⁹³

Wind and solar power are more likely alternatives for both of these fossil fuels.⁹⁴ Due to their intermittent nature, however, there are limits to the maximum amount of near-term penetration that these energy sources will likely achieve in a cost-effective manner. Nonetheless, a report from National Renewable Energy Laboratory (NREL) projected that wind power could achieve a 20 to 30 percent penetration in the eastern United States by 2024, given sufficient investment in transmission upgrades. In the absence of such investment, this level of wind penetration would require significant curtailment or shutting down of wind plants, with a high associated cost.⁹⁵ Sufficiently robust infrastructure is important in that it can more effectively use widely-dispersed wind plants to ‘cancel out’ each other’s variability. While wind generation in particular has been growing at an impressive rate with nearly 10,000 MW installed in 2009,⁹⁶ on par with capacity additions of oil and gas in recent years,^{97,98} it is not likely to approach this 20 percent penetration in the next five years. Indeed, uncertainty regarding Federal support for wind energy resulted in a decrease in new installed capacity in 2010, a total of just over 5,100 MW. Through the third quarter of 2011, new installed capacity for the year stood at 3,360 MW.^{99,100} Solar power currently makes up a much smaller proportion of electricity generation and is not likely to displace a significant amount of fossil fuel generation over that time frame.

Finally, note that the electricity generation industry is shifting from simple-cycle steam turbines to combined-cycle generators for natural gas. Combined-cycle generators are about 25 to 30 percent more efficient than simple-cycle generators in terms of electricity produced per unit

⁹³ Frantzis, Lisa. Job Creation Opportunities in Hydropower. Navigant Consulting. April 26, 2010.

⁹⁴ This is true in terms of electricity produced and thus fuel used on an ongoing basis. With regard to *capacity*, it is a more dubious proposition. Since wind and solar are not firm resources, a certain level of natural gas or oil capacity generally will be required as ‘backstop’ resources to protect against grid problems in times when the supply of these renewables cannot meet the instantaneous demand for electricity.

⁹⁵ EnerNex Corporation, prepared for NREL. Eastern Wind Integration and Transmission Study: Executive Summary and Project Overview. January 2010. http://www.nrel.gov/wind/systemsintegration/pdfs/2010/ewits_executive_summary.pdf

⁹⁶ American Wind Energy Association (AWEA). Market Update: Record 2009 Leads to Slow Start in 2010. May 2010. http://www.awea.org/pubs/factsheets/Market_Update_Factsheet.pdf

⁹⁷ U.S. DOE, EIA. Electric Power Annual 2010 with Data for 2010. November 9, 2011. Table 1.5: Capacity Additions, Retirements and Changes by Energy Source, 2010. <http://www.eia.gov/electricity/annual/>

⁹⁸ Again, it is important to distinguish between capacity and electricity generation. Due to its intermittency, wind has a much lower capacity factor than oil or gas generation. Thus, a megawatt of wind capacity will produce far less electricity over time than a megawatt of natural gas capacity or petroleum, if it is being used for non-peak power. Capacity additions of wind and solar cannot be considered one-for-one substitutes for fossil fuels.

⁹⁹ AWEA Press Release, January 24, 2011. http://www.awea.org/newsroom/pressreleases/release_01-24-11.cfm

¹⁰⁰ AWEA. U.S. Wind Industry, Third Quarter Market Report, October 2011. <http://www.awea.org/learnabout/publications/reports/upload/3Q-2011-AWEA-Market-Report-for-Public-2.pdf>

fuel.¹⁰¹ We can expect a trend towards greater efficiency to continue as newer natural gas generators and power plants come online, meaning that less gas will be needed to meet the same level of electricity demand.

Overall, in the near term, maximum potential for a shift away from oil and gas in the electricity generation sector is limited by the level of oil and gas generator retirements, expected to be about 2,500 MW and 10,500 MW over five years, respectively, and the extent to which these generators can be replaced by renewables, predominantly wind power, and more efficient natural gas combined cycle plants. Based on 2008 capacity factors and fuel efficiency, we estimate that this maximum replacement potential translates into about 182 billion cubic feet of gas and 3.5 million gallons of oil avoided each year. While wind power may place some strains on the grid at high levels of penetration, this is not a near-term concern. Biofuels and other renewables are not likely to play a significant role in replacing fossil fuels over this time period.

4.3 Long-term market analysis of substitutes

As noted above, fossil fuel generators, both oil and gas, have an expected lifespan of about 20 to 25 years. In this timeframe, there will be a more or less complete turnover of the Nation's oil and gas generators, as well as the new additions necessitated by growth in demand. There is significant potential for substitution away from these fuels over that period, dependent on the availability and suitability of other power sources.

Biofuels represent the most obvious potential substitute for petroleum and gas in terms of fuel characteristics. However, as noted above, they are more likely to be used in the transportation sector, which represents a much larger source of demand. Even assuming significant scale-up of new biofuel production capabilities, the maximum amount available from domestic sources would not likely be enough to meet current levels of both transportation and electricity fossil fuel demand. Therefore, biofuels are excluded from further consideration here.

As of 2010, natural gas accounted for 24 percent of electricity generation and petroleum provided an additional one percent. As noted above, NREL has concluded that wind power alone could achieve 20 to 30 percent penetration in the eastern United States by 2024, with adequate investments in transmission infrastructure.¹⁰² Furthermore, a similar study found that 30 percent wind penetration technically is feasible in the western states as well, with some modifications to current practice by grid managers.¹⁰³ In simple terms of magnitude, wind theoretically could displace oil and gas for electricity generation entirely. Wind already is reasonably cost-competitive with oil and gas and will become more so if fuel prices rise and/or if

¹⁰¹ U.S. DOE, EIA. Electric Power Annual with Data for 2010. November 9, 2011. Table 5.4: Average Heat Rates by Prime Mover and Energy Source, 2010. <http://www.eia.gov/electricity/annual/>

¹⁰² EnerNex Corporation, prepared for NREL. Eastern Wind Integration and Transmission Study: Executive Summary and Project Overview. January 2010. http://www.nrel.gov/wind/systemsintegration/pdfs/2010/ewits_executive_summary.pdf

¹⁰³ GE Energy prepared for NREL, Western Wind and Solar Integration Study: Executive Summary. May 2010. http://www.nrel.gov/wind/systemsintegration/pdfs/2010/wwsis_executive_summary.pdf

climate policy results in a carbon tax or cap-and-trade mechanism. The manufacturing process and technology for wind turbines is fairly mature and well-established. Therefore, for wind, the most important constraint will be the ability of the electric grid to accommodate significant amounts of an intermittent resource. Much of the wind potential evaluated by NREL would come from the Great Plains. While the report emphasizes the benefits of regional integration and coordination, this geographic dynamic suggests that a portion of wind power likely will replace coal, rather than oil or gas.¹⁰⁴ In addition, some amount of oil or gas will be needed to balance the intermittency of wind resources. Nonetheless, wind power potentially could replace a major portion of oil- and gas-fired electricity generation.

A substantial portion of the long-term wind potential identified by NREL, 54 gigawatts, is to come from offshore wind. The United States has areas appropriate for offshore wind power development near large coastal urban areas. With growing electricity demand and space constraints on land-based electricity generation and transmission, offshore wind is favorably positioned to play a role in meeting future energy demand.¹⁰⁵ Constructing sufficient transmission infrastructure is a significant barrier. However, with Google and Good Energies, a renewable energy investment firm, committing to significant investment in an undersea transmission ‘backbone’ that would serve projects along the Atlantic coast, there could be sufficient infrastructure to spur additional offshore development.¹⁰⁶ Since U.S. coastal areas rely more heavily on natural gas and small amounts of oil for electricity generation than the Midwest, any offshore wind development would help further reduce dependence on these fossil fuels.

Solar power, although not expected to play a significant role in centralized electricity generation over the next few years, could become more important given the right mix of technological improvements and market or policy influences. A study by the research firm Clean Edge, Inc. and the non-profit Co-op America found that photovoltaic and concentrated solar power could reach 10 percent of electricity generation by 2025, although this would require a capital investment of hundreds of billions of dollars. As a resource that generally is available during times of peak demand, i.e., warm-weather periods, widespread use of solar power would imply significant displacement of both oil and gas. Such a scenario is dependent on significant cost decreases in the manufacturing process, to be driven both by realization of economies of scale and other technological improvements.¹⁰⁷

¹⁰⁴ Although coal is a baseload power source, and thus not directly replaceable by a given wind plant, a widely dispersed network of wind plants could provide sufficiently firm power in the aggregate to eliminate the need for a portion of the region’s coal-fired capacity. The NREL report frames its results in terms of smaller increases in capacity of fossil plants, rather than absolute reductions. However, it appears that they forecast wind to displace a mix of coal and gas plants. See Figure 13, p. 35.

¹⁰⁵ Large-Scale Offshore Wind Power in the United States: Assessment of Opportunities and Barriers. NREL September 2010. <http://www.nrel.gov/wind/pdfs/40745.pdf>

¹⁰⁶ Wald, Matthew L. Offshore Wind Power Line Wins Backing, New York Times. October 12, 2010. <http://www.nytimes.com/2010/10/12/science/earth/12wind.html?ref=business>

¹⁰⁷ Clean Edge, Inc., and Co-Op America. Utility Solar Assessment (USA) Study: Reaching Ten Percent Solar by 2025. June 2008. <http://www.cleandedge.com/reports/reports-solarUSA2008.php>

Overall, given favorable conditions, solar and wind power could be used to replace a significant portion of oil and gas used for electricity generation. The technical constraints posed by their status as intermittent resources mean that these energy sources cannot be used to completely replace fossil fuels, even with investments in the transmission grid and/or in battery storage. While it is not the aim of this report to develop a detailed forecast, some simple math can illustrate the potential scope of substitution. EIA's *Annual Energy Outlook 2011* forecasts electricity generation to grow at one percent annually over the next 25 years.¹⁰⁸ At that rate, total electricity generation would be approximately 5,389 billion MW-hours in 2035, up from 4,119 billion MW-hours in 2008. If wind is in fact able to reach 20 percent and solar to reach 10 percent penetration, this would imply a total of about 1,078 and 539 billion MW-hours respectively produced from these sources. By way of comparison, wind accounted for 1.34 percent of all generation in 2008, while solar was virtually zero. If the assumption is made that half of the growth in these renewables replaces oil and gas, and half coal, this suggests that they could displace 772 billion MW-hours of oil- and gas-fired electricity annually, more than 80 percent of the current total produced from these sources. This is roughly two-thirds of what would come from these fossil fuels in 2035 if they were to continue to hold their current proportions of total generation. If expanded renewables displaced a higher proportion of oil and gas relative to coal, then even more electricity from these sources could be avoided.

