# CHAPTER EIGHT
# TRANSPORTATION FUELS
# REFERENCE CASE

The Future Transportation Fuels (FTF) Reference Case projects fuel demand, supply, greenhouse gas (GHG) emissions, and other key features of the U.S. fuels system to 2050. The FTF Reference Case includes the Energy Information Administration's (EIA) Annual Energy Outlook 2010 (AEO2010) Reference Case, which runs to 2035. In order to meet the study objectives set by the Secretary of Energy, the National Petroleum Council (NPC) has supplemented the AEO Reference Case with (1) extrapolations to 2050 and (2) a GHG emissions baseline for 2005. The extrapolations and the GHG baseline allow the NPC to analyze fuel prospects to 2050 and potential GHG reductions relative to 2005, as requested by the Secretary.[1] The FTF Reference Case is defined as AEO2010 Reference Case + extrapolations to 2050 + 2005 GHG baseline.

## OVERALL OBSERVATIONS ON THE AEO2010 REFERENCE CASE

The FTF Reference Case is the starting point for alternative projections and pathways developed in the study. This chapter summarizes general observations on the Reference Case for specific fuels and vehicle types and describes how the NPC study group made the 2050 extrapolations and set the GHG baselines. These observations are not a critique of the AEO2010, but instead summarize the points of departure for alternative pathways.

**Hydrocarbon liquids** (HCL) play a lesser but still primary role in the U.S. fuels portfolio. The commercial viability of non-petroleum fuels is highly sensitive to assumptions about oil prices.

The AEO2010 Reference Case is a conservative estimate of potential U.S. domestic **natural gas** supply, especially shale and renewable natural gas (RNG),[2] and the possible delinking of natural gas and petroleum prices. Similarly, potential regional factors that would increase gas use, as well as vehicle market and technology developments that would promote natural gas for transportation, are not prominent in the Reference Case.

Relative to other projections cited in this study, the projected volumes and infrastructure for **biofuels** are challenging even in the business-as-usual case. Achieving 300 million tons of biomass per year by 2020 and over 500 million tons by 2035 will require progress along parallel technology pathways, resolution of competing demands for biomass, and creation of major new infrastructure for feedstocks and finished products. A uniform and comprehensive basis will also be needed for GHG accounting.

The Reference Case is conservative in estimating potential **electricity** use for transport. Projected battery cost and the rate of cost reduction have the greatest effect on the cost of electric vehicles. The Reference Case cost of $100,000 per vehicle is exceptionally high relative to other projections cited in this study and would decrease electric vehicle sales. The projected battery cost would be likely to outweigh assumptions about battery lifetime, home charging, and payback periods that might increase sales. Finally, given pending and likely regulations,

1 The Energy Information Administration has neither provided nor endorsed the 2035–2050 extrapolations made in this study. The extrapolations have been generated solely for comparative and analytical use in this study.

2 The AEO2011 released while this study was in progress doubles the estimate.

electricity sector GHG emissions may well be lower than projected in the Reference Case.

The projected sales of **hydrogen-fueled** vehicles in the AEO Reference Case suggest that market growth would be unsustainable, especially considering investments needed in vehicle technology and fueling infrastructure. If hydrogen use in transportation remains as projected over an extended period, the fueling infrastructure would be limited in geographical coverage and density, individual station sales would not provide adequate return on investment, and fuel-cell electric vehicles (FCEVs) would be unlikely to appeal to consumers. With respect to FCEVs and hydrogen as a transportation fuel, there are significant differences in the data used in the AEO2010 projections and other credible data cited in this study.

The AEO Reference Case requires a level of vehicle platform fitness, i.e., integrated design of components and fuel requirements, which will challenge the existing business model for light-duty **vehicle design and manufacturing**. The challenges range from designing vehicles and subsystems that increase fuel economy and reduce GHG emissions to providing clean-sheet options for diversified vehicle segments and markets. The cycle times for vehicle design/manufacturing and replacing the light-duty vehicle fleet pose additional challenges in moving to new fuels portfolios.

In general, while the AEO Reference Case projections are suitable for conventional transportation modes and fuels, the absence of historical market data and the rapid pace of technology may limit their utility in dealing with new technologies such as hydrogen.

## FUELS SUPPLY CHAIN

This study uses the fuels supply chain as the framework for dealing with the complexity and dynamism of the U.S. transportation-fuel system. The study looks at how this system may evolve from now through 2050 while meeting requirements for national security, economic competitiveness, and environmental sustainability. Figure 8-1 is a generic fuel supply chain from natural resource or raw material through product delivery and use in vehicles.

Figure 8-1 lists the five fuel types considered in this study: hydrocarbon liquids, natural gas, biofuels, electricity, and hydrogen. These fuels move along their respective supply chains to the engines and vehicles that carry passengers and freight. Technology appears everywhere in the supply chains and changes it over time. Economics and public policy influence each step, while consumer expectations and behavior are principal drivers of the entire system.

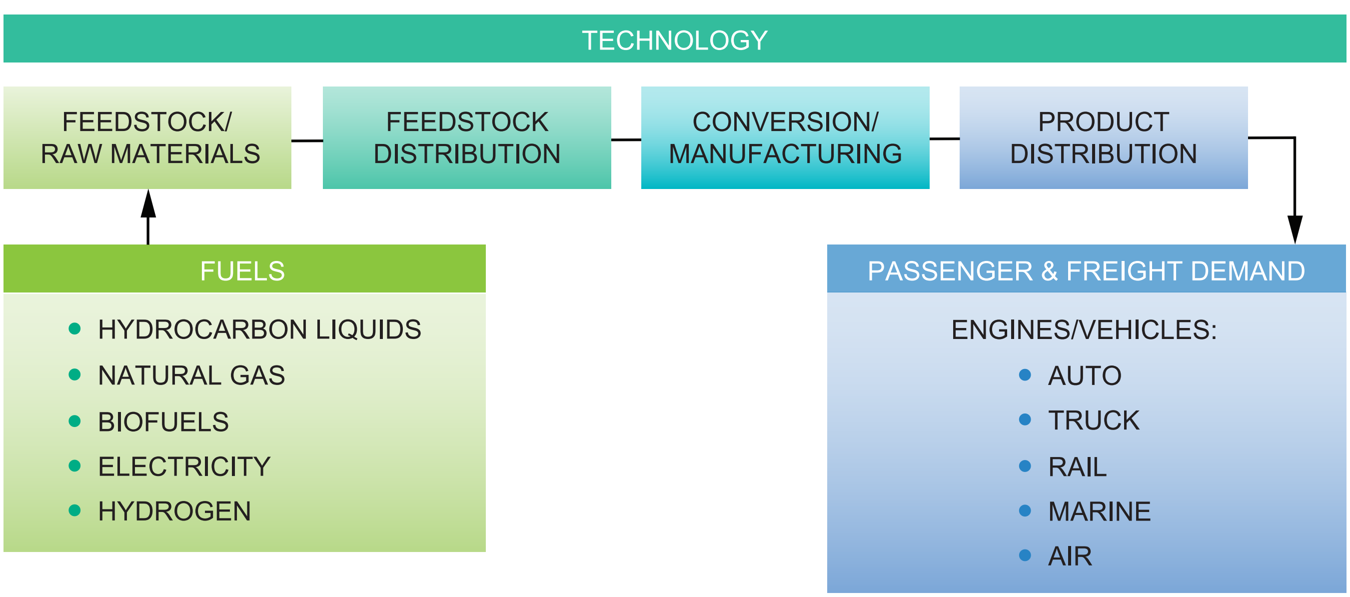



***Figure 8-1.*** *Fuels Supply Chain*

## INDIVIDUAL FUEL AND INTEGRATED SYSTEM ANALYSIS

The first phase of this study considers the current supply chain for individual fuels and the potential evolution of these supply chains through 2050, and describes engine/vehicle platforms likely to be available for each fuel. The analysis includes:

- Demand prospects for the fuel
- Natural resource or feedstock availability and volume
- Technology development needed to bring fuels to commercial viability and scale
- Infrastructure considerations
- Additional material factors that affect fuel supply and demand at scale.

The first-phase analysis creates a picture of how each fuel could individually evolve under generous assumptions about the fuel's potential market penetration, technical advances, infrastructure, GHG footprint, and other critical variables. This phase does not consider the potential interaction or effects between fuels.

The second phase of this study integrates the individual analyses into a set of potential alternatives for the entire fuel system, in stages to 2050. This complex task does consider interactions, tradeoffs, and transition effects between fuels as existing supply chains are changed or new ones are built to diversify the fuels portfolio. The alternative pathways focus on accelerating diversification relative to the FTF Reference Case.

## FTF REFERENCE CASE

The FTF Reference Case has three components: (1) the Energy Information Administration's AEO2010 Reference Case; (2) extrapolations from the AEO Reference Case endpoint in 2035 to 2050, the endpoint for this study; and (3) GHG baseline data for 2005. The FTF Reference Case provides a common starting point for analyzing fuel supply chains and developing alternative cases. The NPC used the following criteria in choosing the AEO2010 Reference Case as the starting point:

- Authoritative and widely credible
  - Publicly available, up-to-date data, and transparent methodology
- Comprehensive
  - Includes demand and supply for all fuel types
  - Includes GHG data
  - Covers study time frame or can be extrapolated to 2050
- Compatible in all respects with the NPC *Prudent Development* study[3]
- Explicit technology and policy assumptions.

By definition, the AEO2010 Reference Case is a conventional or business-as-usual projection of energy demand, supply, and prices through 2035. It assumes that laws and regulations in effect at the end of October 2009 will remain unchanged through 2035, unless the establishing legislation calls for them to end or change. The AEO Reference Case, supplemented with extrapolations to 2050 and a 2005 GHG baseline, frames several core questions:

- Can conventional projections for different fuels and vehicle types be met?
- Can conventional projections be exceeded?
- How can alternatives to the conventional projections be accelerated?
- What actions could industry and government take to reduce life-cycle U.S. transportation GHG emissions by 50% by 2050 relative to 2005 levels?

## NOTE ON ANNUAL ENERGY OUTLOOK 2011

The AEO2011, issued while this study was in progress, includes transportation-related updates that have been noted as necessary in the study. The updates include:

- Doubled volume of recoverable U.S. shale gas resources and addition of new shale oil resources
- Less influence of oil prices on natural gas prices, due partly to increased shale gas supply and improvements in natural gas extraction technologies
- Updated data and assumptions for offshore oil and gas production

3 National Petroleum Council, *Prudent Development: Realizing the Potential of North America's Abundant Natural Gas and Oil Resources*, 2011.

- Increased ethanol-gasoline blending limit (15%) for approved vehicles
- Increased electricity regions from 13 to 22
- Updated costs and sizes of electric and plug-in hybrid electric batteries
- Lower projected light-duty vehicle travel demand
- Incorporation of California's Low Carbon Fuel Standard.

The commentaries below note these updates where they are significant for particular fuels or fuel-vehicle systems.

## ENERGY USE FOR TRANSPORTATION

The AEO2010 Reference Case projects that energy use for transportation will grow from about 28 quadrillion BTU in 2008 to 32.5 quadrillion BTU in 2035. The projected growth rate of about 0.6% annually is lower than the average rate of 1.3% from 1980 to 2008, due to changing demographics, improved fuel economy, and flattening demand for personal travel. Figure 8-2 shows the AEO2010 Reference Case to 2035, with an on-trend extrapolation for 2035–2050.

### Energy Use by Fuel

In the AEO Reference Case, projected consumption increases for all fuels to 2035. However, the fossil-fuel share of total energy use decreases from 84% in 2008 to 78% in 2035 as the use of renewables increases. Total U.S. consumption of liquid fuels in the Reference Case, including fossil fuels and biofuels, grows from 20 million barrels per day (MMB/D) in 2008 to 22 MMB/D in 2035. Petroleum's share of liquid-fuel use in the transportation sector declines as consumption of alternative fuels (biodiesel, E85, and ethanol for blending) increases. Biofuels account for more than 80% of the growth in liquid fuel consumption. Figure 8-3 shows the projection to 2035 and extrapolation to 2050.

Gasoline consumption declines to 2035, with a corresponding increase in diesel and jet fuel use (Figure 8-4). Consumption grows for all fuels except

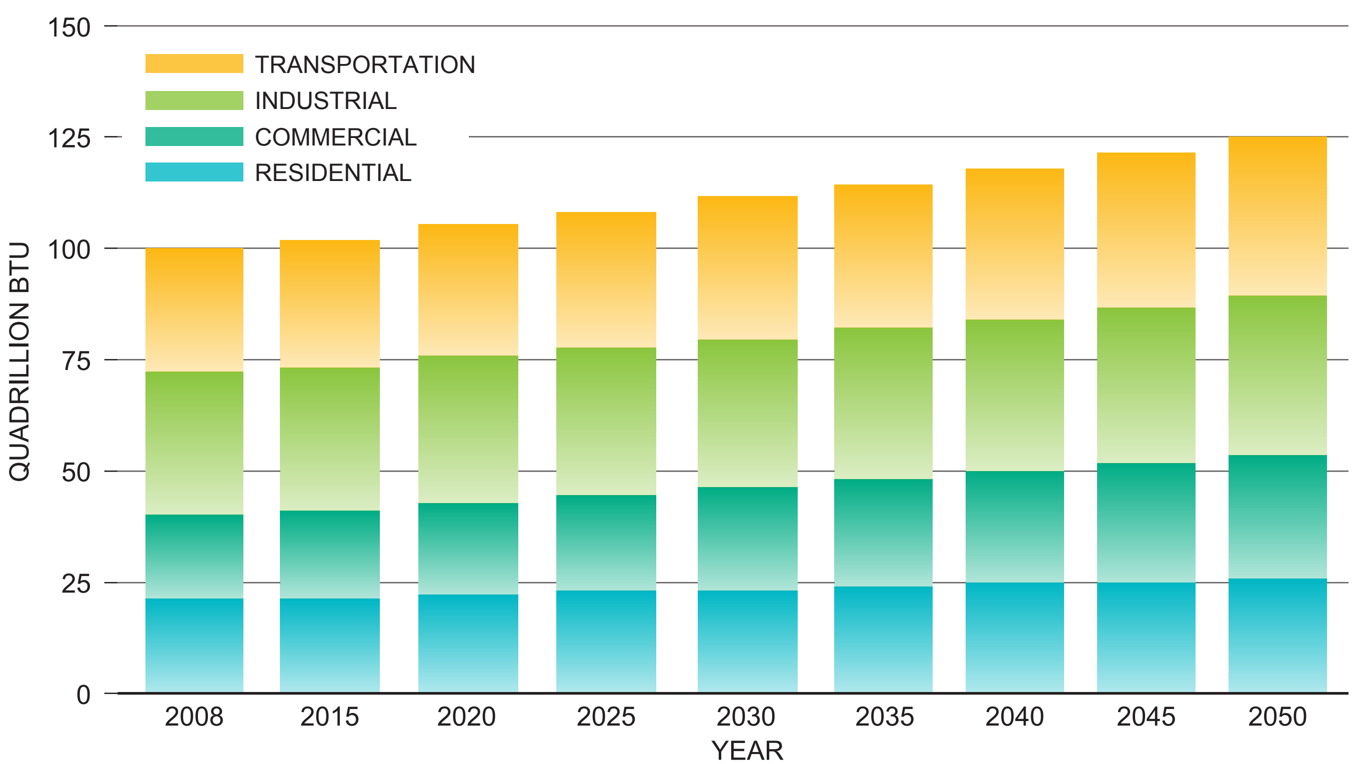



***Figure 8-2.*** *Primary Energy Use by End-Use Sector with 2035–2050 Extrapolation*

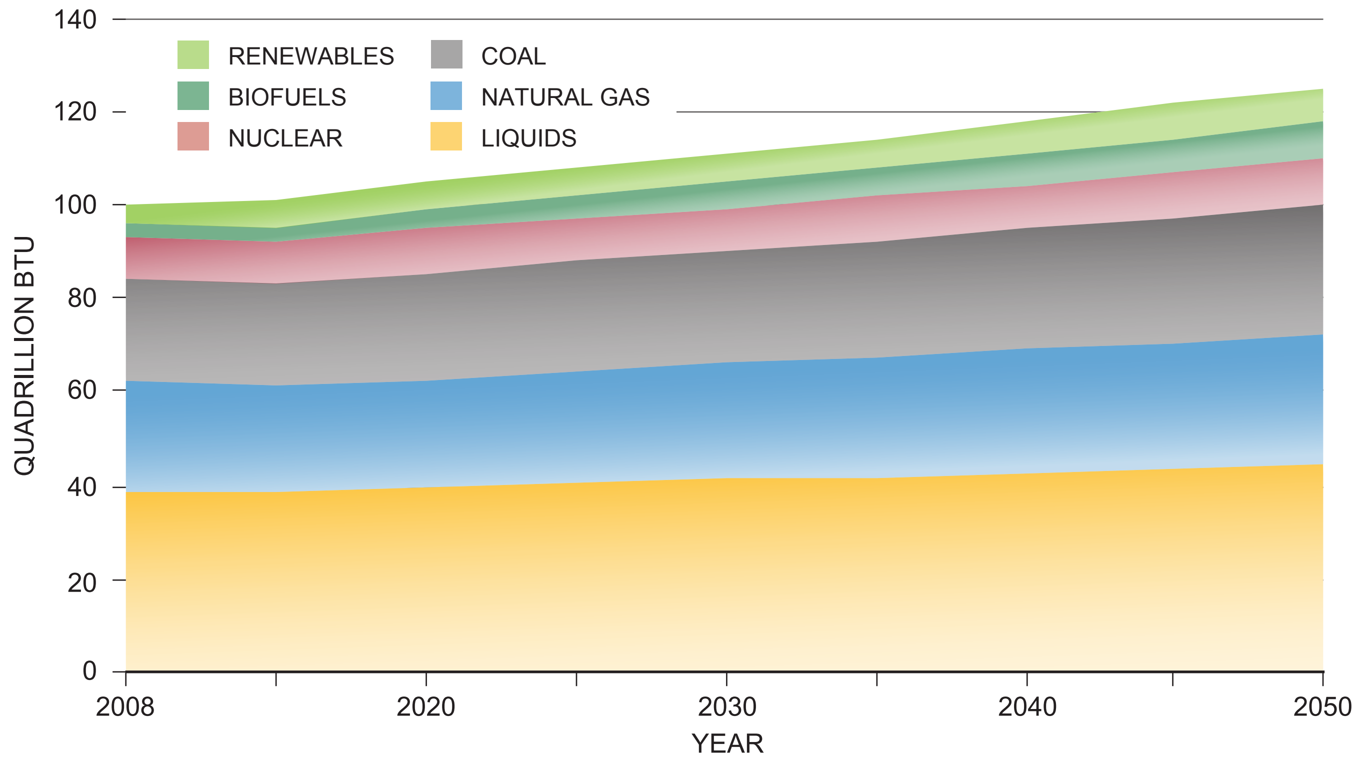



***Figure 8-3.*** *Energy Use by Fuel*

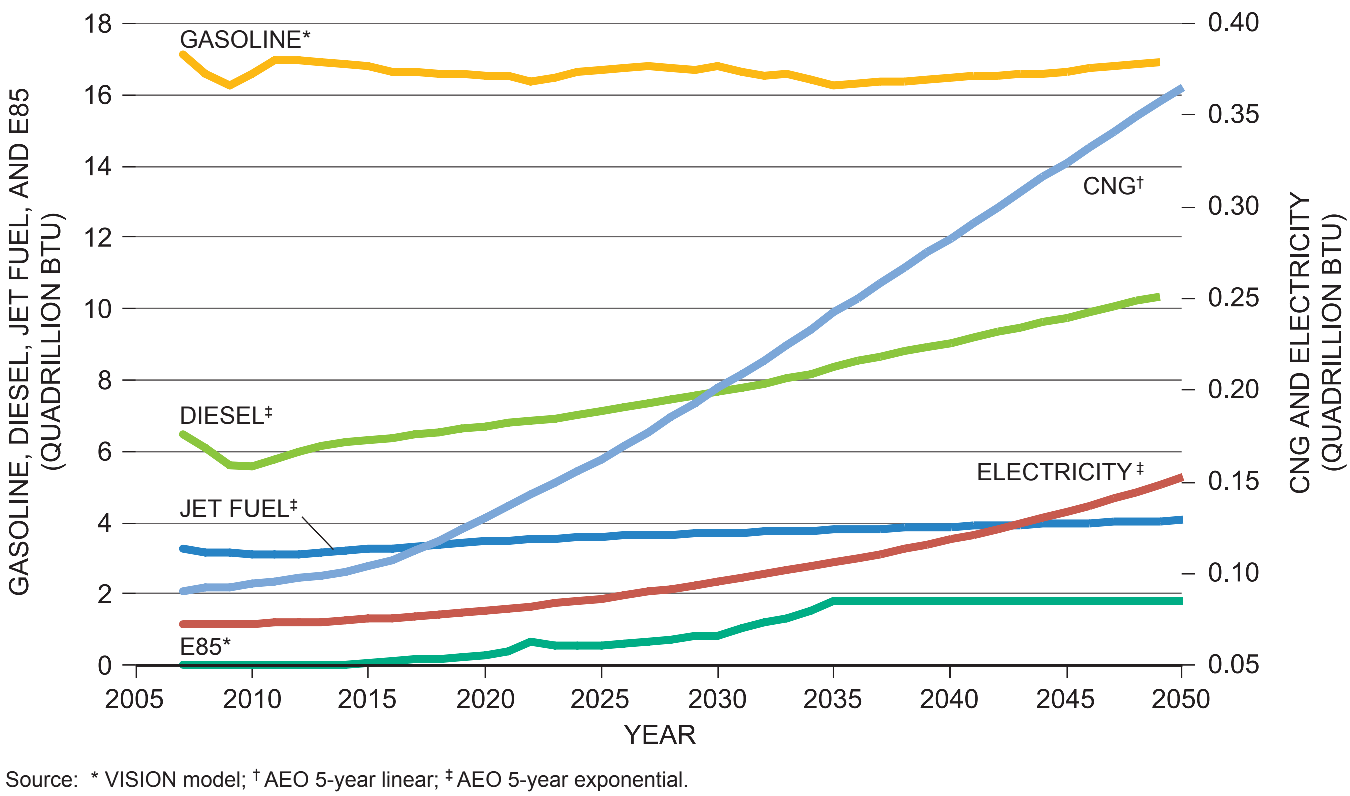



***Figure 8-4.*** *Transportation Sector Fuel Consumption*

gasoline, with compressed natural gas (CNG) showing the most robust increase. Figure 8-4 includes this study's extrapolation to 2050 based on the VISION model, AEO 5-year linear, and AEO 5-year exponential extrapolations. See the section entitled "Extrapolations to 2050" later in this chapter for an explanation of the study's extrapolations.

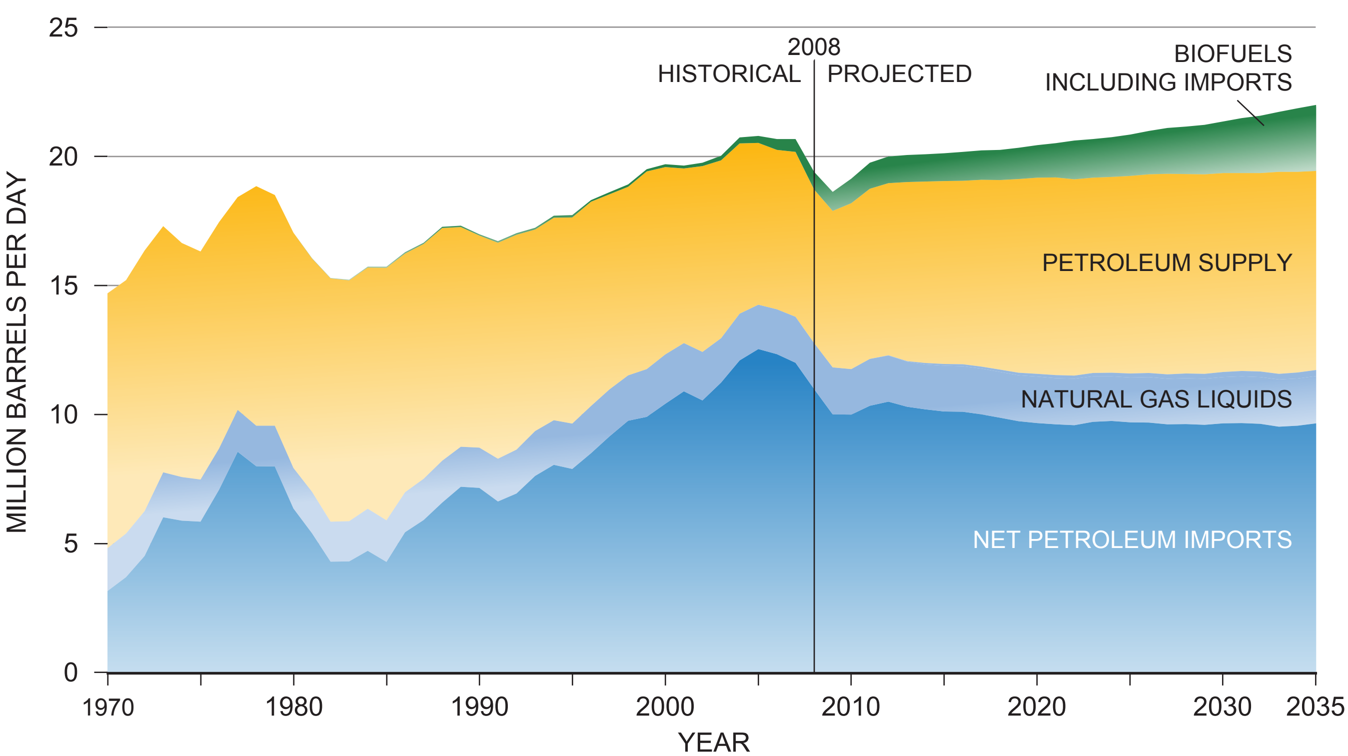
## HYDROCARBON LIQUIDS

EIA liquids supply and demand projections include conventional petroleum liquids—crude oil, natural gas plant liquids, and refinery gain—and unconventional liquids, such as biofuels, bitumen, coal-to-liquids (CTL), gas-to-liquids (GTL), extra-heavy oils, and shale oil (Figure 8-5). Fossil fuels in the AEO Reference Case provide most of the energy consumed in the United States over the next 25 years, although their share of overall energy use falls from 84% in 2008 to 78% in 2035. Renewable sources for generating electricity and producing liquid transportation fuels are the areas of highest projected growth, driven principally by federal and state programs, as well as rising fossil fuel prices.

Demand, production, and imports of liquid fuels are sensitive to the assumed long-term course of oil prices. High-price scenarios reduce demand, while increased domestic production lowers crude imports. Chapter Eleven, "Hydrocarbon Liquids," considers the effect of price fluctuations on the competitive position of hydrocarbon liquids and the potential impact of new technologies on the hydrocarbon resource base and production costs. It also considers potential improvements in refinery efficiency and GHG emissions that are not included in the AEO Reference Case.