Note that nuclear power represents another potential substitute for natural gas. The Nuclear Regulatory Commission is reviewing applications for operating licenses for 22 new nuclear power plants. Power companies are considering additional plants as well.¹⁰⁹ However, since natural gas is used primarily as an intermediate or peak power source, whereas nuclear power is a baseload resource, the potential for substitution is limited. Furthermore, the extent to which nuclear power will be able to successfully compete with other baseload resources such as coal or biomass will depend on climate policy, the relative ease or difficulty of gaining regulatory approval, and fuel cost and availability. Nonetheless, expanded use of nuclear power could result in avoided natural gas use to a greater degree than outlined above.

Finally, we note that climate change and energy policy could have a significant effect on shaping the electricity sector. It is not the intention of this paper to discuss potential policy initiatives and their potential impacts in detail. It is difficult to predict the political appetite for climate and energy policy or the specific tools potentially employed. However, concepts discussed in the last five years include the following:

- *EPA regulation of greenhouse gases as criteria pollutants under the Clean Air Act.* In April 2009, EPA declared carbon dioxide and five other greenhouse gases to be endangering public health and welfare, a precursor for the agency to regulate them under the Clean Air Act. If regulations were promulgated, they likely would reduce coal use and increase oil and gas use.

¹⁰⁸ U.S. DOE, EIA. *Annual Energy Outlook 2011*. April, 2011.
[http://www.eia.gov/forecasts/archive/aeo11/pdf/0383\(2011\).pdf](http://www.eia.gov/forecasts/archive/aeo11/pdf/0383(2011).pdf)

¹⁰⁹ Nuclear Energy Institute. *New Nuclear Plant Status*. January 2011.
<http://www.nei.org/resourcesandstats/documentlibrary/newplants/graphicsandcharts/newnuclearplantstatus/>

- *A nationwide renewable energy standard or clean energy standard.* A renewable energy standard would require electric utilities to meet a minimum amount of electricity demand, e.g., 20 percent, through renewable sources. A clean energy standard, as proposed by the Obama Administration, would credit a broader range of clean electricity sources, including nuclear power, with partial credit for generation from efficient combined-cycle natural gas plants and fossil fuel plants that capture and store carbon dioxide.
- *Subsidies for renewable energy production.* Policymakers could extend existing incentives for generation from renewable sources, such as the production tax credit of 2.1 cents per kilowatt-hour for wind or the investment tax credit of 30 percent of the cost of solar installations, or create new incentives, such as feed-in tariffs similar to those that enabled significant renewable energy capacity expansion in Europe in recent years.

These or other policy measures will influence the mix of renewables, oil, gas, and other resources in the electricity sector, but they will be unlikely to change the maximum potential levels of substitution described above. Even over a 25-year time horizon, natural gas is likely to contribute a significant portion of electricity generation in the United States.

5. OIL AND GAS USES AND ALTERNATIVES: INDUSTRIAL SECTOR

5.1 Current use of oil and gas

The industrial sector used 1.57 billion barrels of petroleum in 2010, with primary energy use of 8,029 trillion Btu. It consumed a similar 7,930 trillion Btu in natural gas, slightly more than the 7,380 trillion Btu used for electricity generation. Therefore, the industrial sector was the second-largest petroleum-consuming sector of the economy after transportation and the highest gas-consuming sector.^{110,111}

Industrial oil use peaked domestically in 1979 at just less than two billion barrels. More recently, levels of consumption have remained relatively steady from year to year. From 1998 to 2007, annual industrial petroleum use held between 1.77 and 1.91 billion barrels, a difference of less than 10 percent. Oil use has remained lower since 2008, due to the economic recession. What has changed over the past decades is the composition of the sector's petroleum inputs. Liquid petroleum gases (LPG) have increased steadily as a proportion of total petroleum, from five percent in 1950, to 24.2 percent in 1980 and 33.3 percent in 2008. As LPG use has grown, residual fuel oil has virtually disappeared, dropping from 33.4 percent of industrial oil in 1950 to

¹¹⁰ U.S. DOE, EIA. *Annual Energy Review 2010*. Table 5.14b: Heat Content of Petroleum Consumption: Industrial Sector, 1949-2010. DOE/EIA-0384(2010), October 19, 2011. <http://www.eia.doe.gov/aer/>

¹¹¹ U.S. DOE, EIA. *Annual Energy Review 2010*. Table 2.1d: Industrial Sector Energy Consumption, 1949-2010. DOE/EIA-0384(2010), October 19, 2011. <http://www.eia.doe.gov/aer/>

just 1.4 percent in 2010.¹¹² Since LPGs are cleaner comparatively than residual fuel oil, this indicates that the net environmental impact of industrial oil use has moderated over time.

Natural gas has a similar story. After peaking in 1973 at 10,388 trillion Btu, industrial natural gas consumption fell sharply in the late 1970s and early 1980s, before climbing back during the 1990s. Natural gas use has been falling again in recent years, from 9,933 trillion Btu in 1997 to 7.380 trillion Btu in 2010.¹¹³ This could reflect a response to a long-term trend of rising natural gas prices over that time period.

Oil and gas are used for three broad purposes within the industrial sector--to generate heat and steam for industrial processes, either in boilers or in direct process heating; for heating and air conditioning of ambient air; and as nonfuel feedstocks for a variety of products, including solvents, lubricants, plastics, asphalt, and various chemicals. Oil and natural gas also are used by many industrial facilities for cogeneration, which produces electricity, as well as usable heat and steam to be consumed either on-site or by neighboring facilities.

The EIA's Annual Energy Review (AER), the source for the summary figures listed above, does not provide more fine-grained information on particular end uses of petroleum and natural gas. For that, we rely on EIA's quadrennial Manufacturing Energy Consumption Survey (MECS), which last reported data for 2006. There are discrepancies between the industrial sector as defined in the AER and manufacturing facilities as defined in the MECS, with the MECS appearing to cover a smaller amount of total industrial activity. Nonetheless, the two are similar enough for us to use manufacturing facilities as a proxy for the entire industrial sector. Doing so allows us to examine the particular end uses of oil and gas within the industrial sector in greater detail.

Exhibit 5.1 shows total energy use in manufacturing facilities for both fuel and non-fuel applications. Specific end uses are discussed in greater detail below.

¹¹² U.S. DOE, EIA. *Annual Energy Review 2010*. Table 5.13b: Estimated Petroleum Consumption: Industrial Sector, 1949-2010. DOE/EIA-0384(2010), October 19, 2011. <http://www.eia.doe.gov/aer/>

¹¹³ U.S. DOE, EIA. *Annual Energy Review 2010*. Table 2.1d: Industrial Sector Energy Consumption, 1949-2010. DOE/EIA-0384(2010), October 19, 2011. <http://www.eia.doe.gov/aer/>

EXHIBIT 5.1 MANUFACTURING FACILITIES ENERGY USE, TRILLION BTU

END USE	NET ELECTRICITY		NATURAL GAS		PETROLEUM		COAL		OTHER		TOTAL	
	2002	2006	2002	2006	2002	2006	2002	2006	2002	2006	2002	2006
Boiler Fuel												
Conventional Boiler Use	9	41	1,306	1,281	99	96	255	129	--	--	1,679	1,547
CHP and/or Cogeneration Process	4	--	857	838	61	69	521	417	--	--	1,443	1,324
Direct Uses - Process												
Process Heating	343	346	2,742	2,487	142	110	368	345	--	--	3,595	3,288
Process Cooling and Refrigeration	194	206	45	32	2	1	*	*	--	--	241	239
Other Process Use	1,681	1,692	169	269	23	41	12	66	--	--	1,885	2,068
Direct Uses - Nonprocess												
Facility HVAC	262	265	417	378	13	13	5	2	--	--	699	658
Facility Lighting	196	198	--	--	0	0	--	--	--	--	196	198
Other Facility Support	48	60	30	30	1	1	*	*	--	--	79	91
Other Nonprocess Use	3	8	10	8	1	7	0	*	--	--	14	23
Boiler Fuel and Direct Uses Subtotal	2,740	2,817	5,576	5,322	342	342	1,162	961	--	--	9,831	9,442
Nonfuel Uses (Btu equivalent)	0	0	674	398	3,022	2,380	799	473	3,693	3,711	8,189	6,962
Boiler Fuel, Direct Uses and Nonfuel Uses Total	2,740	2,817	6,251	5,719	3,364	2,722	1,961	1,434	3,693	3,711	18,020	16,404
Other Uses												
Onsite Transportation	4	7	2	3	53	55	--	--	--	--	59	65
Conventional Electricity Generation	--	--	55	19	1	4	14	3	--	--	70	26
End Use Not Reported	96	26	162	168	56	58	6	52	6,006	5,820	6,306	6,125
Total	2,840	2,850	6,470	5,909	3,474	2,839	1,981	1,489	9,699	9,531	24,455	22,620

-- Not applicable

* Estimate less than 0.5

Numbers do not add due to rounding.