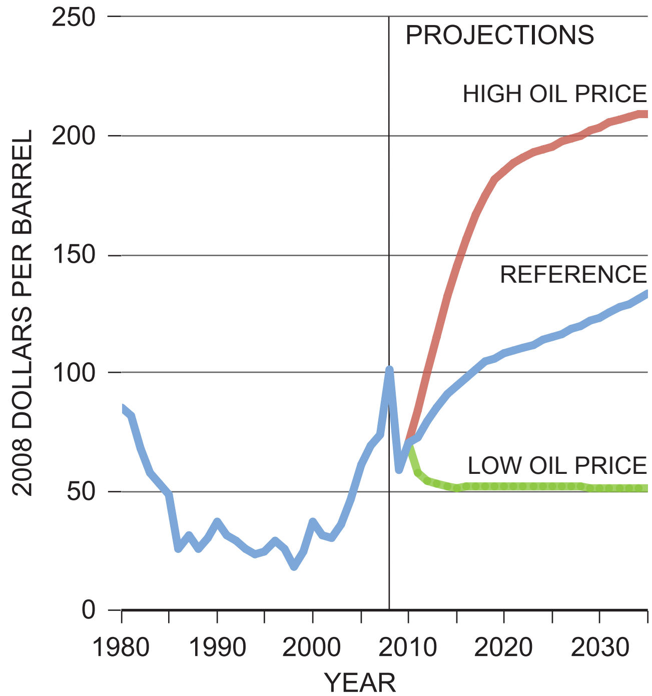
### Hydrocarbon Liquids Commentary

Differences across oil price scenarios in the AEO2010 Reference Case (Figures 8-6 through 8-9) are primarily driven by EIA assumptions about the behavior of the Organization of the Petroleum Exporting Countries (OPEC) and access to non-OPEC oil resources. In the Reference Case, OPEC targets a market share of 40% of total world liquids production, while access limitations in resource-rich non-OPEC countries continue to restrain the growth of



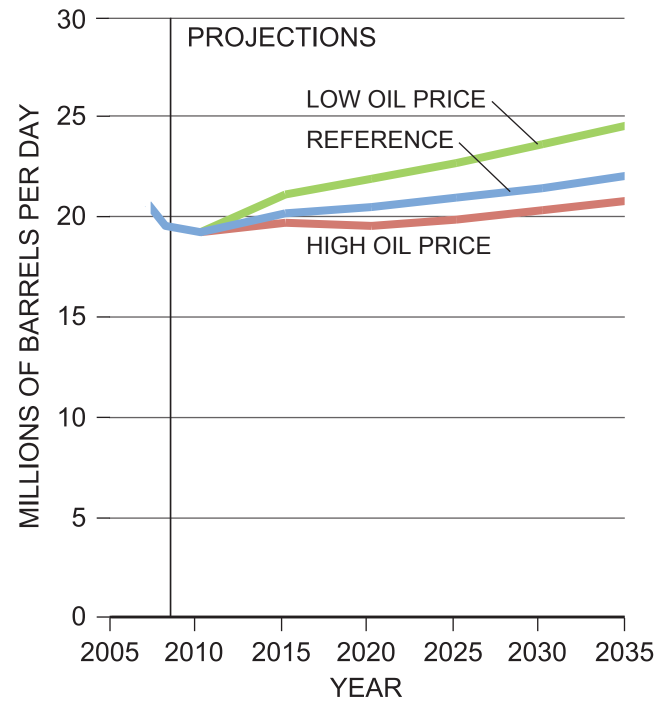

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2010*.

***Figure 8-5.*** *Total U.S. Liquids Fuel Supply*



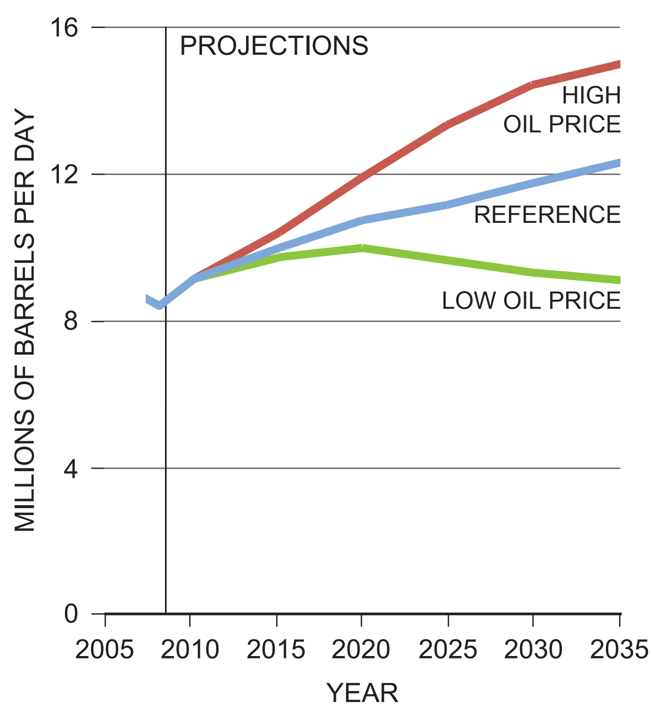

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2010.*

***Figure 8-6.*** *AEO2010 Liquids Outlook in Oil Price Cases – Average Annual World Oil Prices*



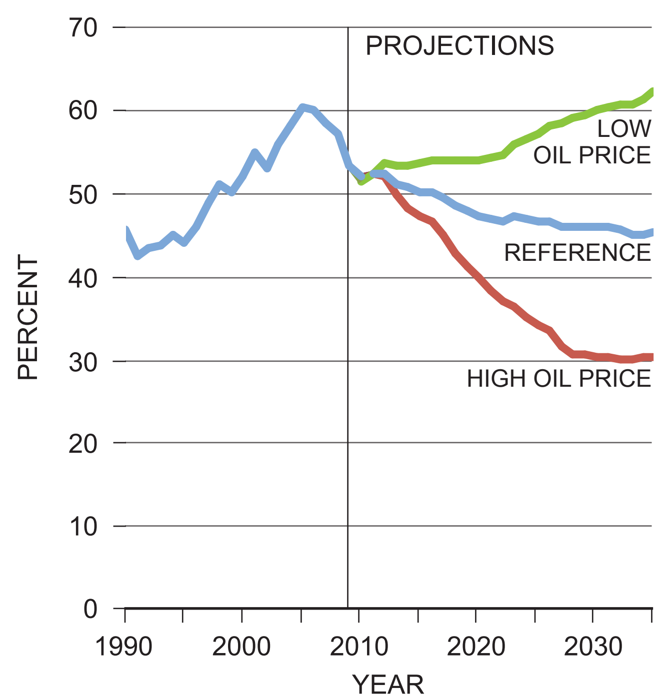

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2010.*

***Figure 8-7.*** *AEO2010 Liquids Outlook in Oil Price Cases – U.S. Liquids Consumption*




Source: U.S. Energy Information Administration, *Annual Energy Outlook 2010.*

***Figure 8-8.*** *AEO2010 Liquids Outlook in Oil Price Cases – U.S. Liquids Production*




Source: U.S. Energy Information Administration, *Annual Energy Outlook 2010.*

***Figure 8-9.*** *AEO2010 Liquids Outlook in Oil Price Cases – Net U.S. Liquids Imports* non-OPEC liquids production. In the High Oil Price Case, OPEC market share falls to 35% and non-OPEC resource-rich countries further restrict access to resources. In the Low Oil Price Case, OPEC's share rises to almost 50%, while access to non-OPEC resources improves relative to the Reference Case.

Demand is reduced in the High Oil Price Case, while increased domestic production lowers crude oil imports. U.S. supply is more sensitive than demand to assumed prices. Projected U.S. liquid imports range from ~ 6 MMB/D in the high-price scenario to over 15 MMB/D in the low-price scenario. The Reference Case projects that U.S. liquids production will slowly increase—based on higher biofuel and domestic oil production—with a resulting decline in liquid fuel imports.

Price assumptions influence projected global liquid production (Table 8-1). Global conventional crude oil production in the Reference Case grows moderately from 72 MMB/D in 2008 to 82 MMB/D in 2035. Conventional crude oil production in 2035 ranges from 97 MMB/D to 62 MMB/D in the low-price and high-price scenarios, respectively. Unconventional liquids play a growing role in all AEO2010 oil price cases, with the largest volume in the High Oil Price Case.

Figure 8-10 shows additional types of unconventional liquids. Biofuel, the most important unconventional liquid, is projected to grow rapidly. Other unconventional hydrocarbon liquids, including GTL, CTL, and bitumen grow more slowly.

Oil supply in the AEO2010 Reference Case is geographically diverse, with very similar distribution of oil production in 2008 and 2035. Oil price does influence projected crude oil source. Oil supply from North America is highest in the High Oil Price Case due to increased U.S. oil production and increased production from Canadian oil sands, while Middle East OPEC production is lower in this scenario.

Projected U.S. oil use remains near its present level through 2035. The small growth in total liquids demand is met by biofuels, with ethanol accounting for 17% of gasoline consumption by 2035 (Figure 8-11). Increased U.S. biofuels and petroleum supply outpace the small increase in demand and result in decreased oil imports. While biofuels grow rapidly, they fall short of the 36 billion gallon Renewable Fuel Standard (RFS) target in 2022. However, with continued growth, biofuels exceed the 2022 target by 2035. This projection requires a large increase in biofuel technologies that are not currently commercial, including cellulosic ethanol and, notably, biomass-to-liquids (BTL).

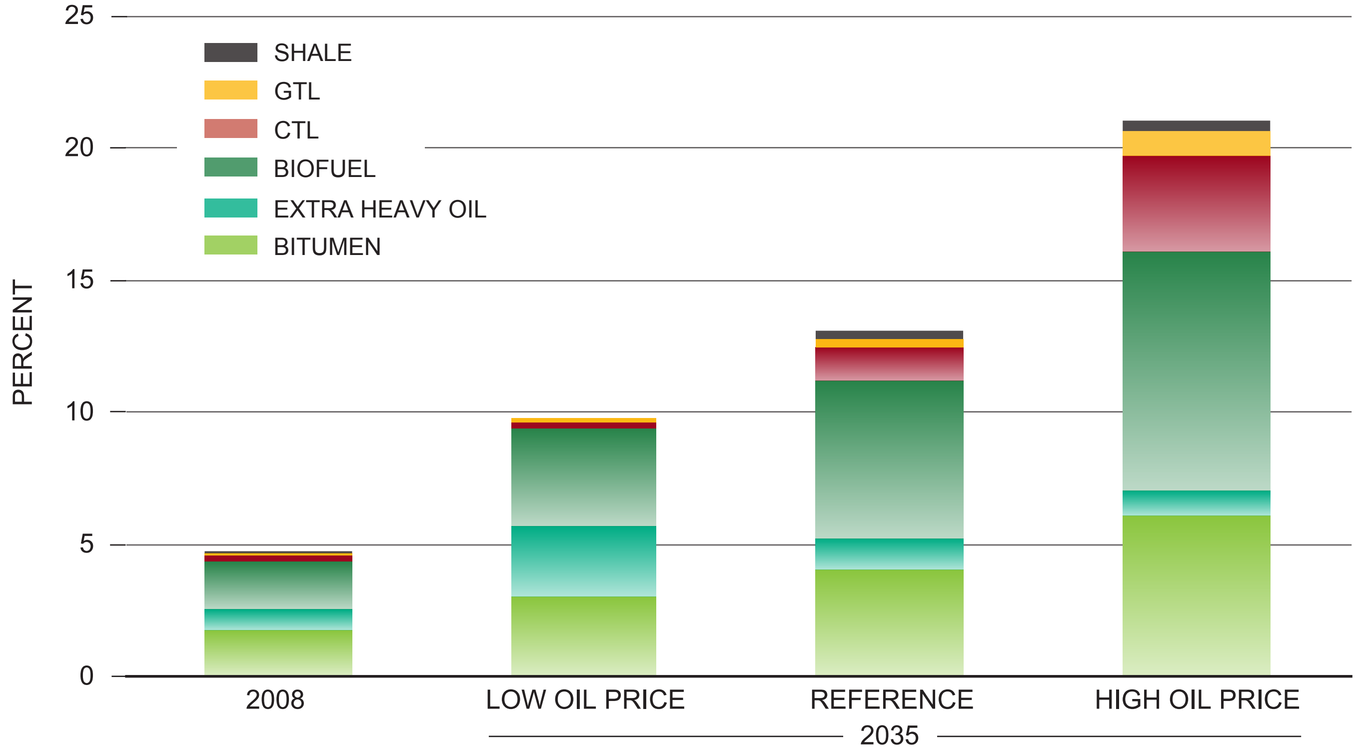
### *Liquid Fuel Demand*

While projected fuel consumption in the Reference Case is flat to 2035, demand for diesel and jet fuel increases slightly (Figure 8-12). Biodiesel and BTL comprise 19% of total diesel use. Ethanol is used both as E10 and E85. The Reference Case projects a significant increase in E85 use, based on the assumption that owners of flexible-fuel vehicles largely use E85.

| | 2008 | Oil Price Case | | |
|---|---|---|---|---|
| | | Low | Reference | High |
| | | 2035 | | |
| Conventional Crude* | 71.6 | 97.1 | 82.1 | 62.3 |
| Natural Gas Plant Liquids | 7.9 | 11.8 | 12.6 | 12.3 |
| Refinery Gain | 2.1 | 3.2 | 2.7 | 2.0 |
| **Conventional Subtotal** | **81.6** | **112.0** | **97.4** | **76.7** |
| Unconventional Crude† | 2.2 | 6.9 | 6.7 | 7.9 |
| CTL and GTL | 0.3 | 0.5 | 1.8 | 4.1 |
| Biofuels (oil equivalent) | 1.0 | 1.9 | 2.7 | 4.0 |
| **Unconventional Subtotal** | **3.5** | **9.3** | **11.2** | **16.0** |
| **Total Liquids** | **85.1** | **121.3** | **108.6** | **92.7** |

* Crude oil and lease condensates.
† Oil sands, extra-heavy crude, and shale oil.