Sources: U.S. DOE, EIA. Manufacturing Energy Consumption Survey 2006. Table 5.2: End Uses of Fuel Consumption, 2006; Table 2.2: Nonfuel (Feedstock) Use of Combustible Energy, 2006. June 2009. <http://www.eia.gov/emeu/mecs/mecs2006/2006tables.html>

5.1.1 Process heating

Process heating is the practice of heating particular materials used in manufacturing, such as metals, plastics, and ceramics. Process heating softens, melts, or evaporates materials, and may be used to catalyze chemical reactions. This can be accomplished through a variety of equipment types, including furnaces, ovens, dryers, and specially designed heaters for the process in question. Process heating systems may use fuel directly or may be either electricity- or steam-based. Only direct fuel-burning equipment is considered here.

Process heating is the largest industrial fuel use of natural gas. Excluding onsite transportation within industrial facilities, electricity generation, and unspecified uses, process heating accounted for 47 percent of industrial natural gas use in 2006. In 2002, the date of EIA's previous MECS survey, this number stood at 49 percent. Total gas use for process heating dropped by nine percent over that time period.

Process heating is also a major industrial use of petroleum, if nonfuel applications are excluded. Process heating represented 32 percent of industrial petroleum fuel use in 2006, once again excluding transportation, electricity generation, and unspecified uses. Petroleum use for process heating dropped 23 percent from 2002, at which point it had accounted for 42 percent of industrial petroleum fuel use. If nonfuel applications are included, process heating accounted for less than five percent of total petroleum use in both 2002 and 2006.^{114,115}

5.1.2 Boilers and cogeneration

Boilers use a fuel source such as oil or gas to produce steam, which is in turn used to heat other materials and/or the ambient environment, or to drive turbines. EIA's MECS distinguishes boilers from direct process heating, which does not use steam as an intermediary. The equipment used is different between these two processes, although the end application may often be the same, i.e., heating a manufacturing input.

Conventional boilers accounted for 28 percent of industrial petroleum use for fuel in 2006, with cogeneration responsible for another 20 percent, for a total of 48 percent. The numbers were somewhat lower for natural gas, at 24 percent and 16 percent respectively. Again, these figures exclude onsite transportation, non-cogeneration electricity production, nonfuel applications, and unspecified uses. There has been relatively little change in these proportions from 2002. Including nonfuel use has only a modest impact on natural gas, but drops the proportion of petroleum use for boilers and cogeneration dramatically, to four percent for boilers and three

¹¹⁴ U.S. DOE, EIA. Manufacturing Energy Consumption Survey (MECS) 2006. Table 5.2: End Use of Fuel Consumption, 2006. June 2009. See also the same table in MECS 2002. <http://www.eia.gov/emeu/mecs/mecs2006/2006tables.html>

¹¹⁵ U.S. DOE, EIA. Manufacturing Energy Consumption Survey (MECS) 2006. Table 2.2: Nonfuel (Feedstock) Use of Combustible Energy, 2006. June 2009. See also the same table in MECS 2002. <http://www.eia.gov/emeu/mecs/mecs2006/2006tables.html>

percent for cogeneration. Both natural gas and petroleum use for boilers and cogeneration were virtually unchanged in absolute terms from 2002 to 2006.^{116,117}

5.1.3 Heating, Ventilation, and Air Conditioning (HVAC)

After process heating and boilers and cogeneration, HVAC is the only significant industrial end use of petroleum and natural gas except use as chemical feedstocks. The HVAC sector accounted for four percent of petroleum and seven percent of natural gas fuel use in both 2002 and 2006. The proportion of petroleum use drops to less than one percent when nonfuel applications are factored in. Natural gas use for HVAC saw a modest decline in absolute terms from 2002, matching the overall pattern in industrial gas use, while petroleum remained constant.^{118,119}

5.1.4 Non-energy uses

While nonfuel applications make up a relatively small proportion of industrial gas use, just seven percent in 2006, down from 11 percent in 2002, they account for nearly 90 percent of petroleum consumption. Thus, the use of petroleum products as chemical feedstocks deserves particular attention.

¹¹⁶ U.S. DOE, EIA. Manufacturing Energy Consumption Survey (MECS) 2006. Table 5.2: End Use of Fuel Consumption, 2006. June 2009. See also the same table in MECS 2002.
<http://www.eia.gov/emeu/mecs/mecs2006/2006tables.html>

¹¹⁷ U.S. DOE, EIA. Manufacturing Energy Consumption Survey (MECS) 2006. Table 2.2: Nonfuel (Feedstock) Use of Combustible Energy, 2006. June 2009. See also the same table in MECS 2002.
<http://www.eia.gov/emeu/mecs/mecs2006/2006tables.html>

¹¹⁸ U.S. DOE, EIA. Manufacturing Energy Consumption Survey (MECS) 2006. Table 5.2: End Use of Fuel Consumption, 2006. June 2009. See also the same table in MECS 2002.
<http://www.eia.gov/emeu/mecs/mecs2006/2006tables.html>

¹¹⁹ U.S. DOE, EIA. Manufacturing Energy Consumption Survey (MECS) 2006. Table 2.2: Nonfuel (Feedstock) Use of Combustible Energy, 2006. June 2009. See also the same table in MECS 2002.
<http://www.eia.gov/emeu/mecs/mecs2006/2006tables.html>

EXHIBIT 5.2 MANUFACTURING FACILITIES SELECT NONFUEL USES OF NATURAL GAS AND PETROLEUM FOR NONFUEL, TRILLION BTU EQUIVALENT

END USE	NATURAL GAS		PETROLEUM	
	2002	2006	2002	2006
Petroleum Refineries	0	0	3,307*	3,399*
Chemicals:				
Petrochemicals	37	0	899	W
Other Basic Organic Chemicals	162	74	717	W
Plastic Materials and Resins	66	11	1,283	1,180
Nitrogenous Fertilizers	295	176	0	0
All Other Chemicals	69	91	108	W
Total Chemicals	629	352	3,007	2,297
All other applications	45	46	15	83
Total (All Nonfuel)	674	398	6,329*	5,779*

W Data withheld in source material to prevent disclosing data on individual establishments.

* Numbers shown here include 3,307 trillion Btu in 2002 and 3,399 trillion Btu in 2006 in ‘other’ fuel used at petroleum refineries, which we assume comes from petroleum.

Source: U.S. DOE, EIA. Manufacturing Energy Consumption Survey (MECS) 2006. Table 2.2: Nonfuel (Feedstock) Use of Combustible Energy, 2002 and 2006. <http://www.eia.gov/emeu/mecs/mecs2006/2006tables.html>

Over half of the nonfuel consumption of petroleum takes place at petroleum refineries. In addition to various forms of petroleum fuels, refineries also produce a range of petrochemicals, including lubricating oils, paraffin wax, and asphalt and tar. However, the information available is not sufficiently detailed to indicate petroleum use for each of these products.^{120,121}

The next most significant source of demand is plastics materials and resins, which accounts for nearly 20 percent of nonfuel petroleum consumption.¹²² Plastics come in a wide variety of forms and are used for an equally wide variety of applications. Almost all plastics are composed of chains of carbon and hydrogen, sometimes with other elements included. This structure makes petroleum an ideal feedstock for plastics. Most plastic manufacturing processes have very little material waste and incorporate virtually all of the petroleum input into the final product.¹²³

¹²⁰ Ibid.

¹²¹ The input source for this sector is classified as ‘other’ in the MECS table regardless of the actual material type (petroleum, natural gas, coal). However, given the function of oil refineries, this energy is almost certainly taken from petroleum products. This discrepancy accounts for much of the ‘other’ nonfuel consumption in the table above.

¹²² U.S. DOE, EIA. Manufacturing Energy Consumption Survey (MECS) 2006. Table 2.2: Nonfuel (Feedstock) Use of Combustible Energy, 2006. June 2009. <http://www.eia.gov/emeu/mecs/mecs2006/2006tables.html>

¹²³ Graedel, Thomas E. and Jennifer A. Howard-Grenville. Greening the Industrial Facility: Perspectives, Approaches, and Tools. New York: Springer, 2005.

Other major consuming sectors of nonfuel petroleum are classified as ‘petrochemicals’ and ‘other basic organic chemicals.’ Again, the information available does not provide any further detail. ‘Other basic organic chemicals’ also is a major nonfuel user of natural gas. However, the most significant nonfuel consumer of natural gas is nitrogenous fertilizers, which are widely used throughout the agricultural sector.¹²⁴

Notably, nonfuel use of both petroleum and natural gas was significantly lower in 2006 than in 2002. The most significant decline for each came in chemicals. Detailed information was not available for petroleum. For natural gas, the decline was especially significant in nitrogenous fertilizers which fell by 40 percent, basic organic chemicals which dropped by 54 percent, and plastics which fell by 83 percent. Although there is less detail, data from earlier years suggests this may be a sustained decrease rather than an isolated phenomenon. There was relatively little change in nonfuel consumption of petroleum at petroleum refineries or for plastics, the only major categories for which data are available for both years.¹²⁵

5.2 Near-term analysis of substitutes

Industrial equipment is typically long-lived. The Chartered Institute of Building Services Engineers (CIBSE) lists the “indicative life expectancy” for boilers at 15 to 25 years, and gas or oil fired furnaces at 15 years.¹²⁶ In addition, such equipment often represents a significant expenditure. As a result, turnover rates are relatively low. Only in extreme circumstances would a change in fuel prices prompt a facility manager to replace petroleum- or gas-fired equipment significantly in advance of its planned retirement date. For that reason, any form of fuel switching that would require replacing major equipment as a long-term but not a near-term possibility is included.

Near-term substitution will require alternative fuel sources that are compatible with existing equipment. For petroleum, this implies liquid biofuels such as ethanol or biodiesel. As discussed in the transportation chapter, near-term biofuel use will most likely be driven largely by policy requirements. The Renewable Fuel Standard currently in place sets a target of 20.5 billion gallons of renewable fuel use *for transportation* by 2015. This is more than the total domestic production forecast for that year by EIA’s *Annual Energy Outlook 2011*.^{127,128} Even if this dynamic of demand outstripping supply corrects itself somewhat, there is unlikely to be any significant quantity of liquid biofuels left over for use in industrial, fuel-based applications.