***Table 8-1.*** *AEO2010 Reference Case Global Liquids Production in 2008 and 2035 (Million Barrels per Day)*




Source: U.S. Energy Information Administration, *Annual Energy Outlook 2010.*

***Figure 8-10.*** *Unconventional Liquids Production*

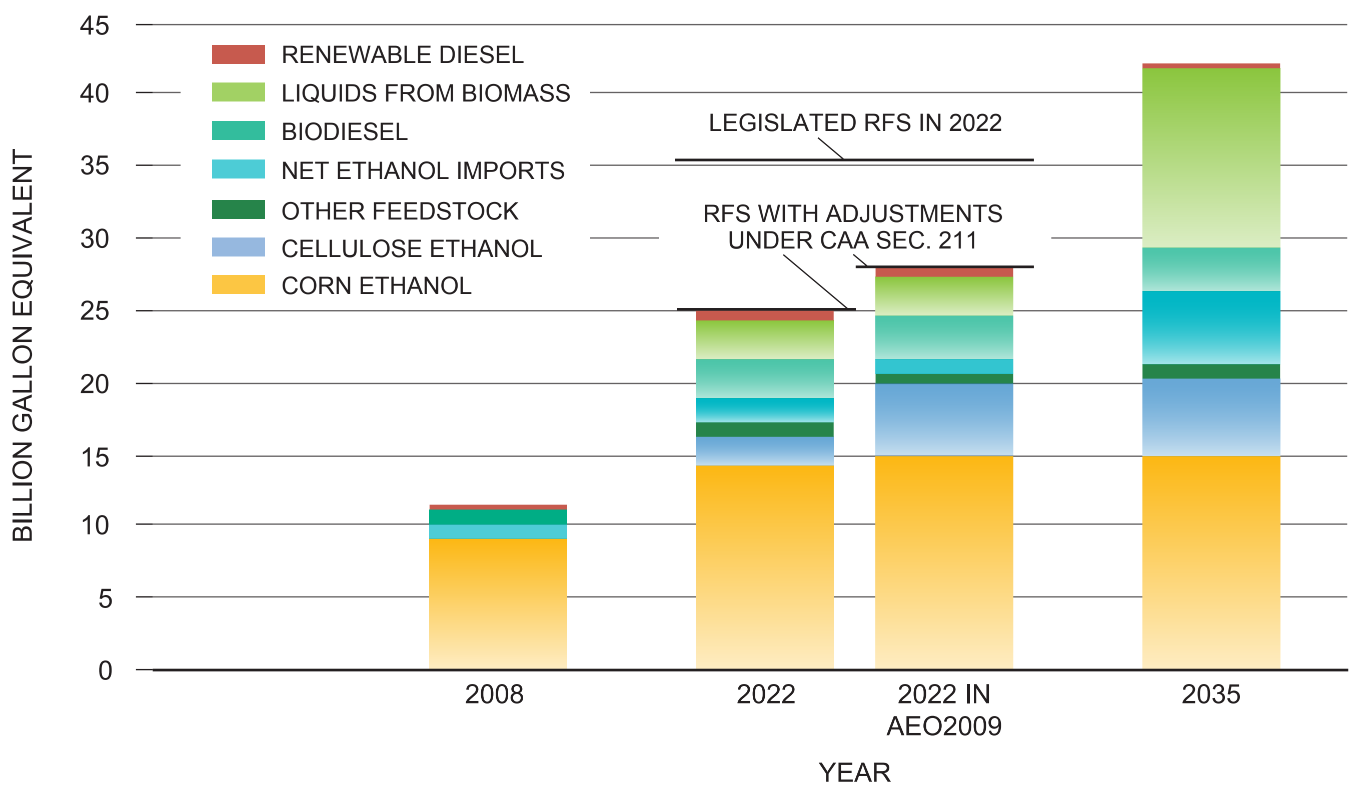
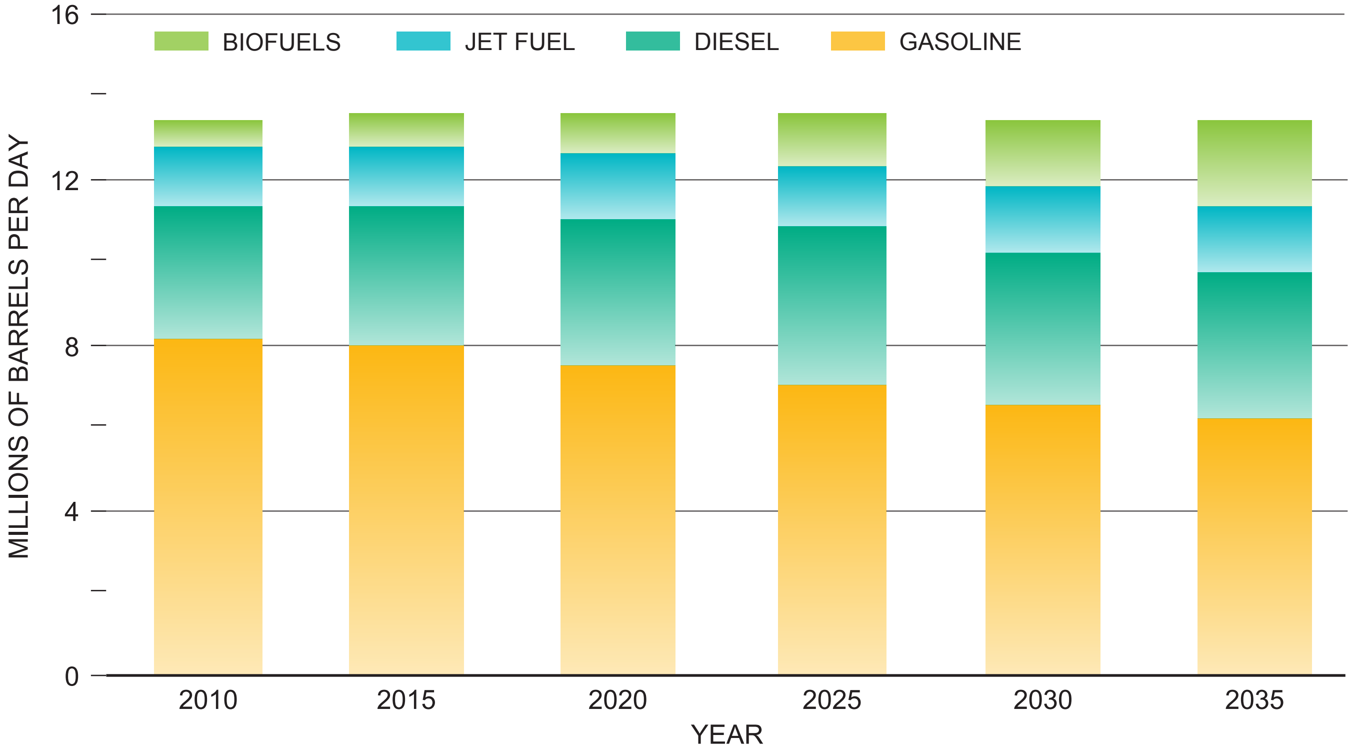



***Figure 8-11.*** *Projected Biofuel Supply*




Source: U.S. Energy Information Administration.

***Figure 8-12.*** *Projected Fuel Consumption*

## NATURAL GAS

U.S. natural gas production in the AEO2010 Reference Case grows from 20.6 trillion cubic feet in 2008 to 23.3 trillion cubic feet in 2035. Figure 8-13 shows projected U.S. gas production by source.[4]

The Reference Case assumes a disparity between the relative prices of light crude oil and natural gas on an energy equivalent basis. It also assumes that substitution of natural gas for petroleum products will be limited by the infrastructure investments required to achieve market scale and narrow the price gap in the U.S. market.

### Natural Gas Commentary

Relative to other sources cited in this study, the AEO2010 Reference Case shows modest growth in natural gas use as a transportation fuel. Chapter Fourteen, "Natural Gas," describes alternative prospects in which natural gas has greater impact as a transportation fuel and contributor to energy security and GHG reduction. The Reference Case shows an expansion of the current market for heavy-duty natural gas vehicles (NGVs) to annual new sales of ~22,000 per year in 2035 (gross vehicle weight >10,000 lbs). The sales growth results in a total NGV fleet population of ~260,000 vehicles by 2035, representing 1.7% of a total fleet of 15 million HD vehicles (gross vehicle weight >10,000 lbs). By 2035, natural gas represents 1.8% of total fuel consumption by the heavy-duty vehicle fleet, amounting to ~0.09 trillion cubic feet of gas per year, or 0.05 million barrels of oil per day. However, the Reference Case includes only limited discussion of potential light-duty use, as well as rail and marine markets for natural gas. Potential changes in operational models for trucking fleets (e.g., return-to-base or point-to-point) may also affect vehicle and fueling requirements in ways not considered in the Reference Case.

While not considered in the AEO2010 Reference Case, the relative price differential between diesel and natural gas, or potential delinking of natural gas and crude oil products may have significant

4 The AEO2011 more than doubles the volume of technically recoverable U.S. shale gas resources assumed in AEO2010, while also adding new shale oil resources.

effects.[5] Modeling NGV penetration as a function of fuel price differences across the United States for natural gas, masks potential regional effects. These include cases where gas infrastructure already exists or is being developed; market penetration in areas with high diesel and gasoline prices; and areas with existing or planned fleet hubs. Potential regional price differentials between natural gas and petroleum can create a market pull for infrastructure, as, for example, in gas corridors along highway routes, not represented in the Reference Case. Similarly, Chapter Fourteen considers prospective economies of scale in natural gas infrastructure (e.g., different scaling effects for LNG and CNG) not included in the Reference Case.

### Natural Gas Vehicles and Engines

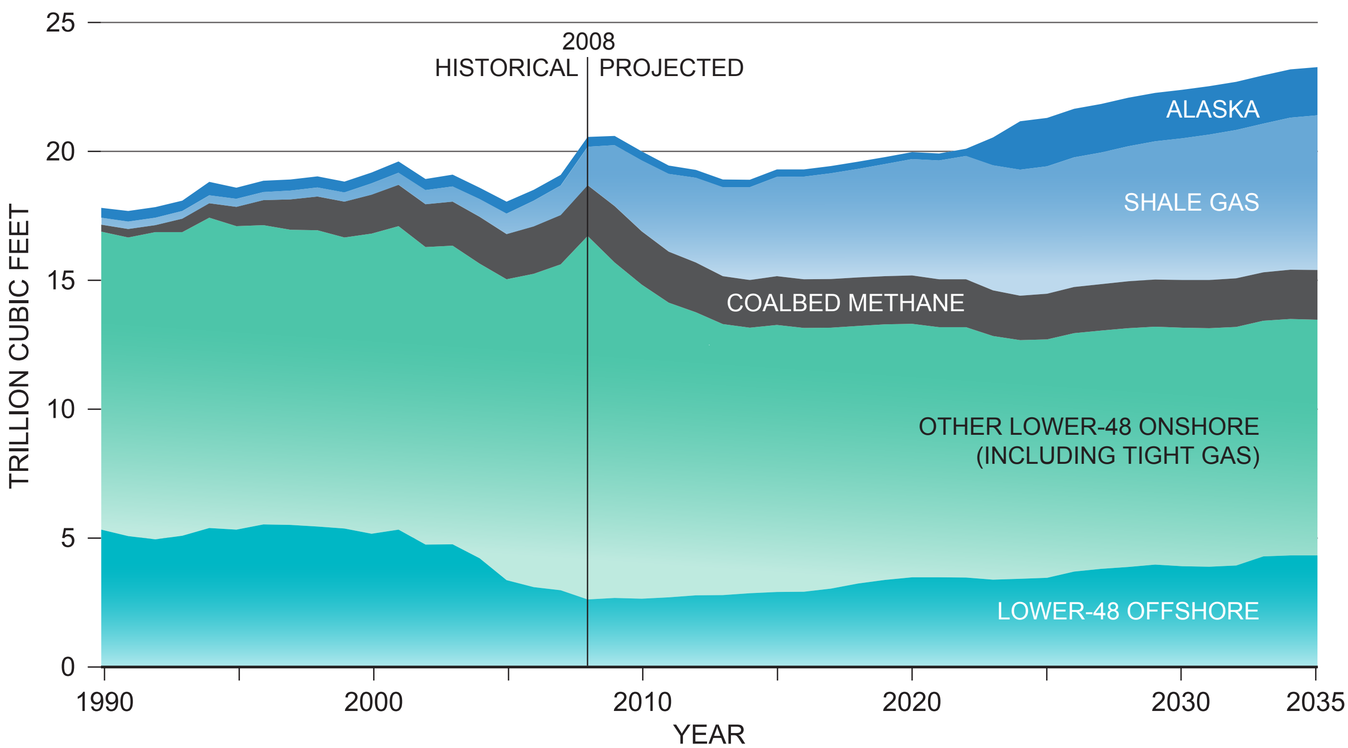
The AEO's segmentation of the heavy truck market (>10,000 lbs) does not identify existing and transitional applications of heavy-duty NGVs based on geographic concentration, infrastructure expansion, and targeted applications by engine/vehicle type. Buses and sanitation trucks, for example, have been using natural gas for many years, but these fleets are not evident in the AEO's market penetration model. Similarly, the Demand model does not include potential cost reductions for heavy-duty NGVs resulting from scale and technology. Since most heavy-duty NGVs are currently design-constrained by diesel engine features, technology development and engine/vehicle specifications based on natural gas rather than diesel could improve NGV cost vs. performance.

5 The AEO2011 reduces the effect of oil prices on natural gas prices, due partly to increased shale gas supply and improvements in gas extraction technologies.

### Renewable Natural Gas

As discussed in Chapter Fourteen, renewable natural gas has considerable supply potential. For example, organic waste feedstocks in the United States, if converted to gas, could potentially displace 30% or more of current diesel consumption.[6]

6 Gas Technology Institute, *The Potential for Renewable Gas: Biogas Derived from Biomass Feedstocks and Upgraded to Pipeline Quality*, prepared for the American Gas Foundation, September 2011, http://www.gasfoundation.org/ResearchStudies/agf-renewable-gas-assessment-report-110901.pdf.




Source: U.S. Energy Information Administration, *Annual Energy Outlook 2010*.