¹²⁴ U.S. DOE, EIA. Manufacturing Energy Consumption Survey (MECS) 2006. Table 2.2: Nonfuel (Feedstock) Use of Combustible Energy, 2006. June 2009. See also the same table in MECS 2002. <http://www.eia.gov/emeu/mecs/mecs2006/2006tables.html>.

¹²⁵ Ibid; see also the same table in MECS 1998.

¹²⁶ CIBSE. Indicative Life Expectancy for Building Services Plant, Equipment and Systems. N.d. <http://www.cibse.org/pdfs/newOOMtable1.pdf>

¹²⁷ EPA Finalizes Regulations for the National Renewable Fuel Standard Program for 2010 and Beyond. U.S. EPA, Office of Transportation and Air Quality. February 2010. <http://www.epa.gov/otaq/renewablefuels/420f10007.pdf>

¹²⁸ U.S. DOE, EIA. *Annual Energy Outlook 2011*. DOE/EIA-0383(2011), April 2011. <http://www.eia.gov/forecasts/archive/aeo11/>

For non-fuel uses such as plastics, there may be greater potential for substitution away from petroleum. The manufacture of biobased plastics, mostly produced from starch, sugar, and cellulose, increased by 600 percent between 2000 and 2008, although they still represent a small proportion of total plastics.¹²⁹ Globally, demand for bioplastics is forecast to grow at approximately 25 percent annually from 2010 to 2015.¹³⁰ This suggests potential for biobased plastics to replace a portion of conventional plastics.

Plastics manufacturing accounted for the equivalent of 1,198 trillion Btu of petroleum consumption in 2006. While it is not clear what proportion of total plastic produced domestically currently derives from non-petroleum sources, five to 10 percent appears to be reasonable based on global estimates.^{131,132} From this base, the projected growth rates in bioplastic manufacture just reported would suggest that an additional 130 to 260 trillion Btu of petroleum for plastics manufacturing could be replaced by biological feedstocks over the next five years. This amounts to approximately 1.5 to three percent of total industrial petroleum use.¹³³

The other readily available petroleum substitute for plastics manufacturing is recycled plastic, which can replace virgin materials. A large amount of potentially recoverable plastic is discarded in the United States each year. For example, only 7.1 percent of all plastic discarded in municipal solid waste in 2009 was recovered. However, even this represents a modest improvement from earlier years when the recovery rate was approximately six percent from 1990 through 2005.¹³⁴ In the near-term, dramatically increased recovery of plastic seems unlikely. However, if the trend of modest increases from 2005 to 2009 continues, recycling rates could reach 8.75 percent by 2015, amounting to about 2.6 million tons of plastic. The incremental increase of 0.5 million tons recycled would save about 11 trillion Btu of oil.

¹²⁹ Ceresana Research. Market Study: Bioplastics. June 2009. <http://www.ceresana.com/en/market-studies/plastics/bioplastics/>

¹³⁰ Pira International. The Future of Bioplastics for Packaging to 2020. December 13, 2010. <http://www.pira-international.com/pha-and-bio-derived-pe-to-drive-bioplastic-packaging-market-to-2020.aspx>

¹³¹ U.K. National Nonfood Crop Centre. Renewable Polymers Factsheet: Bioplastics. February 19, 2010. <http://www.nfcc.co.uk/publications/nfcc-renewable-polymers-factsheet-bioplastics>

¹³² Nova Institute. Bioplastics Market Worldwide 2007-2025. 2009. <http://innovation-bioplastique.com/2009/02/13/bioplastics-market-worldwide-2007-2025/>

¹³³ U.S. DOE, EIA. Annual Energy Review 2010. Table 5.13b: Estimated Petroleum Consumption: Industrial Sector, 1949-2010. DOE/EIA-0384(2010), October 19, 2011. <http://www.eia.doe.gov/aer/>

¹³⁴ U.S. EPA, Office of Solid Waste. Municipal Solid Waste in the United States: 2009 Facts and Figures. Table 2: Recovery of Municipal Solid Waste, 1960 to 2009. December 2010. <http://www.epa.gov/wastes/nonhaz/municipal/pubs/msw2009rpt.pdf>

5.3 Long-term analysis of substitutes

There is greater potential for substitution in the longer term as industrial facilities replace their existing oil- and gas-fired equipment, affording them the opportunity to switch to systems using alternate fuel sources. Many facilities may switch from oil to gas, but we do not evaluate this possibility here, focusing instead on moves away from oil and gas to other fuel sources. Other substitutes include biofuels, electricity, and expanded use of the substitutes noted above for plastics manufacturing, i.e., recycled plastic or biobased chemicals. While there is significant variation between different types of equipment, an appropriate rule of thumb is that industrial equipment is replaced every 25 years. This represents the appropriate timeframe for our long-term analysis.

The potential for biofuel production has already been discussed in detail in the transportation chapter and is not repeated here. As described, biofuels could displace a significant portion of petroleum use over the next 25 years, perhaps up to 30 percent of total nationwide consumption. Biofuels are unlikely to have much impact on natural gas. However, with three-fourths of U.S. petroleum use taking place in the transportation sector, most of the substitution is likely to take place there. Thus, there is comparatively little room for expanded biofuel use in the industrial realm. Furthermore, due to the limits on potential biofuel supply, based on available land to dedicate to growing fuel crops, if overall biofuel use does approach the upper boundary of 30 percent, any substitution of biofuels for petroleum that did happen in the industrial sector would come at the expense of similar substitution elsewhere. This would be true for biobased inputs for plastics manufacturing, as well as for fuel use.

Industrial facilities also could use equipment powered by electricity instead of oil- and gas-fired equipment. Given that most industrial oil- and gas-using equipment is used simply to provide heat, e.g., for process heating or in boilers, such a move generally would be thermodynamically inefficient. While electricity generation and consumption produces considerable energy losses, combustion for heat is far more efficient at utilizing embodied energy from a fuel source. Even so, electricity is a viable option, and if generated from renewable sources, it may result in lower environmental impacts.

As with biofuels, the potential for expanded use of renewable energy has been discussed previously in this report and is not repeated here. We do note, however, that substitution of electrical equipment for oil- and gas-fired combustion equipment would result in an increase in overall electricity demand. As with biofuels, if renewable power generation approaches the upper boundaries outlined previously, any renewable electricity use by industrial sources would simply displace renewable energy use that would have occurred elsewhere.

Significantly increased plastic recycling represents the final mode of substitution away from industrial petroleum use. A recent report on the European plastics industry notes that Germany recycled the highest proportion of its post-consumer plastic waste of any European country, at 33.9 percent. An additional 60 percent of Germany's plastic waste was sent to waste-to-energy plants.¹³⁵ Compared to the contemporaneous 7.1 percent U.S. recycling rate, this would

¹³⁵ PlasticsEurope, EuPC, EuPR, and EPRO. Plastics – the Facts 2010.

http://www.plasticseurope.org/documents/document/20101006091310-final_plasticsthefacts_28092010_lr.pdf

constitute an ambitious goal. We therefore use it as an upper boundary on the potential for long-term recycling in the United States.

Thirty million tons of plastic waste was generated in this country in 2009. This figure has held relatively constant in recent years.¹³⁶ If this level of waste production continues into the future, 33.9 percent recycling would represent an increase of 26.8 percent above recent levels, or an additional eight million tons of plastic. This level of recycling would save 192 trillion Btu of petroleum, or about 2.4 percent of 2010 total industrial petroleum use.¹³⁷

6. OIL AND GAS USES AND ALTERNATIVES: RESIDENTIAL AND COMMERCIAL SECTOR

This chapter discusses oil and gas consumption in the commercial and residential sectors. Similar to the industrial sector, oil and gas use in residences and commercial establishments is dominated by a small number of specific end uses. There has been a long-term shift away from oil use toward electricity in these applications, while natural gas use has not changed as dramatically. The potential substitutes for commercial and residential use of oil and gas are similar to those for the industrial sector, consisting mainly of electricity and biogas, although efficiency also could be considered a feasible substitute in certain applications. The current trend of increased building efficiency and weatherization, supported in part by investments through the American Recovery and Reinvestment Act (ARRA), favors decreasing use of oil and gas in the residential and commercial sector.

6.1 Current use of oil and gas

The commercial and residential sectors consume negligible amounts of petroleum compared to the transportation and industrial sectors, but contribute more substantially to natural gas consumption. Residences used 1,220 trillion Btu of petroleum in 2010; commercial buildings used 717 trillion Btu, for a total of 1,937 trillion Btu or 395 million barrels.¹³⁸ This amounts to 5.2 percent of nationwide petroleum consumption. For natural gas, the residential sector consumed 5,061 trillion Btu in 2010 and the commercial sector consumed 3,276 trillion Btu, for

¹³⁶ U.S. EPA, Office of Solid Waste. Municipal Solid Waste in the United States: 2009 Facts and Figures. Table 2: Recovery of Municipal Solid Waste, 1960 to 2009. December 2010. <http://www.epa.gov/wastes/nonhaz/municipal/pubs/msw2009rpt.pdf>

¹³⁷ U.S. DOE, EIA. Annual Energy Review 2010. Table 5.14b: Heat Content of Petroleum Consumption Estimates: Industrial Sector, 1949-2010. DOE/EIA-0384(2010), October 19, 2011. <http://www.eia.doe.gov/aer/>

¹³⁸ U.S. DOE, EIA. Annual Energy Review 2010. Table 5.14ab: Heat Content of Petroleum Consumption Estimates: Residential and Commercial Sectors, 1949-2010, DOE/EIA-0384(2010), October 19, 2011. <http://www.eia.doe.gov/aer/>

a total of 8,337 trillion Btu.¹³⁹ Combined, these sectors accounted for 34 percent of gas consumption, greater than industrial levels and electricity generation.¹⁴⁰

Petroleum consumption has been falling steadily in both the residential and commercial sectors since the early 1970s. Residential petroleum consumption reached its highest point in 1972, at 2,856 trillion Btu, while commercial use peaked one year later at 1,604 trillion Btu. Overall oil use has fallen by nearly 60 percent for both sectors since that time.¹⁴¹

As with the industrial sector, the composition of the residential and commercial sectors' petroleum inputs has evolved over time. In the residential sector, kerosene use has dropped precipitously, from 25.8 percent of the total in 1949 to 2.5 percent in 2010. Meanwhile, LPGs have more than made up the difference. Even more dramatically, in the commercial sector, residual fuel oil, which accounted for nearly half of all petroleum consumed in 1949, was down to just 11.7 percent of consumption in 2010. It was replaced mainly by distillate fuel oil, which almost doubled from 30.4 percent to 56.1 percent over the same time period.¹⁴² The replacement of residual fuel oil with distillate fuel oil, in particular, points to lower overall emissions from oil combustion over time.

After growing steadily from approximately 1,000 trillion Btu in 1950 to nearly 5,000 trillion Btu in 1970, annual residential natural gas consumption has remained between 4,000 and 5,250 trillion Btu over the past 40 years. Commercial gas use, meanwhile, remained steady throughout the 1970s and 1980s, increased by about 20 percent during the early 1990s, and has leveled off since. Growth in commercial gas use has been essentially flat since 1996.¹⁴³

Most residential petroleum and natural gas use is for space heating and water heating. To a lesser extent, these fuels are used for appliances such as ranges, ovens and refrigerators. Similarly, commercial gas and oil use is dominated by space heating and water heating, with additional small amounts for cooking and miscellaneous other applications. Electricity was another major energy source for these applications. The split between these fuel sources by end use is shown in the table below. Due to discrepancies between different data sources, the totals in the table do not match those reported above. Note that for residential buildings, the most

¹³⁹ U.S. DOE, EIA. Annual Energy Review 2010. Table 2.1b: Residential Sector Energy Consumption, 1949-2010, and Table 2.1c: Commercial Sector Energy Consumption, 1949-2010. DOE/EIA-0384(2010), October 19, 2011. <http://www.eia.doe.gov/aer/>

¹⁴⁰ Ibid.

¹⁴¹ U.S. DOE, EIA. Annual Energy Review 2008. Table 2.1b: Residential Sector Energy Consumption, 1949-2008, and Table 2.1c: Commercial Sector Energy Consumption, 1949-2008. DOE/EIA-0384(2008), June 26, 2009. <http://www.eia.doe.gov/aer/>

¹⁴² U.S. DOE, EIA. Annual Energy Review 2010. Table 5.14a: Heat Content of Petroleum Consumption: Residential and Commercial Sectors, 1949-2010. DOE/EIA-0384(2010), October 19, 2011. <http://www.eia.doe.gov/aer/>

¹⁴³ U.S. DOE, EIA. Annual Energy Review 2008. Table 2.1b: Residential Sector Energy Consumption, 1949-2008, and Table 2.1c: Commercial Sector Energy Consumption, 1949-2008. DOE/EIA-0384(2008), June 26, 2009. <http://www.eia.doe.gov/aer/>

recent year for which end-use data were available was 2005. To balance comparability with currency throughout this section, we use 2008 data for commercial buildings.^{144,145} Exhibit 6.1 also shows electricity consumption by these sectors, which was discussed in the electricity generation chapter.

EXHIBIT 6.1 RESIDENTIAL AND COMMERCIAL SECTOR ENERGY USE, TRILLION BTU

END USE	RESIDENTIAL SECTOR, 2005				COMMERCIAL SECTOR, 2008			
	OIL	NATURAL GAS	ELECTRICITY	TOTAL	OIL	NATURAL GAS	ELECTRICITY AND OTHER	TOTAL
Space Heating	1,070	2,950	280	4,300	240	1,560	1,000	2,800
Water Heating	290	1,410	420	2,120	20	440	320	780
Cooking & Appliances	50	430	2,770	3,250	--	170	2,800	2,970
Air Conditioning	--	--	880	880	--	30	4,110	4,140
Other	--	--	--	--	210	290	5,870	6,370
Total	1,410	4,790	4,350	10,550	470	2,490	14,100	17,060

Notes: Totals do not match those reported in text due to discrepancies between data sources.

Sources: 1) U.S. DOE, EIA. Annual Energy Review 2010. Table 2.5: Household Energy Consumption and Expenditures by End Use and Energy Source, Selected Years, 1978-2005. DOE/EIA-0384(2010), October 19, 2011. <http://www.eia.doe.gov/aer/> 2) U.S. DOE, Office of Energy Efficiency and Renewable Energy. Buildings Energy Data Book 2010. Table 3.1.4: 2008 Commercial Energy End-Use Splits, by Fuel Type (Quadrillion Btu). March 2011. <http://buildingsdatabook.eren.doe.gov/>

6.1.1 Space heating

Space heating is the most significant use of petroleum and natural gas in both the residential and commercial sectors, accounting for three-fourths of residential oil use and 62 percent of residential gas use in 2005. Electricity use for space heating was comparatively small. A similar proportion of natural gas use in the commercial sector was for space heating in the recent and comparable year of 2008, 63 percent. Oil use was minimal and electricity more substantial.^{146,147}

¹⁴⁴ U.S. DOE, EIA. Annual Energy Review 2008. Table 2.5: Household Energy Consumption and Expenditures by End Use and Energy Source, Selected Years, 1978-2005. DOE/EIA-0384(2008), June 26, 2009. <http://www.eia.doe.gov/aer/>

¹⁴⁵ U.S. DOE, Office of Energy Efficiency and Renewable Energy. Buildings Energy Data Book 2010. Table 3.1.4: 2008 Commercial Energy End-Use Splits, by Fuel Type (Quadrillion Btu). March 2011. <http://buildingsdatabook.eren.doe.gov/>

¹⁴⁶ U.S. DOE, EIA. Annual Energy Review 2010. Table 2.6: Household Energy Consumption and Expenditures by End Use and Energy Source, Selected Years, 1978-2009. DOE/EIA-0384(2010), October 19, 2011. <http://www.eia.doe.gov/aer/>

¹⁴⁷ U.S. DOE, Office of Energy Efficiency and Renewable Energy. Buildings Energy Data Book 2010. Table 3.1.4: 2008 Commercial Energy End-Use Splits, by Fuel Type (Quadrillion Btu). March 2011. <http://buildingsdatabook.eren.doe.gov/>

Perhaps surprisingly, given the low total amount of electricity used for residential space heating, 35 percent of homes used electricity as their primary heating type in 2009, a figure that has climbed steadily since 1980. The apparent mismatch between total consumption and proportional use suggests that electricity is used for heating primarily in areas with mild winters and low heating demand. The increasing percentage use of electricity has come mostly at the expense of heating oil, whose use dropped from 17 percent of homes in 1980 to 6 percent in 2009. The proportion of homes with natural gas as their primary heating fuel has declined only slightly over that same period, from 55 to 50 percent of homes. Other factors favoring electricity may include steady improvements in electric heat pump efficiency and development of hybrid-heating systems that combine electric with gas heating, with each source used within its most efficient temperature band. However, historically low prices for natural gas since the most recent EIA data in 2009 could result in increasing market share for gas heating.

6.1.3 Water heating

After space heating, water heating is the other most significant end use of oil and gas in the residential and commercial sectors, comprising 21 percent of residential oil use and 29 percent of residential gas use in 2005. In the commercial sector, water heating used negligible amounts of oil, but accounted for 18 percent of natural gas use in 2008.^{148,149}

As might be expected, a similar proportion of homes use natural gas for water heating, as for space heating, or 51 percent in 2009. This has remained essentially unchanged since 1980. Just 7 percent of homes used petroleum, fuel oil or LPG, for water heating in 2005, down from 13 percent in 1980. The remaining 39 percent of homes relied on electricity for water heating in 2005, a modest increase from 33 percent in 1980. Less than one percent of homes used other energy sources, such as solar water heating.¹⁵⁰

6.1.4 Cooking and appliances

Cooking and appliances represent the final major end uses of residential and commercial gas. About nine percent of residential and seven percent of commercial gas use went toward cooking and appliances with residences also using a small amount of petroleum for these purposes. There is no information readily available on the proportion of homes using oil, gas, and other fuels for these end uses. In absolute terms, however, natural gas use for appliance applications grew by about 20 percent from 1980 to 2005, less than the rate of population growth. Meanwhile, oil use

¹⁴⁸ U.S. DOE, EIA. Annual Energy Review 2010. Table 2.6: Household Energy Consumption and Expenditures by End Use and Energy Source, Selected Years, 1978-2009. DOE/EIA-0384(2010), October 19, 2011. <http://www.eia.doe.gov/aer/>

¹⁴⁹ U.S. DOE, Office of Energy Efficiency and Renewable Energy. Buildings Energy Data Book 2010. Table 3.1.4: 2008 Commercial Energy End-Use Splits, by Fuel Type (Quadrillion Btu). March 2011. <http://buildingsdatabook.eren.doe.gov/>

¹⁵⁰ U.S. DOE, EIA. Annual Energy Review 2010. Table 2.6: Household Energy Consumption and Expenditures by End Use and Energy Source, Selected Years, 1978-2009. DOE/EIA-0384(2010), October 19, 2011. <http://www.eia.doe.gov/aer/>

remained essentially unchanged and electricity use increased by 80 percent.^{151,152} The rise in total electricity use could be due in part to increased per-capita consumption, but seems more likely that, matching the trend with space heating and water heating, an increasing proportion of homes are using electricity rather than oil or gas as their primary fuel. It would stand to reason that a home that used gas or oil for one major end use would be more likely to use it for others as well.

6.2 Near-term analysis of substitutes

Furnaces and boilers, water heaters, and cooking appliances, the equipment directly responsible for oil and gas consumption in the commercial and residential sectors, are durable, long-lived goods. Water heaters have an average life span of 13 years, while furnaces, boilers and range/ovens typically last for 20 years or more.¹⁵³ Such items also represent significant investments for most buyers. Thus, similar to industrial consumers, residential and commercial consumers would be unlikely to replace their oil- or gas-fired equipment any earlier than necessary except under extreme conditions. For that reason, any fuel-saving strategy that would require major new equipment to be a long-term, but not a near-term possibility, is considered.