***Figure 8-13.*** *Projected U.S. Natural Gas Production by Source*

RNG has relatively low technology barriers, since it uses natural gas engines, pipeline infrastructure, liquefaction and compression technology, fueling stations, and storage identical to conventional natural gas. Anaerobic digestion and biogas upgrading technologies for making RNG from organic wastes are established and globally adopted. In addition, RNG has the lowest life-cycle GHG emissions of any alternative fuel and, depending on biomass feedstock, can be calculated as carbon negative.

## BIOFUELS

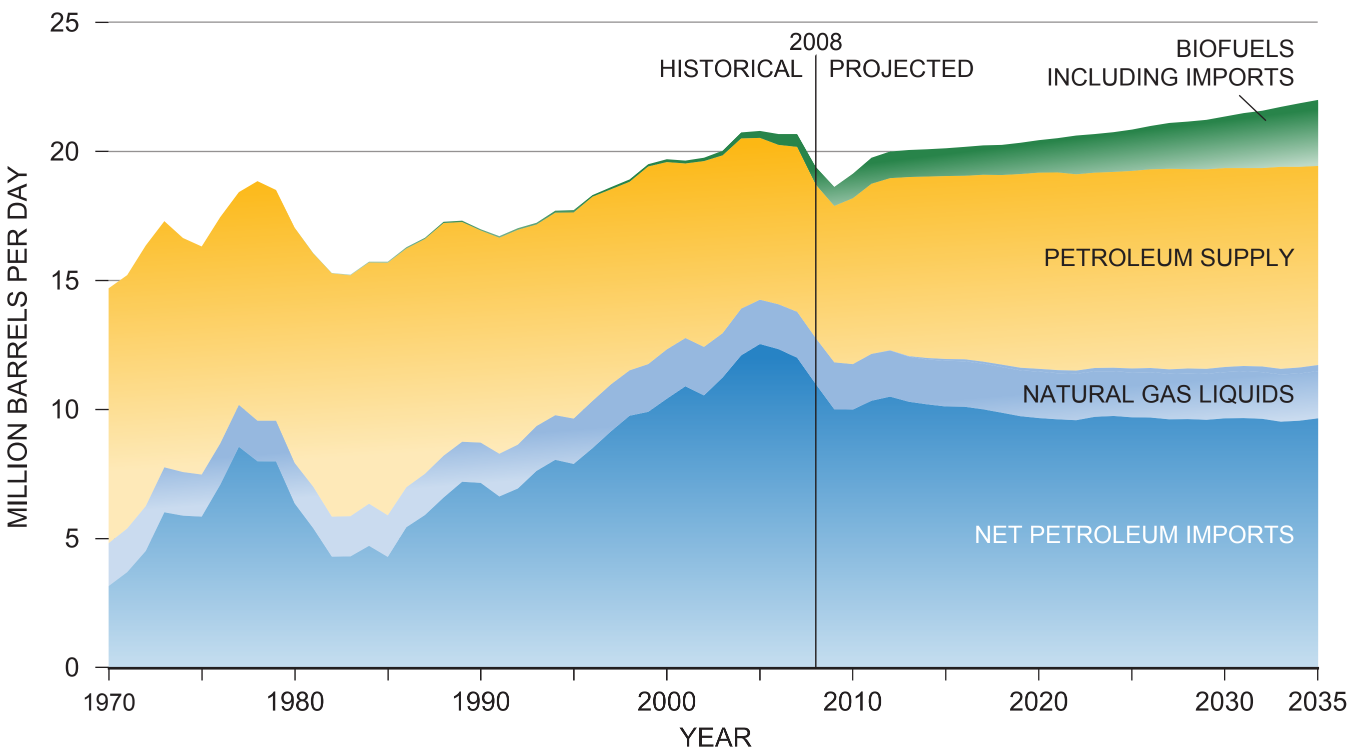
Figure 8-14 shows projected biofuels production in the Reference Case as a portion of liquids supply. U.S. oil use remains near its present level through 2035, with the small increase in overall liquids met by biofuels.

Figure 8-15 projects biofuel volumes by feedstock. Ethanol accounts for about 17% of gasoline consumption by 2035. While projected ethanol imports grow in volume, imports as a share of total liquids fuel supply decrease, due to growing U.S. biofuels and petroleum supply. Although biofuel volumes grow rapidly, they do not meet the 36 billion gallon RFS target in 2022. However, with continued growth, biofuels exceed the 2022 target by 2035.

### Biofuels Commentary

As discussed in Chapter Four, "Priorities for Technology Investment," and in Chapter Twelve, "Biofuels," the volumes shown in Figure 8-15 are challenging. They require advances along multiple technologies, such as cellulosic ethanol and BTL, as well as feedstock and infrastructure development. Blendwall issues may also limit the projected growth in ethanol use.

The relatively rapid growth in adoption of biofuels in the Reference Case requires significant infrastructure development, with 300 million tons of biomass available by 2020 and more than 500 million tons by 2035. Figure 8-16 shows projected biomass requirements. The projected biomass volumes are approximately triple the current biomass handled in the existing corn infrastructure. Meeting these volumes will require constructing processing plants at a sustained peak rate over a




Source: U.S. Energy Information Administration, *Annual Energy Outlook 2010*.

***Figure 8-14.*** *Biofuels as a Portion of Liquid Fuels Supply*

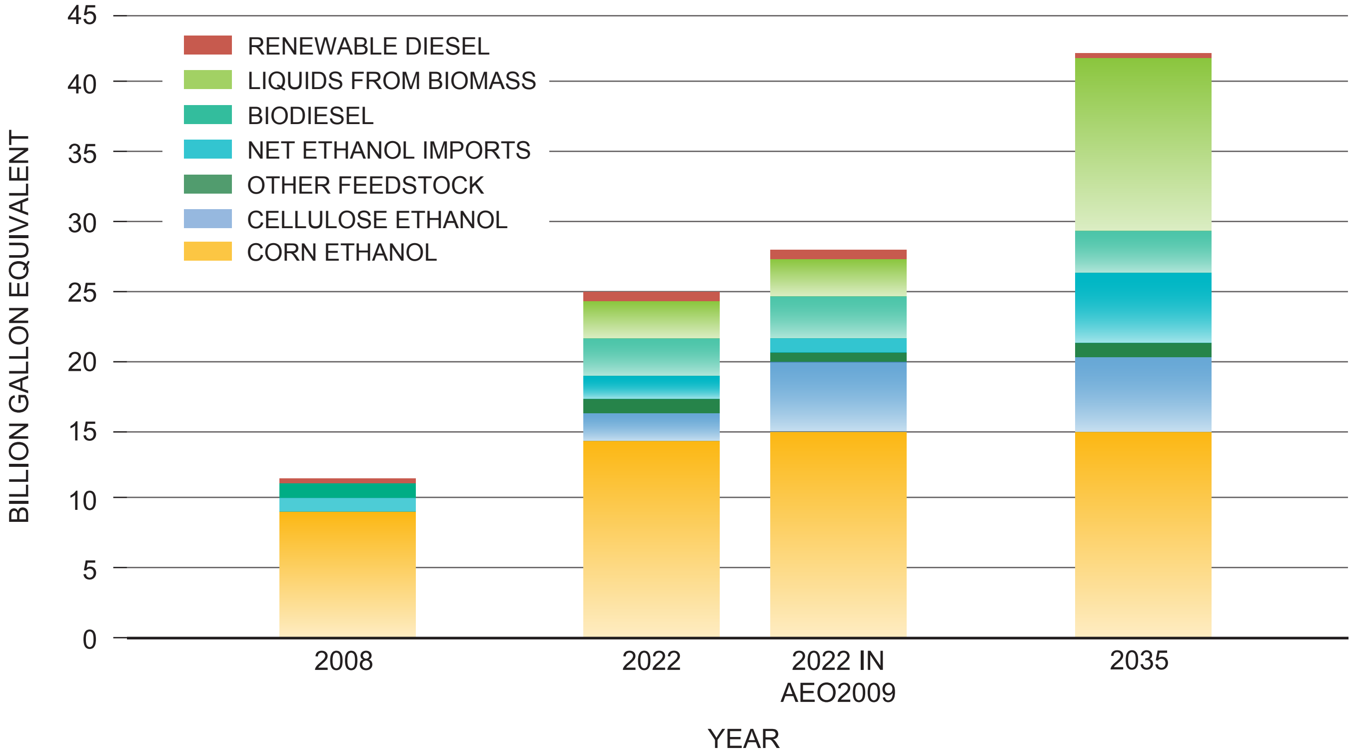



***Figure 8-15.** Biofuel Feedstocks in the Reference Case*

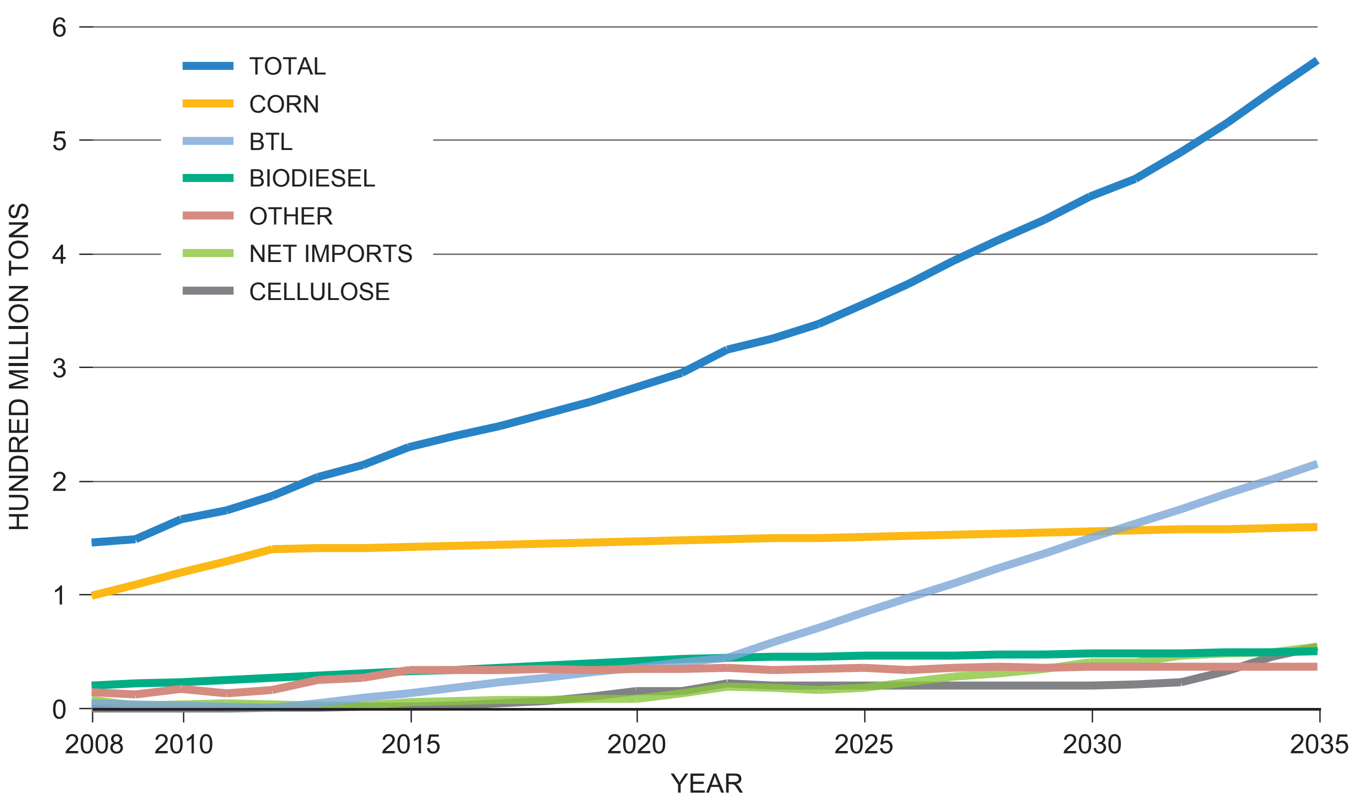



***Figure 8-16.** Projected Biomass Requirements in the Reference Case*

number of years. The transportation and storage capacity needed to meet these requirements does not currently exist and would need to grow in parallel.

As advanced biofuels become increasingly available, the cost of biomass delivered must be economically competitive in the environment for raw materials. The AEO2010 projects that ~1.5 billion gallons of cellulosic ethanol will be produced in the United States in 2020. The projection implies that production of cellulosic ethanol will be economically viable relative to other cellulosic biofuels that meet the GHG reduction criteria of the RFS. The Reference Case projects that the wholesale cost of gasoline in 2020 will be $2.79/gallon in 2008 dollars, with a range of $1.56 to $4.56 for the Low and High Oil Price Cases. The break-even wholesale cost of ethanol would be $1.86/gallon on a BTU basis. However, a recent ConocoPhillips-Iowa State-NREL study on the biochemical production of cellulosic ethanol calculates an $n^{th}$ plant baseline cost of $5.15/gallon gasoline equivalent in 2007 dollars, which corresponds to $3.40/gallon of ethanol in 2007 dollars.[7] The cost difference relative to the Reference Case is significant.

In projected U.S. biofuels production 2015–2035, it is not evident why cellulosic ethanol plateaus in 2022 and does not resume growth until approximately 2032, while other new biofuels grow without interruption after 2022.

### *Renewable Fuel Standard*

The AEO2010 assumes that the RFS2 program is implemented as written, with the exception that cellulosic renewable fuels requirements will not be met and will have to be adjusted downward. In fact, the Environmental Protection Agency (EPA) waiving the cellulosic requirement by more than 50% in 2010 triggered a legal obligation to undertake a rulemaking to reduce RFS2 requirements. Meeting the requirements for cellulosic and advanced renewable fuels will require clarity about the respective responsibilities of refiners, importers, and terminal operators. At present, Energy Independence and Security Act (EISA) and EPA RFS2 regulations impose an obligation on refiners and importers, although decisions about whether to blend general renewable fuels, advanced renewable fuels, or cellulosic renewable fuels will be made at the terminal. This situation may increase the difficulty of meeting cellulosic and advanced renewable fuels requirements.