Given that dynamic, we identify two broad strategies for near-term reductions in oil and gas use in these sectors. The first strategy considered is fuel switching or, more likely, fuel blending by oil and gas distribution utilities. Heating oil, which is often distributed by trucks, could be replaced or supplemented by ethanol or biodiesel, both of which are discussed earlier in this report. Although with greater transition costs, wood pellets are another substitute fuel for homes with heating oil. Fossil fuel natural gas can be supplemented with equivalent gas produced from renewable sources.

Biogas, which is created through the anaerobic breakdown of organic material, is produced mainly from manure, sewage, or agricultural wastes in digesters, or in landfills, where such anaerobic digestion occurs naturally. While such gas is used primarily in industrial facilities for heating applications or by utilities for electricity generation, with some processing to remove moisture and impurities, similar to the process for fossil fuel natural gas, biogas can be refined to nearly pure methane and injected into distribution pipelines for use in the commercial and residential sectors. The potential for increased use of biogas was discussed in the industrial sector chapter of this report. If the United States reaches the levels of biogas production discussed, any biogas used to offset fossil fuel consumption in the commercial and residential sectors would simply replace substitution at industrial facilities or in the electricity generation sector.

¹⁵¹ U.S. DOE, EIA. Annual Energy Review 2010. Table 2.6: Household Energy Consumption and Expenditures by End Use and Energy Source, Selected Years, 1978-2009. DOE/EIA-0384(2010), October 19, 2011.
<http://www.eia.doe.gov/aer/>

¹⁵² U.S. DOE, Office of Energy Efficiency and Renewable Energy. Buildings Energy Data Book 2010. Table 3.1.4: 2008 Commercial Energy End-Use Splits, by Fuel Type (Quadrillion Btu). March 2011.
<http://buildingsdatabook.eren.doe.gov/>

¹⁵³ California Energy Commission. Consumer Energy Center: Choices at Home. N.d.
<http://www.consumerenergycenter.org/home/>

The second strategy considered for reducing oil and gas use in commercial and residential sectors is efficiency upgrades to decrease space heating demand. This refers to efficiency improvements for buildings in retaining heat, rather than the efficiency of the heating equipment itself. Adding insulation, sealing leaks, and installing more efficient windows reduces the thermal transmissivity of a building envelope, thereby reducing the oil or gas needed to maintain a comfortable temperature in the winter. These actions also can save electricity from lower demand for space cooling in the summer or space heating where electricity rather than oil or gas is the primary energy source.

In recent years, this approach has emerged as a major energy-saving strategy, largely because it often can deliver substantial energy use reductions at a fairly modest cost. In addition to ARRA-based investments, another prominent example is the Recovery Through Retrofits initiative, overseen by the Council on Environmental Quality's Middle Class Task Force. This initiative focused on overcoming market barriers to residential efficiency improvements, access to information, financing, and workforce training.¹⁵⁴ This follows on the efforts of numerous public utilities commissions and similar organizations as well as 26 states that have enacted energy savings targets, which often establish specific obligations or financial incentives for utilities to reduce energy consumption. Utilities in many jurisdictions are required to collect a separate monthly charge from customers, to be used only to fund efficiency programs. Others operate under a decoupling regulatory framework in which profits are determined not by direct revenues from energy sales, but rather from performance against a number of targets, including efficiency measures implemented. While such regulatory efforts initially focused on electric utilities, an increasing number apply to gas utilities as well.¹⁵⁵

On the household scale, DOE estimated that participants in its low-income weatherization program reduced their annual gas heating consumption by 32 percent.¹⁵⁶ Because the low-income households participating in this program have somewhat less efficient housing stock than the general population, this may overstate the potential gains somewhat. Nonetheless it indicates that there is room for substantial improvement among the entire universe of residential consumers. Forty million households are eligible for DOE's weatherization program.¹⁵⁷

On a larger level, states with gas reduction goals generally have set more modest statewide targets. For example, Massachusetts has a goal of 1.15 percent gas savings by 2012 and

¹⁵⁴ White House Council on Environmental Quality. Recovery Through Retrofit: Saving Homeowners Money and Creating Jobs. N.d. <http://www.whitehouse.gov/administration/eop/ceq/initiatives/retrofit>

¹⁵⁵ American Council for an Energy-Efficient Economy. State Energy Efficiency Resource Standard (EERS) Activity. June 2011. http://www.aceee.org/files/pdf/factsheet/State%20EERS%20Summary%20June%202011_1.pdf

¹⁵⁶ U.S. DOE, Office of Energy Efficiency & Renewable Energy. Weatherization Assistance Program. DOE/GO-102009-2846, May 2009. http://www1.eere.energy.gov/wip/pdfs/wap_factsheet.pdf

¹⁵⁷ Eisenberg, Joel F. Oak Ridge National Laboratory. Weatherization Assistance Program Technical Memorandum Background Data and Statistics. ORNL/TM-2010/66, March 2010. http://weatherization.ornl.gov/pdfs/ORNL_TM-2010-66.pdf

Minnesota's goal is 1.5 percent savings in 2013. New York has the most aggressive and long-term goal, calling for a 14.7 percent reduction in gas demand by 2020.¹⁵⁸

In the near term, it is unlikely that all homes eligible for weatherization assistance, whether from DOE or from state- or utility-level programs, will take advantage of them. Nonetheless, if all state-level programs weatherized as many homes as DOE's nationwide program, this would translate into a total of 200,000 homes per year, or one million over a five-year period.¹⁵⁹ Based on the average efficiency improvements noted above, this level of participation could result in 8.5 trillion Btu in natural gas savings, or an equivalent amount in oil or electricity.¹⁶⁰

6.3 Long-term analysis of substitutes

Over a longer timeframe, commercial and residential consumers will need to their replace space and water heating equipment and appliances as these objects reach the end of their useful lifespan. This will provide consumers an opportunity to shift away from oil- and gas-fired equipment. Construction of new building stock and renovations of existing buildings allow further prospects for substitution.

The lowest capital cost substitution would typically be to replace oil- or gas-fired space and water heating equipment and appliances with electric-powered units, which are readily available and widely used. As noted above, in 2005, 30 percent of households used electricity as the primary energy source for space heating and 39 percent used it for water heating. Both of these proportions have been growing over the past several years.¹⁶¹

Despite the lower upfront costs of electric space and water heating equipment, fuel costs may be much higher compared to oil and gas. The Federal Energy Management Program estimates the annual energy cost of a typical gas water heater as approximately half the cost of an electric unit¹⁶². The California Energy Commission reports that electricity usually costs three times as much as gas.¹⁶³ While gas water heaters generally are more expensive up front, the difference in

¹⁵⁸ Nowak, Seth et al. Energy Efficiency Resource Standards: State and Utility Strategies for Higher Energy Savings. American Council for an Energy-Efficient Economy. Report U113, June 2011. <http://www.aceee.org/sites/default/files/publications/researchreports/u113.pdf>

¹⁵⁹ U.S. DOE, Office of Energy Efficiency & Renewable Energy. Weatherization Assistance Program. DOE/GO-102009-2846, May 2009. http://www1.eere.energy.gov/wip/pdfs/wap_factsheet.pdf

¹⁶⁰ 3% reduction in space heating gas demand per participating household times 1 million participating households / 111 million total households times 2,950 trillion Btu total household space heating gas demand equals 8.5 trillion Btu savings.

¹⁶¹ U.S. DOE, EIA. Annual Energy Review 2010. Table 2.6: Household End Uses: Fuel Types and Appliances, Selected Years, 1978-2005. DOE/EIA-0384(2010), November 19, 2011. <http://www.eia.doe.gov/aer/>

¹⁶² U.S. DOE, Energy Federal Energy Management Program. Energy Cost Calculator for Electric and Gas Water Heaters. November 3, 2010. http://www1.eere.energy.gov/femp/technologies/eep_waterheaters_calc.html#output

¹⁶³ California Energy Commission. Consumer Energy Center: Water Heaters. N.d. <http://www.consumerenergycenter.org/home/appliances/waterheaters.html>

fuel costs outweighs this initial price premium. A cost comparison for space heating is more complicated, and depends on the type of electric heating technology chosen. Appliances that use resistance heating such as electric furnaces, baseboard heaters and electric oven/ranges generally are uneconomical compared to gas or oil units.^{164,165} On the other hand, air source heat pumps which operate on the same principle as central air conditioners are very efficient at moderate temperatures and may be cost competitive with oil or even natural gas, depending on local fuel prices and climate.¹⁶⁶ Some manufacturers also offer systems that combine heat pumps with natural gas backup heat, instead of traditional resistance heating, allowing consumers to take advantage of the most efficient heat source for a given ambient temperature.¹⁶⁷ Therefore, electricity remains a viable substitute for some end uses. The associated environmental impacts would depend on the fuel mix used to produce the electricity. These issues have been discussed previously and are not repeated here.

A second substitute comes in the form of renewable energy, specifically solar water heaters. Solar water heaters use collectors to gather solar energy, which then is used to heat water in a storage tank. Active solar water heaters contain a circulating pump, while passive systems do not. Although solar water heaters are most effective in warm, sunny areas such as Florida or California, they can be used in colder locations as well. Germany, for example, has more than 9,800 MW_{th} of solar thermal capacity installed, while Austria has more than 3,200 MW_{th}. Most, but not all, of this is for water heating.¹⁶⁸ In the United States, all 50 states have some form of incentive for solar water heating systems, while the Federal Government provides a tax credit covering 30 percent of the installed cost of such systems.¹⁶⁹

Solar water heaters usually have a gas or electric backup to provide supplemental heating on cloudy days, in cold seasons, or in high-demand hours. As a result, they do not eliminate gas use entirely. The Solar Rating & Certification Corporation and the Energy Star program both estimate that typical solar water heaters cut gas consumption in half.^{170,171} If applied nationwide,

¹⁶⁴ U.S. DOE, Office of Energy Efficiency & Renewable Energy. Energy Savers: Furnaces and Boilers. February 9, 2011. http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12530

¹⁶⁵ California Energy Commission. Consumer Energy Center: Stoves, Ranges and Ovens. N.d. <http://www.consumerenergycenter.org/home/appliances/ranges.html>

¹⁶⁶ EIA maintains a detailed heating cost calculator at http://tonto.eia.doe.gov/ask/generalenergy_faqs.asp#compare_heating_fuels

¹⁶⁷ Heat output of an air source heat pump declines with ambient temperature. Below a certain point, generally around 30-35°F, a back-up heat source is required to maintain home temperature.