The ethanol blendwall is likely to raise additional problems in meeting the RFS2 requirements. Beyond the blendwall, the RFS2 assumes that large volumes of E85 will be used. However, most retail gasoline stations in the United States are not owned by the obligated parties, and it is these non-obligated retailers who will have to act to expand the use of E85. The incentives for this action are not clear at present.

It is also unclear whether the AEO2010 projected volumes for various renewable fuels will meet the GHG reduction thresholds specified in EISA. While the AEO2010 states that carbon emissions from biofuels are presumed to be carbon neutral, EISA specifies that renewable fuels must meet emission reduction thresholds in order to qualify in the various renewable fuel categories. The assumption of carbon neutrality may result in projected biofuel volumes that are high relative to other sources cited in this study.

## ELECTRICITY

Projected sales of electric vehicles (EVs) in the AEO2010 Reference Case are low relative to other sources, largely based on prospective vehicle costs, battery life, vehicle range, and availability of charging infrastructure. Battery cost, together with the rate of cost reduction over time, is the largest component of EV cost and consumer adoption. Chapter Thirteen, "Electric," examines alternatives to the battery costs and characteristics used in the Reference Case and their potential effects on the vehicle fleet. The chapter also develops alternative views on other factors that drive the size and composition of the electric vehicle market:

- Vehicle architecture (blended operation vs. all-electric operation)
- Potential market mix of EVs and plug-in hybrid electric vehicles (PHEV)
- Charging infrastructure
- Vehicle range

7 F. K. Kazi, J. A. Fortman, R. Anex, G. Kothandaraman, D. Hsu, A. Aden, and A. Dutta, "Page 6" in *Techno-Economic Analysis of Biochemical Scenarios for Production of Cellulosic Ethanol,* Technical Report NREL/TP-6A2-46588 (National Renewable Energy Laboratory), June 2010.

- Vehicle-grid connectivity and energy storage
- Electricity-sector GHG emissions
- Prospective regulations and legislation.

## Electricity Commentary

### *Vehicles*

The AEO2010 assumes a limited selection of EV and PHEV offerings, with both vehicle types priced at more than $100,000. Based on vehicle launch announcements by Original Equipment Manufacturers, EV and PHEV offerings will be much greater than projected in the Reference Case, in terms of vehicle size, body style, and price. The wider choice of vehicle types, sizes, and prices are likely to produce to higher sales volumes than projected in the AEO Reference Case. Other sources in the literature forecast EV and PHEV sales that are significantly higher than the Reference Case projections.[8]

The Reference Case also discounts EV ranges due to the absence of workplace/public charging and actual vs. stated driving range. However, if workplace/public charging for PHEVs is not as significant an issue, the discount factor for PHEVs would be less, and perhaps zero. The build-out of charging infrastructure over time would decrease the discounted EV range and increase consumer adoption relative to the Reference Case.

### *Battery Development and Cost*

Battery costs and rate of cost reduction are the greatest contributors to EV cost and consumer adoption. Since the literature includes a wide range of current and projected costs, as well as different techniques for evaluating costs—e.g., cell vs. pack, or cost to original equipment manufacturer vs. cost to consumer—it is important to evaluate vehicle adoption using a range of assumptions for battery costs. It should also be noted that projections that use a weighted-average of nickel-metal hydride and lithium-ion costs until the costs are equivalent, and lithium-ion after that point, will underestimate vehicle costs in the early years.

8 Deutsche Bank, *Electric Cars: Plugged In 2,* November 2009; UC-Berkeley, Center for Entrepreneurship and Technology, *Electric Vehicles in the United States,* August 2009; Pike Research, *Plug-in Electric Vehicles,* 3rd Quarter, 2010; and J. D. Power and Associates, *Drive Green 2020: More Hope than Reality,* November 2010.

The AEO Reference Case does not incorporate battery life, assuming, in effect, that the battery will last the life of the vehicle, or ~15 years for new vehicles. However, battery life is a key uncertainty. Replacing the battery within the vehicle lifetime would increase total cost of ownership, which could reduce consumer demand. Since vehicle architecture (blended operation vs. all-electric operation) will significantly affect the lifetime of the battery, varying assumptions should be used to model battery life.

### *Charging Infrastructure*

The AEO Reference Case assumes that all EV/PHEV purchasers will be able to charge their vehicle at home, and that there is no cost to enable this. While PHEV batteries can be charged using a standard 110V outlet, this does not mean that all PHEV buyers will be able to use home charging. For example, only 63% of homes in the United States currently have attached garages or carports. The larger battery size in EVs and consumer preference to add a full day's worth of driving energy to the battery each night make it likely that EV owners will charge using a 240V receptacle. Charging at 240V incurs purchase costs ranging from several hundred to several thousand dollars, in addition to installation costs. Multiple Dwelling Units, such as apartment complexes, may face significant 240V installation and cost challenges, as well as vehicle accessibility issues. Finally, the Reference Case assumes that workplace/public charging will not be available, which would limit the utility of EVs.

The AEO Reference Case does not, by definition, include the potential effect of future regulations affecting the utility industry, such as further caps in criteria emissions, reductions in GHGs, and increased requirements for renewable generation. Given the prospects for such regulation, projected electricity-sector emissions are likely to be lower than shown in the Reference Case. These regulations may increase the average cost of electricity by more than the total projected increase of 5% by 2035. Similarly, the Reference Case does not include other factors that could have a significant effect on electricity use for transportation, including battery recycling, the supply of rare earth elements, and the use of vehicle batteries as distributed energy sources.

## HYDROGEN

The AEO2010 Reference Case projects annual FCEV light-duty sales ranging from ~6,000 in 2020 to ~8,600 in 2035 (Figure 8-17). Based on these sales rates, the FCEV stock is projected to reach about 110,000 vehicles out of a total 300 million by 2035. This small FCEV stock represents negligible hydrogen fuel penetration into the transportation fleet by 2035.

Hydrogen use is projected to start in 2013 and grow very slowly to 4.5 trillion BTU in 2035, representing 0.01% of total transport-sector energy needs of 32,460 trillion BTU (Figure 8-18). Hydrogen is used entirely in the light-duty vehicle fleet (car and light truck), with no penetration shown for commercial, heavy-duty vehicle, or bus transport.

### Hydrogen Commentary

The AEO Reference Case projection of hydrogen-fueled vehicle sales across multiple market segments suggests that market growth would be unsustainable, especially considering investments needed in vehicle technology and fueling infrastructure. If hydrogen use for transportation remains as projected over an extended period, the fueling infrastructure would be limited in geographical coverage and density, individual station sales would be too small to provide adequate return on investment, and FCEVs would be unlikely to have an appealing value proposition for consumers.

AEO2010 projections are based on trends, economic outlooks, assumed future technical progress, currently enacted policies, and a sophisticated national energy system model. While the projections are suitable for conventional transportation modes and fuels, the lack of historical market data and the rapid pace of technology may limit their utility in dealing with new technologies. With respect to FCEVs and hydrogen as a transportation fuel, there are significant differences in the data used in the AEO2010 projections and data available from other sources.

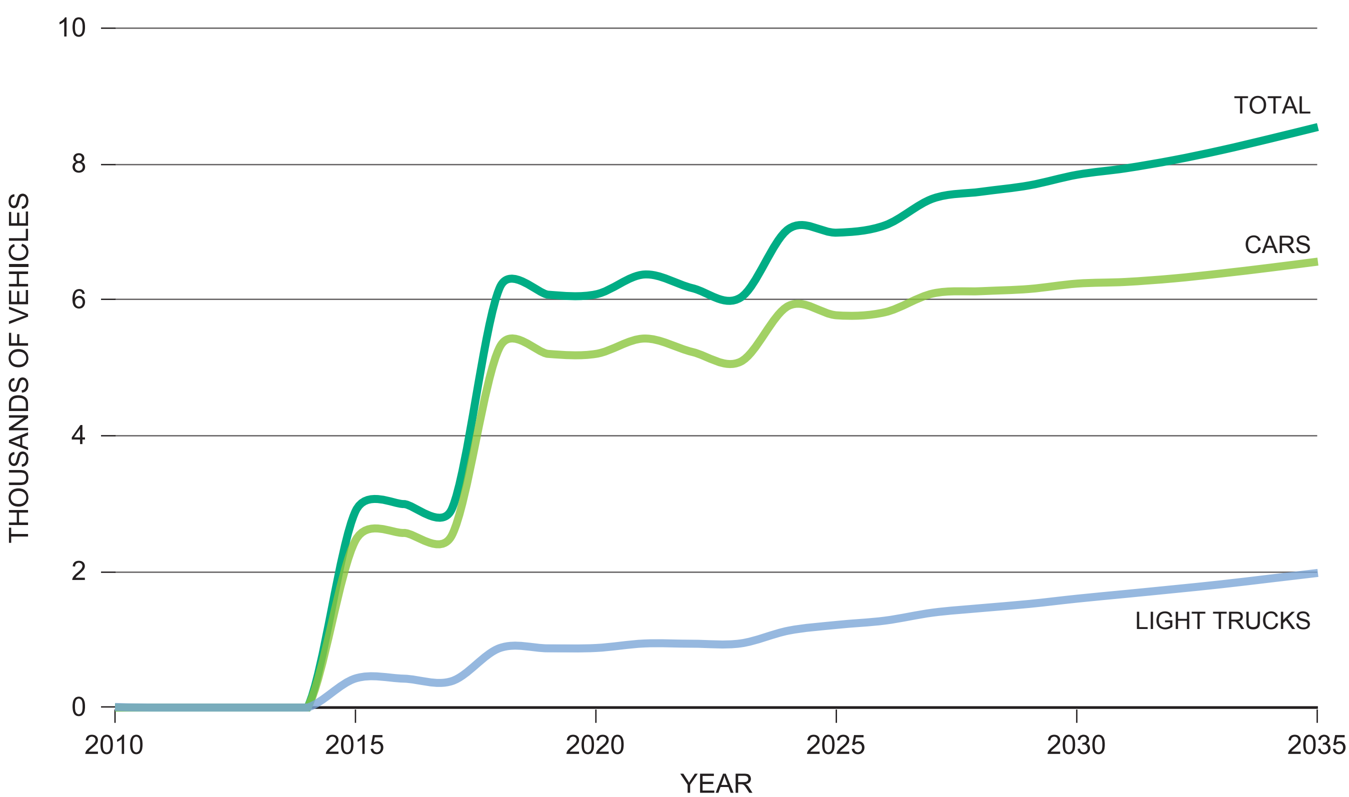



***Figure 8-17.*** *AEO2010 Hydrogen Fuel Cell Electric Vehicle Sales to 2035*

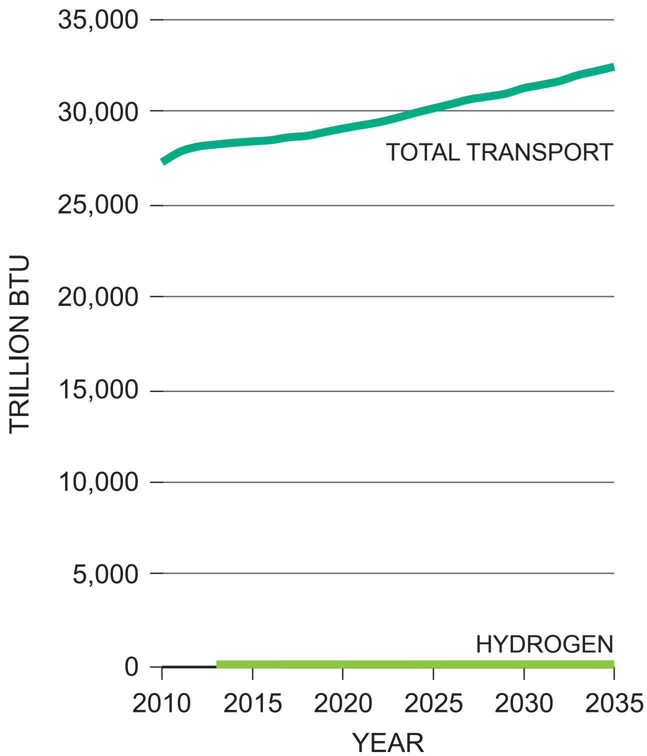



***Figure 8-18.*** *AEO2010 Hydrogen and Total Transport Fuel Use*

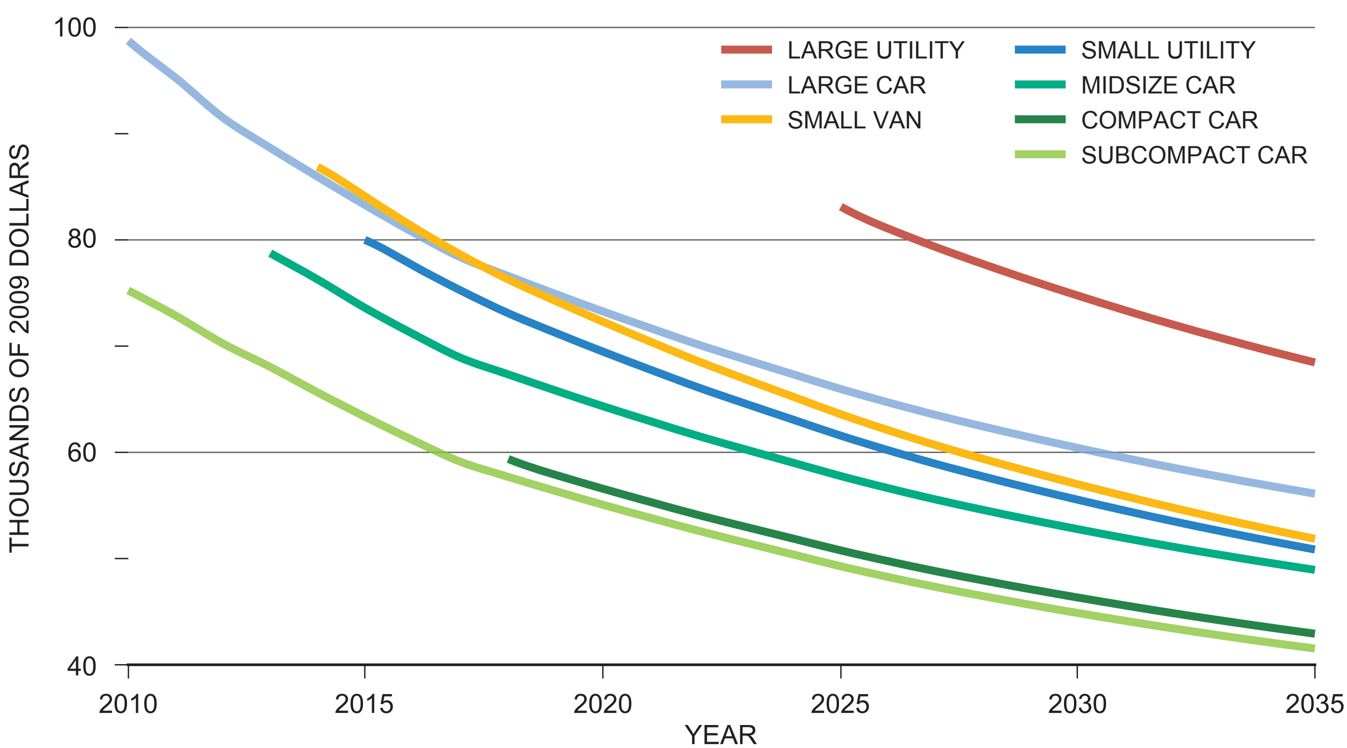
### *FCEV Retail Price*

A key factor in the market success of FCEVs will be their retail price relative to other vehicles. While the AEO2010 Reference Case shows a decline in new FCEV prices over time (Figure 8-19), they remain much more expensive than conventional gasoline vehicles through 2035 (Figure 8-20). These projections are inconsistent with other published projections.[9] The technology assumptions, economies-of-scale, or other factors that may underlie these significant differences are not evident.