¹⁶⁸ Eurobserv'er. Solar Thermal and Concentrated Solar Power Barometer. May 2011. http://www.eurobserv-er.org/pdf/solar_thermal_barometer_2011.pdf

¹⁶⁹ N.C. Solar Center and Interstate Renewable Energy Council. Database of State incentives for Renewables & Efficiency. N.d. <http://www.dsireusa.org/>

¹⁷⁰ Solar Rating and Certification Corporation. Solar Facts – System Ratings: OG-300 Certification of Solar Water Heating Systems. N.d. http://www.solar-rating.org/facts/system_ratings.html

this would imply residential gas savings of 700 trillion Btu and an additional oil savings of 150 trillion Btu. Solar water heating in the commercial sector could contribute modest savings. Adoption on this scale is extremely unlikely. Even a 10 percent adoption, with savings of 70 trillion and 15 trillion Btu, would represent a substantial increase over current levels. Less than one percent of U.S. homes used solar water heaters in 2005.¹⁷² This would require significant policy support. Without generous tax credits or other incentives, the higher upfront cost of a solar water heating system would make it uneconomical for most consumers to purchase, especially in less favorable climates.

Another alternative heating option is the geothermal or ground source heat pump. Geothermal heat pumps take advantage of stable year-round temperatures below ground or in groundwater, to provide a heat source in the winter or heat-sink in the summer. Geothermal heat pumps use 25 to 50 percent less energy than conventional heating and cooling systems, and provide excellent humidity control.¹⁷³ High installation costs for underground or waterborne heat exchanger piping have limited the use of geothermal heat pumps. They generally are installed in new construction homes.

The other options for long-term substitution involve improvements to the building stock itself. Improved building-envelope efficiency has been discussed as a short-term option. As stated earlier, if 200,000 homes per year are renovated, the resulting savings could reach 8.5 trillion Btu annually after five years. Simply extending this trend to a 25-year period would indicate that renovations to five million homes could save 42.5 trillion Btu in oil, gas, or electricity used for space heating. Of course, a more aggressive approach covering more homes would see proportionally greater impacts.

Over the long run, the building stock also will go through a more fundamental transformation, as new buildings are built to replace aging ones and to accommodate population growth. One well-regarded analysis estimates that 89 million new or replaced homes and 190 billion square feet of nonresidential building will be constructed by 2050. Two-thirds of buildings that will exist at that time did not exist in 2007.¹⁷⁴ For context, in 2009, there were an estimated 114 million households nationwide.¹⁷⁵

¹⁷¹ U.S. DOE and U.S. EPA Energy Star. Solar Water Heaters. N.d. http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=WSE

¹⁷² U.S. DOE, EIA. Annual Energy Review 2008. Table 2.6: Household End Uses: Fuel Types and Appliances, Selected Years, 1978-2005. DOE/EIA-0384(2008), June 26, 2009. <http://www.eia.doe.gov/aer/>

¹⁷³ U.S. DOE. Benefits of Geothermal Heat Pump System. http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12660

¹⁷⁴ Ewing, Reid et al. *Growing Cooler: The Evidence on Urban Development and Climate Change*. Urban Land Institute, 2008.

¹⁷⁵ U.S. DOE, EIA. Annual Energy Review 2010. Table 2.6: Household End Uses: Fuel Types and Appliances, Selected Years, 1978-2009. DOE/EIA-0384(2010), October 19, 2011. <http://www.eia.doe.gov/aer/>

Given the massive scale of building expected, more efficient construction could produce substantial savings in oil and gas use for space heating, as well as electricity, for both heating and cooling. This could take the form of a greater number of high-efficiency buildings, such as those constructed to standards such as Energy Star or Leadership in Energy and Environmental Design (LEED), or improvements to building codes that raise minimum performance requirements for all buildings.

Minimum building energy efficiency standards have been tightening in recent years. The International Energy Conservation Code (IECC), a model code, is expected to require 30 percent energy savings in its 2012 form as compared to the 2006 code, which itself represented a significant improvement over prior years. Such a move would have far-reaching impacts. Thirty nine states have adopted residential codes based on some version of the IECC and most of these have adopted either the 2006 or 2009 versions. A similar number of states have adopted commercial energy codes based on the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) 90.1, another model code.¹⁷⁶ Presumably, these states will continue to adopt newer versions of these codes as they are released.

On the upper end of the spectrum, voluntary standards have pushed 'green' buildings to outperform industry averages. The two most important such standards are Energy Star, managed by EPA and DOE, and the U.S. Green Building Council's LEED family of standards. The Energy Star program reports that 16,084 buildings and plants are currently Energy Star-certified.¹⁷⁷ To earn this designation, buildings must be more efficient than 75 percent of comparable buildings nationwide, which is roughly equivalent to 25 percent less energy use. LEED has been more widely adopted. As of March 2011, there were just over 30,000 registered commercial LEED building projects.¹⁷⁸ A 2008 study found that, while there was considerable variation between projects, the average LEED-certified commercial building had energy use 25 percent below that of conventional buildings.¹⁷⁹ While this is similar to the results of the Energy Star program, LEED measures against presumed results from conventional new buildings, whereas Energy Star compares its buildings to existing buildings. This discrepancy notwithstanding, we can assume that new commercial buildings meeting either the LEED or the Energy Star standard will result in at least a 25 percent reduction in energy use below current levels.

Both Energy Star and LEED have programs addressing homes. Energy Star homes must be at least 15 percent more efficient than the 2004 International Residential Code. With the additional energy-saving features included, they are typically 25 to 30 percent more efficient than standard

¹⁷⁶ Online Code Environment & Advocacy Network. Code Status. N.d. <http://www.bcap-energy.org/node/5>

¹⁷⁷ U.S. DOE and U.S. EPA Energy Star. Energy Star Certified Buildings and Plants. N.d. http://www.energystar.gov/index.cfm?fuseaction=labeled_buildings locator

¹⁷⁸ U.S. Green Building Council. About LEED. March 2011. <http://www.usgbc.org/DisplayPage.aspx?CMSPageID=1720>

¹⁷⁹ Turner, Cathy and Mark Frankel. Energy Performance of LEED for New Construction Buildings. New Buildings Institute, March 4, 2008. <http://www.usgbc.org/ShowFile.aspx?DocumentID=3930>

homes. More than one million U.S. homes currently meet the Energy Star standard.¹⁸⁰ The LEED for Homes program has not achieved similar penetration, with just under 50,000 registered homes as of March 2011. As with commercial buildings, LEED measures energy gains versus standard new buildings. It estimates an average of 30 percent energy savings for LEED-certified homes.¹⁸¹

It safely can be assumed that most if not all new residential and commercial buildings will meet the stricter minimum standards envisioned by the latest IECC and ASHRAE energy codes. Meanwhile, the overall impact of LEED, Energy Star and other voluntary green building standards will depend on market penetration. While not attempting a definitive analysis, we can make some rough, order-of magnitude approximations to demonstrate the scale of potential savings. Replacing half of all currently existing residences and commercial buildings over the next 25 years, through new construction or retrofits, with buildings that are 25 percent more efficient in space heating (a conservative estimate, since space heating will likely account for a disproportionate level of total energy savings), would translate into an aggregate 12.5 percent reduction in space heating energy demand, or about 564 trillion Btu of natural gas and 164 trillion Btu of oil. If 10 percent of these buildings met Energy Star and/or LEED standards and realized a further 25 percent improvement from the new baseline, they would save an additional 42 trillion Btu of natural gas and 12 trillion Btu of oil from space heating. In total, under these assumptions more efficient new buildings could save approximately 782 trillion Btu of oil and natural gas per year within 25 years.

7. ENVIRONMENTAL COSTS OF ENERGY ALTERNATIVES

This section focuses on the potential environmental costs associated with the primary alternatives to oil and gas. The purpose of this section is not to explore this subject in great detail. Rather, we make the point that negative as well as positive externalities, i.e., costs borne by society that are not reflected in a good's price, can be attributed to *all* forms of energy production and any complete consideration of alternatives would seek to take these costs into account. An exception could be made when increased energy efficiency, or simple conservation, are the oil or gas substitutes, as those actions often will result in decreased use of the energy resources that give rise to environmental costs. The debate surrounding the so-called "Jevons paradox" is noted, which suggests that increased efficiency in fact leads to greater overall energy consumption. The merits of that argument are beyond the scope of this report.

As described in the sections above, the primary alternatives to the direct use of oil and gas across all sectors are biofuels and electricity production for heat or for stationary or mobile power, using non-hydrocarbon fuel sources, i.e., coal, fissionable materials, or renewable resources. The following are brief overviews of the environmental cost considerations associated with each

¹⁸⁰ U.S. DOE and U.S. EPA Energy Star. Qualified New Homes. N.d. http://www.energystar.gov/index.cfm?c=new_homes.hm_index

¹⁸¹ U.S. Green Building Council. LEED for Homes. May 2011. <http://www.usgbc.org/DisplayPage.aspx?CMSPageID=1720>

of these alternatives. Much of this information is drawn from a study of energy-related externalities published by the National Academies Press in 2010.¹⁸²

7.1 Biofuels

Externalities associated with biofuels potentially occur at each of four life-cycle stages.

- Feedstock production
- Feedstock transportation to a processing facility
- Transportation of biofuels to distribution points
- Downstream effects of biofuel use.