### *FCEV Fuel Economy and Hydrogen Fuel Prices*

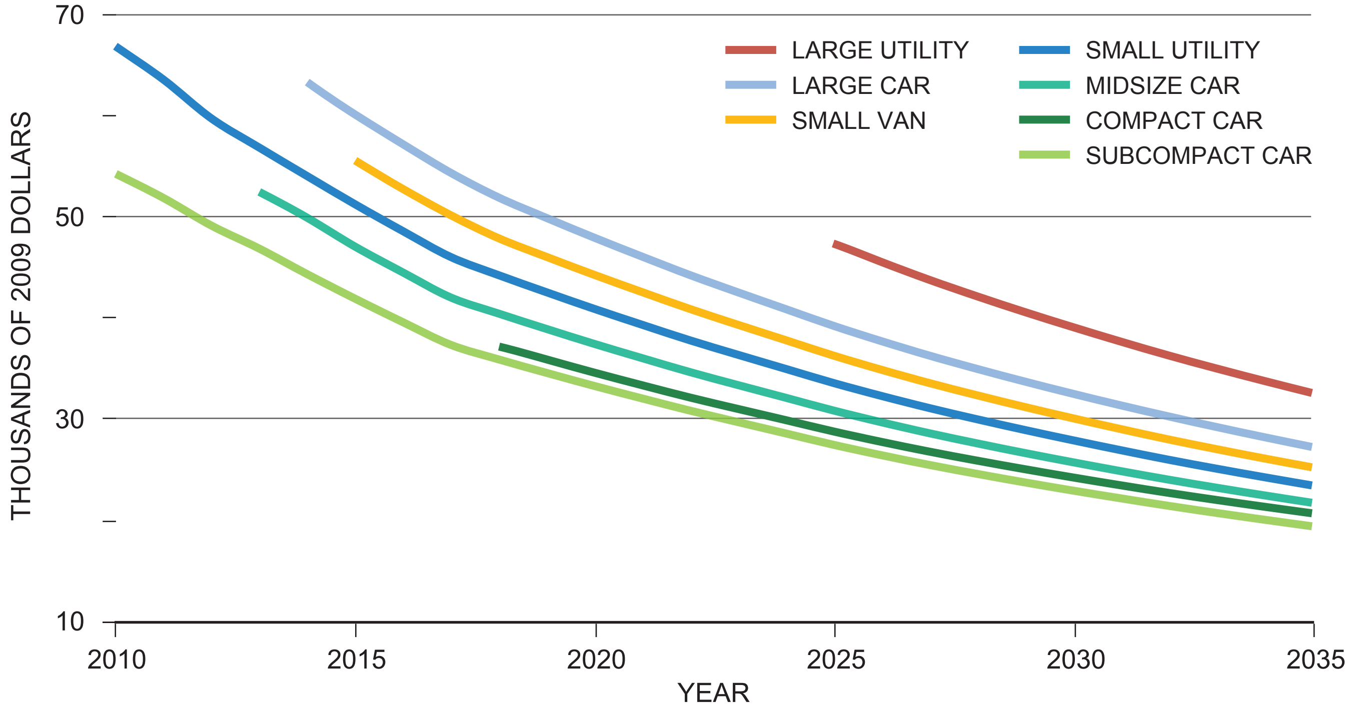
Fuel economy and fuel prices are often of comparable importance to new vehicle prices in calculating the overall cost of vehicle ownership. AEO2010 projects EPA-rated FCEV fuel economy as shown in Figure 8-21 and averages 53.2 mpg for new passenger cars and 42.5 mpg for new light-duty trucks.

9 McKinsey & Company, *A Portfolio of Power-Trains for Europe: A Fact-Based Analysis,* November 2010.



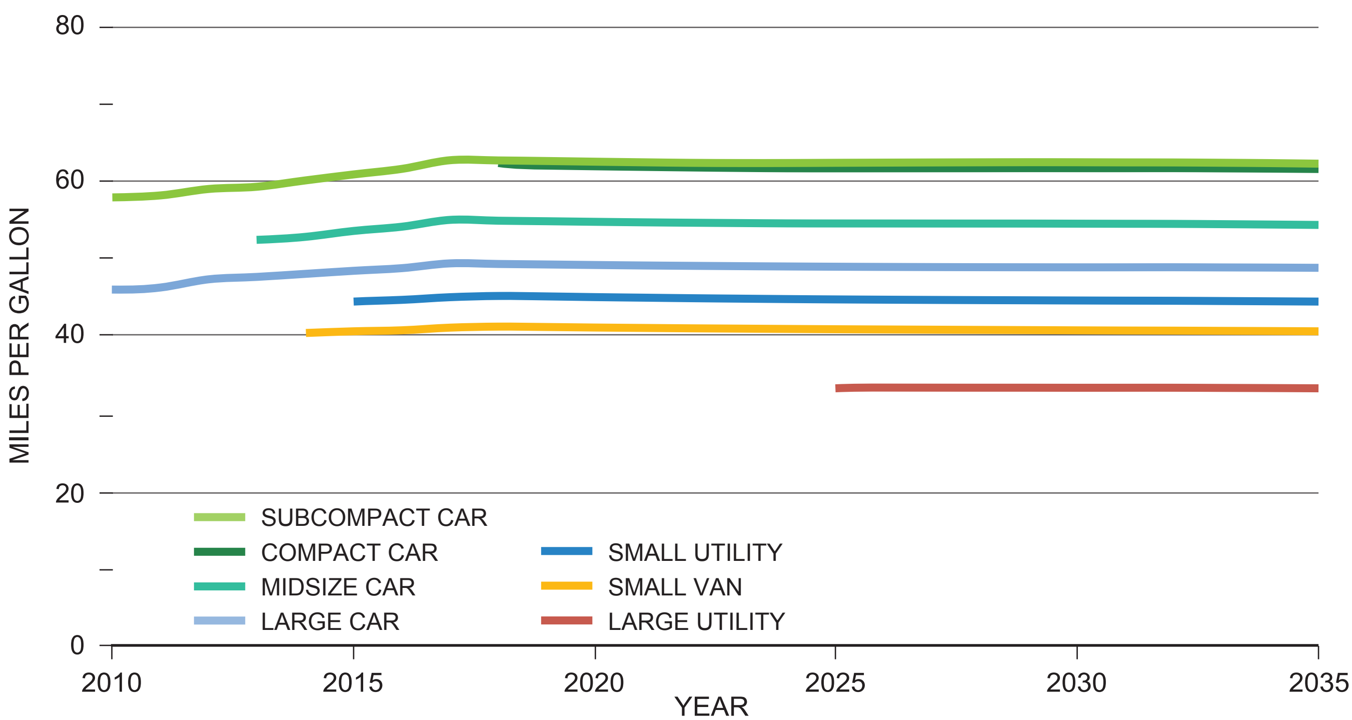

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2010.*

***Figure 8-19.*** *AEO2010 Hydrogen Fuel Cell Electric Vehicle Prices*




Source: U.S. Energy Information Administration, *Annual Energy Outlook 2010.*

***Figure 8-20.*** *AEO2010 Hydrogen Fuel Cell Electric Vehicle Price Premiums over Conventional Gasoline Vehicles*




Source: U.S. Energy Information Administration, *Annual Energy Outlook 2010.*

***Figure 8-21.*** *AEO2010 Hydrogen Fuel Cell Electric Vehicle Fuel Economy*

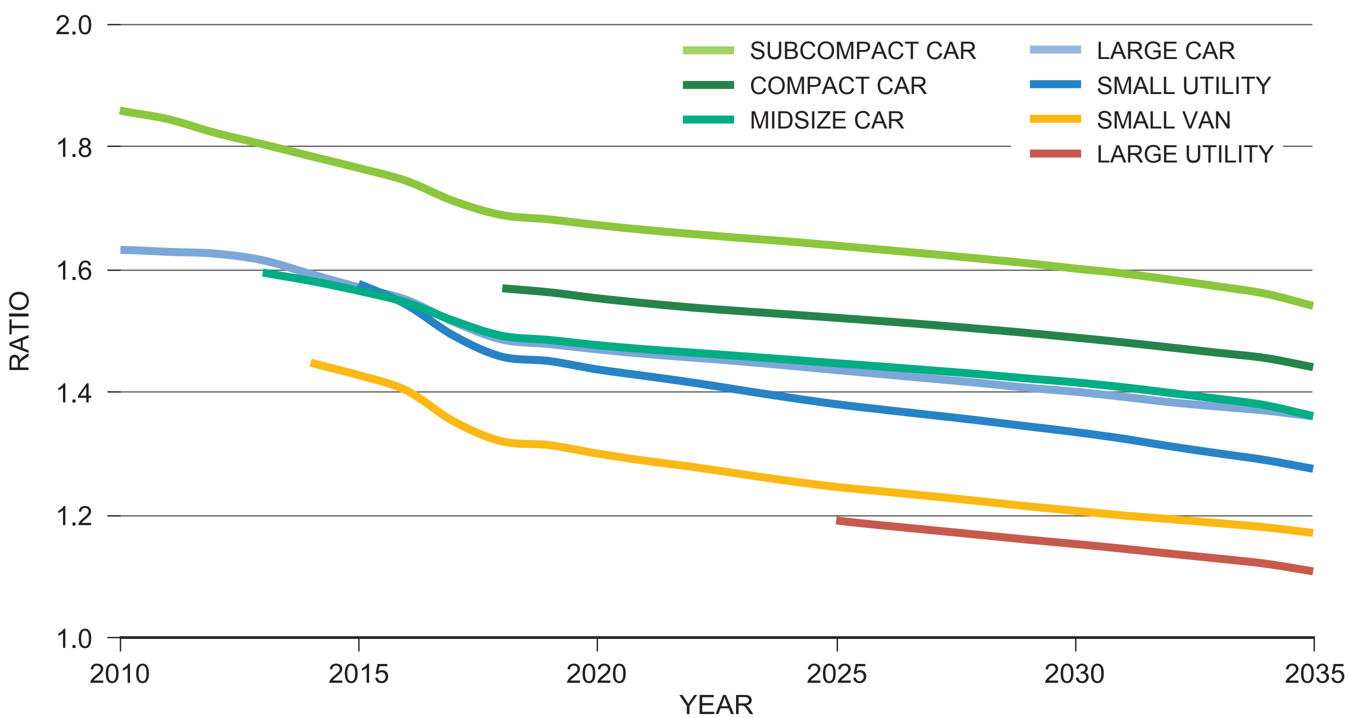
While these fuel economy figures are impressive relative to today's conventional vehicles, they represent almost no improvement from projected 2015 levels. One explanation for the lack of improvement in the overall FCEV segment fuel economy would be a shift to larger vehicles over time. However, Figure 8-21 shows that the improvement remains flat within each vehicle segment. This lack of improvement in the AEO is further discussed below.

Figure 8-22 projects FCEV fuel economy vs. conventional gasoline vehicle fuel economy over time. Most sources, including GREET and California's Low-Carbon Fuel Standard, assign a fuel economy ratio of FCEVs to conventional gasoline vehicles of about 2.3. In contrast, the ratios in AEO2010 vary over time from 1.86 for the subcompact car class in 2010 to as little as 1.11 for the large utility class in 2035.

The AEO Reference Case shows a sharp contrast between FCEVs and other light-duty vehicle technology options. Comparing small utility vehicles, a vehicle class that adopts many future technology options, shows the disparity in projected fuel economy improvements from 2015 to 2035. AEO2010 does not indicate why FCEVs will not benefit from technology advances, especially those that apply across vehicle platforms—e.g., low rolling resistance tires, lightweight materials, aerodynamics, improved batteries and power electronics, etc. In addition, while hydrogen fuel prices are a key part of the FCEV value proposition, the AEO2010 does not include hydrogen price projections. As a result, it's not clear how hydrogen pricing factors into the AEO's transportation model or compares with projections for other fuels.