The latter three types of externalities are not unique to biofuels, and generally reflect the production of greenhouse gases (GHG) and criteria air pollutants. Feedstock production, however, introduces several potential costs that warrant separate consideration. These include, but are not limited to:

- GHG emissions during tilling and planting, nutrient and pesticide application, and harvesting and shipping of the feedstock. This impact may be smaller for non-corn feedstocks, such as perennial grasses, the growth and harvesting of which may require fewer and less energy-intensive inputs.
- Soil erosion and water quality impacts associated with nutrient and pesticide runoff with lesser impacts generally associated with non-corn feedstocks.
- Potential loss of wildlife habitat and biodiversity when additional lands are cultivated to meet feedstock demands.

7.2 Electricity production using alternatives to oil and gas

7.2.1 Coal

The externalities associated with coal are well-known and include both environmental and social costs. On the upstream side of coal-fired power plants, these costs include:

- Injuries and illnesses attributable to coal mining operations.
- Non-occupational injuries and fatalities resulting from the large-scale movement, particularly by train, of coal from mine to power plant.
- Loss of habitat and changes in water quality, prior to any restoration activities, due to surficial mining, including the practice known as mountain top removal/valley fill.

Significant downstream externalities are those resulting from combustion-related pollutant emissions which lead to adverse human health, visibility, agricultural, and other impacts. OECM

¹⁸² National Research Council, Committee on Health, Environmental, and Other External Costs and Benefits of Energy Production and Consumption. 2010. *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use*. Washington, DC: National Academies Press.

assesses some of these impacts in the context of the No Action Alternative. See Section 2 of this report. The emission of GHGs, as well as a variety of metals such as mercury from coal-fired power plants, also are important externalities.

In addition to emissions-related externalities, coal combustion results in externalities related to the disposition of combustion residuals such as fly ash, which can be managed wet in surface impoundments or dry in landfills. The wet impoundments can be a source of groundwater contamination if protective liners do not exist or are not well-maintained. Insufficient management of impoundments also can result in structural failures and the release of large quantities of waste material, potentially causing significant ecological damage. Fugitive dust emissions from dry wastes managed in landfills are another externality that may be important to take into consideration with respect to the use of coal.

7.2.2 Nuclear

As with coal, nuclear energy gives rise to both upstream and downstream externalities, including:

- Localized impacts on ecological resources and groundwater due to uranium mining activities.
- Emissions from the facilities at which uranium conversion and enrichment occurs.
- Low risk/high consequence events that might result in the release of radioactive materials from nuclear power plants.
- Risks associated with the long-term management of low- and high-level radioactive wastes.

7.2.3 Wind, solar, and other forms of renewable energy

A primary benefit of using renewable energy resources as an alternative to fossil fuels is the absence of environmental costs associated with fuel extraction and production and with emissions during energy production. However, wind, solar, biomass, and other forms of renewable energy are not externality-free, especially when examined from a life-cycle perspective. For example:

- The siting of utility-scale wind energy projects can create space and use conflicts. Though of somewhat limited significance on land, given the relatively small footprint of individual turbines, such conflicts are potentially more significant in the offshore environment where several large projects are currently being considered. The physical presence of large turbine arrays or arrays of wave energy generators can result in conflicts with other ocean uses such as commercial fishing and marine transportation.
- The construction and operation of wind and wave energy projects in the marine environment also can disturb habitats through the placement of foundations or moorings and introduce pollutants into the environment either through emissions from the vessels used to construct and maintain the facilities or through accidental releases of fuel or hydraulic fluids from vessels or offshore substations.
- Wind turbines as well as electric vehicles may use large quantities of rare earth elements. These elements currently are mined and processed almost exclusively in China, which

places restrictions on exports, leading to concerns about supply security in the face of increasing demand.¹⁸³ Foreign mines also may be subject to less rigorous environmental and safety standards than those in the United States.

- The manufacture of solar photovoltaic components can be energy-intensive; thus, the benefits of emission-free energy production are offset to some degree by the emissions associated with the energy source upon which manufacturing is dependent.
- The manufacture of solar photovoltaic components also can be dependent on a variety of metals, the extraction and transport of which have environmental costs similar to those associated with the extraction and transport of other resources, such as coal and uranium.
- Biomass resources used for electricity generation or in combined heat and power applications can result in the same feedstock production and transportation-related environmental costs as those described above for biofuels.

8. MODELING ASSUMPTIONS AND SENSITIVITY TO ALTERNATE CASES

MarketSim incorporates a modified version of EIA's 2009 Annual Energy Outlook (AEO) Reference Case, updated to reflect ARRA. This modified version is based on a custom run of their National Energy Modeling System (NEMS) that BOEM requested from EIA. The AEO reference case normally is based on baseline assumptions for future OCS oil and gas leasing. However, MarketSim requires a reference case that reflects the No Action Alternative, i.e. the reference case in the absence of any additional OCS lease sales.

NEMS is a market-based equilibrium model with modules representing each of the fuel supply markets, conversion sectors, and end-use consumption sectors of the energy system. NEMS also includes macroeconomic and international modules. Each module incorporates the impact of government policies, combined with the most likely trajectories for, primary energy prices, technology adoption, and global economic growth. To produce a policy-neutral forecast, the AEO reference case used in NEMS incorporates only existing laws, rules and regulations, taking into account the effective start and end date of each.

The discussion of energy alternatives in this report demonstrates the potential -- independent of OCS leasing decisions -- for significant reductions in oil and gas demand, both from increased efficiency and the transition to alternative fuels. A number of factors can influence this demand shift, including government policies, technology innovation, economic activity and the relative prices of fuels. To explore the impact of these factors, EIA's AEO also includes a number of "side cases" that look at the impact of deviations from the baseline assumptions used in the reference case.¹⁸⁴ These side cases include:

¹⁸³ U.S. DOE. Critical Materials Strategy. December, 2011. <http://energy.gov/pi/office-policy-and-international-affairs/downloads/2011-critical-materials-strategy>

¹⁸⁴ U.S. DOE. *Annual Energy Outlook 2011*. Appendix E: NEMS overview and brief description of cases. April, 2011. <http://www.eia.gov/forecasts/archive/aeo11/>

- ***Policies and Standards Cases:*** The EIA reference case is policy neutral, taking into account the impact of government policies, including regulations, standards, incentives, subsidies, etc., in effect at the time the model is run. Policies are assumed to remain in place only through the date specified in the current authorizing legislation. Side cases for more aggressive policy scenarios include the “no sunset” case, which assumes that current policies are extended indefinitely, and the extended policies case, which assumes even more aggressive improvements in efficiency standards and the adoption of a renewable fuels standard. As expected, these cases result in lower overall energy consumption and increased use of renewable fuels, particularly for electricity generation. In 2035, total energy consumption in the AEO 2011 Extended Policies case is nearly 7 percent below the projection in the Reference case. Other cases look specifically at more rapid increases in fuel economy standards.
- ***Technology Cases:*** In the High Technology cases for the residential, commercial and industrial sectors, technology improvements and cost reductions occur more rapidly than in the reference cases. In the Best Available Technology cases, future equipment purchases are based on the most efficient technology available by fuel, regardless of upfront costs. Other cases look at the impact of technology and cost improvements, both in resource extraction and power generation, for different energy sources.
- ***Price Cases:*** AEO price cases explore different assumptions for primary energy prices, including oil and gas.
- ***Greenhouse Gas Cases:*** These cases explore the impact of varying levels of carbon pricing.

In general, the results of these side cases illustrate the potential variability in the future energy market conditions and examine many of the substitution opportunities discussed in the sections above. The changes to the market under these cases generally include reductions in overall energy consumption and may accelerate shifts to oil and gas alternatives. However, they do not alter the fundamental dependence of the U.S. economy on oil and gas or reduce oil demand to the point that the United States would become a net exporter. Furthermore, the impact of any of these NEMS side cases would affect both the No Action Alternative and the Proposed Action. For these reasons, the percentage changes of the energy impacts under the No Action Alternative, shown in exhibit 2.1, are unlikely to change significantly under alternate NEMS cases. For this reason, BOEM did not conduct detailed MarketSim analyses for each side case.

Finally, it is important to note that the Secretary’s authority is confined to a decision on the leasing program options, not the policy levers that would lead to the NEMS side cases. As a result, information based on the policy-neutral forecast in the AEO reference case, reflecting only current laws, rules, and regulations, is the most useful for the Secretary in making a decision. Other factors beyond the Secretary’s authority that could lead to side cases, include innovations in energy efficiency and renewable energy technologies; major changes in consumer attitudes affecting willingness to pay for “green” energy; and unforeseen changes in global energy markets.

9. CONCLUSION

This report provides supplemental background information to the Programmatic Environmental Impact Statement (EIS) and the Proposed Final Program decision document for the Five Year Program. This report presents the estimated market response and environmental impacts associated with the absence of OCS oil and gas production anticipated from the new program. These results, developed using MarketSim and OECM, inform the environmental cost considerations that would need to be taken into account in evaluating the net benefits of any transition away from production of oil and gas resources from future OCS lease sales. The paper also discusses possible near-term and longer-term alternatives to oil and gas in each use sector (transportation, electricity production, industrial, and commercial and residential), including a qualitative discussion of the potential environmental and social costs of these alternatives. It is important to recognize that the broader consideration of energy alternatives necessarily includes consideration of these costs, just as BOEM considers the environmental and social costs of each program area option. The paper concludes with a brief discussion of the modeling assumptions inherent in the NEMS inputs to MarketSim and a comparison of these assumptions to AEO side cases that address energy alternatives. These side cases show the potential for a more rapid shift to energy alternatives than in the AEO reference case, but not at a pace that would change the fundamental dependence of the U.S. economy on oil and gas.



The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.



The Bureau of Ocean Energy Management Mission

The Bureau of Ocean Energy Management (BOEM) manages the exploration and development of the nation's offshore resources. It seeks to appropriately balance economic development, energy independence, and environmental protection through oil and gas leases, renewable energy development and environmental reviews and studies.