### *Fuel Cell Electric Vehicle Range and Implied Fuel Storage Capacity*

The AEO2010 Reference Case projects new light-duty vehicle range (Supplemental Table 71 of AEO2010 Reference Case) that, combined with fuel economy projections, provides an estimate of useable, on-board hydrogen storage capacity. The projections suggest unnecessarily high requirements for on-board hydrogen storage. In 2035, for example, on-board hydrogen storage for a subcompact car and a large utility vehicle would be 9.3 kilograms and 21.1 kilograms, respectively. For




Source: U.S. Energy Information Administration, *Annual Energy Outlook 2010.*

***Figure 8-22.*** *AEO2010 Fuel Cell Electric Vehicle Fuel Economy vs. Conventional Gasoline Vehicle Fuel Economy* today's conventional gasoline vehicles, 300 miles is generally considered to be a minimum acceptable range. FCEVs have demonstrated 300-mile range without compromising interior cargo space, but packaging of the hydrogen storage cylinders has been identified as a challenge. It is unlikely, therefore, that FCEV designers would aim for 578 to 718 mile ranges as shown in AEO2010. Costs associated with unnecessarily high hydrogen storage capacity may be one reason that FCEVs do not fare well in the AEO2010 consumer choice modeling results.

### *Hydrogen Fuel Feedstock Mix and GHG Footprint*

AEO2010 does not detail the assumed feedstock mix for production of hydrogen. Natural gas, the dominant feedstock in current U.S. industrial hydrogen production, offers significant per-mile GHG reduction over a conventional gasoline vehicle when converted to hydrogen for use in an FCEV.[10]

In addition, hydrogen has diverse feedstock and production options, ranging from fossil fuels (natural gas and coal) to renewables (biomass, wind, solar) to nuclear, with various levels of GHG emissions and costs.

### *Hydrogen Fueling Infrastructure*

The commerciality and market acceptance of hydrogen as a transportation fuel is materially dependent on consumers' ability to fuel conveniently and reliably. Several infrastructure options are available with varying economics, technical readiness, and scalability. Fueling infrastructure rollout and availability needs to be considered when forecasting the potential use of hydrogen as a transportation fuel. However, the per-kilogram cost of a widespread hydrogen fueling infrastructure would be extremely high under the low FCEV market penetration projected by AEO2010, regardless of station technology options.

### *Future Policy Impacts on FCEVs*

The AEO Reference Case projects light-duty vehicle Corporate Average Fuel Economy (CAFE) standards (based on EPA and National Highway Traffic Safety Administration [NHTSA] rules) increasing to 35 mpg in 2020 before flattening to 2035. AEO2010 does not, by definition, reflect potential future policy measures that might require additional zero emission vehicle sales, much lower carbon intensity of fuels, or significant GHG reduction. Such policies would likely improve the competitiveness of FCEVs, offering the possibility for greater market penetration than shown in AEO2010.

10 U.S. Department of Energy, "Well-to-Wheels Greenhouse Gas Emissions and Petroleum Use for Mid-Size Light-Duty Vehicles," Program Record # 10001, October 2010, www.hydrogen.energy.gov/pdfs/10001_well_to_wheels_gge_petroleum_use.pdf.

## LIGHT-DUTY ENGINES/VEHICLES

The AEO2010 Reference Case projects a 2.3% annual growth rate in new light-duty vehicle fuel economy for the 2010–2020 period, based on existing regulations (Figure 8-23). For the 2020–2035 period, when lower technology costs and consumer demand drive increased fuel economy, the projected annual growth rate for light-duty vehicles is 1.5%. The projected increases in light-duty fuel economy are achieved primarily by adopting a set of possible vehicle and subsystem technologies. Projected increases in heavy-duty vehicle efficiency are small through 2035.

The Reference Case raises fundamental questions about the prospective vehicle fleet, including:

- Benefits and cost of vehicle fuel economy technologies, including diesel and hybridization
- Changing fuel economy of the vehicle fleet over time
- Biofuel availability and consumption
- Market share of vehicle classes
- Customer acceptance and willingness to pay for fuel economy
- Fuel-vehicle GHG emissions.

## Light-Duty Engines/Vehicles Commentary

### *Fuel Economy Technology*

Fuel economy of light-duty vehicles can be impacted by the manufacturer's adoption of vehicle system technology, using the Manufacturers' Technology Choice Model, or by the consumer's choice for alternative fuels or hybridization, depicted by the Consumer Vehicle Choice Model. The Manufacturers' Technology Choice Model adopts vehicle

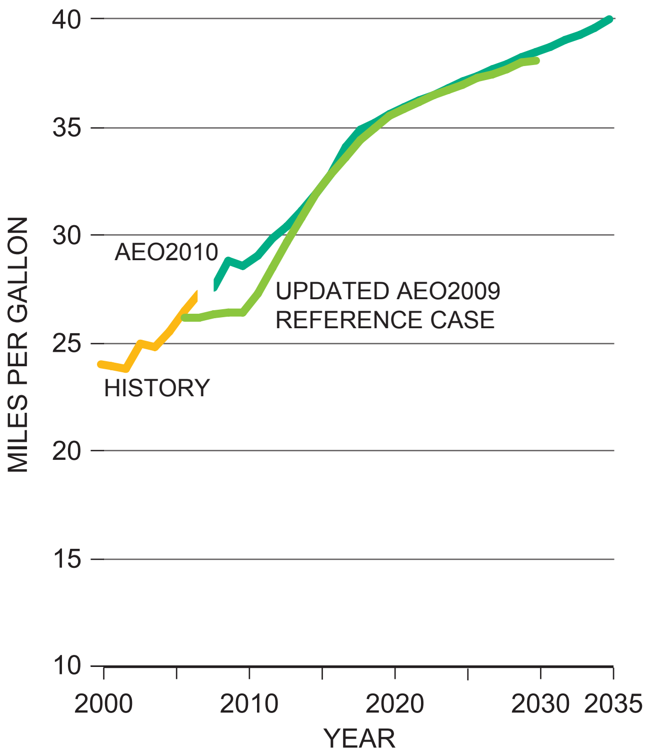



***Figure 8-23.** New Car Efficiency in AEO2010 Reference Case*

system technologies for all vehicle types (conventional gasoline, gasoline hybrid, diesel, etc.) based on the value of fuel economy and/or performance improvement. Manufacturers select the most cost-effective fuel economy technology to meet fuel economy regulations or satisfy customer demand for fuel economy. Demand for fuel economy is based on expected payback of customer investment with 3-year fuel cost savings at a real 15% discount rate. The Consumer Vehicle Choice Model predicts market share of gasoline hybrid, diesel, and flexible-fuel vehicles based on various attributes and the customer value assigned to these attributes.

### *Fuel Economy Assumptions*

The AEO2010 uses fuel economy standards that reflect current law through model year 2011. For model years 2012 through 2016, fuel economy standards reflect NHTSA and EPA proposed standards. For model years 2017 through 2020, the standards reflect EIA-assumed increases that ensure a light-duty vehicle combined fuel economy of 35 mpg is achieved by model 2020. For model years 2021 through 2030, fuel economy standards are held constant at model year 2020 levels, with fuel economy improvements still possible based on an economic cost benefit analysis only. AEO2010 assumptions about fuel economy standards result in a regulation-driven 2.3% annual growth rate in new light-duty vehicle fuel economy for 2010–2020. The projected annual growth rate for 2020–2035, where lower technology costs and consumer demand drive increased fuel economy, is 1.5%.

In the AEO2010 Reference Case, light-duty vehicle fuel economy increases are achieved primarily through adoption of a subset of 63 possible vehicle and subsystem technologies. These assumptions (Tables 7.1 and 7.2 of the AEO Reference Case) show efficiency effects and cost of a variety of technologies. It is particularly important to clarify whether the technologies listed are independent of each other or are incremental compared to other technologies. For example, it is not evident whether the benefits and costs of a continuously variable transmission apply to a 4-speed or 6-speed automatic. In addition, the AEO2010 does not identify the technologies adopted each year for each vehicle type. Table 68 of the AEO Reference Case shows technology adoption shared for conventional gasoline vehicles only. There is no equivalent table showing technology adoption for gasoline hybrids, flexible fuel vehicles, or diesels.

The NPC has used the output tables of the AEO2010 Reference Case to examine the technology cost-benefit assumptions. AEO Reference Case Table 70 shows vehicle prices by class in each propulsion category for 2007–2035. Table 69 has similar results for fuel economy. Using 2007 conventional gasoline vehicles as a baseline, the NPC calculated the increase in retail price as a function of the reduction in fuel consumption. Figure 8-24 shows the results for three different vehicle classes at five-year intervals between 2010 and 2035.

The symbols in the lower left corner of Figure 8-24 are the results for conventional gasoline vehicles. Price and fuel consumption results lie generally on a single line having a slope of about $75 price increase per percent of fuel consumption reduction. The magnitude of fuel consumption reduction and slope are generally consistent with that of the National Research Council (NRC).[11]

11 National Research Council of the National Academies, *Assessment of Fuel Economy Technologies for Light-Duty Vehicles,* 2011.

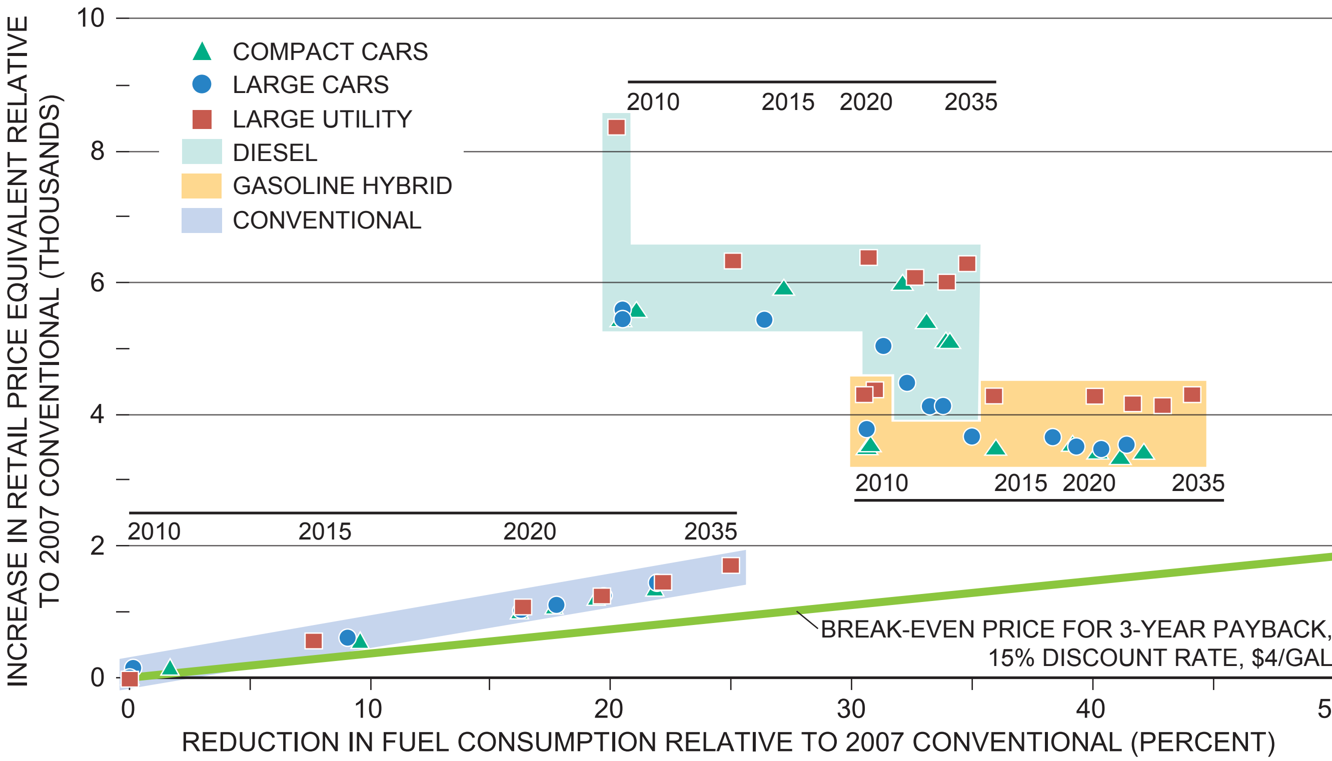



***Figure 8-24.*** *AEO2010 Reference Case Results Displayed as Fuel Consumption Reduction and Incremental Price Equivalent Relative to 2007*

Gasoline hybrid results are grouped in the middle right region of Figure 8-24, which shows fuel consumption reduction for this system growing from 30% in 2010 to 45% in 2035. Presumably, this reduction results from adding additional technology to gasoline hybrid vehicles. Since vehicle prices are relatively flat over this time period, the AEO Reference Case suggests that reductions in hybrid costs offset the additional technology being added to reduce fuel consumption. Since engines on hybrid vehicles spend less time running at light loads, some of the technology options that reduce fuel consumption on conventional vehicles will not provide similar benefits on hybrids. However, the Reference Case may include such benefits for both conventional and gasoline-hybrid vehicles, although the systems are not compatible.

The AEO2010 treats hybrid costs as the sum of battery costs and hybrid system costs. While battery costs increase due to the greater power and energy requirements of larger vehicles, the costs of hybrid systems, including motors, for light-duty trucks are assumed to be the same as those for compact cars. Since larger vehicles require larger motors, this assumption is open to question. Hybrid incremental cost assumptions in the AEO2010 are lower than the NRC figures for all vehicles, but particularly for large light-duty trucks. AEO2010 Reference Case cost assumptions for such trucks are about half the NRC figures.

The AEO2010 sets battery prices based on energy storage, so that technology that reduces the cost of future batteries on a $/kilowatt-hour basis is also assumed to benefit hybrid vehicle batteries. However, batteries in hybrid systems are valued primarily for the power they deliver, not the energy they store. For example, hybrid costs in the AEO2010 do not include the costs of electric air conditioning, a technology that is likely to be required when hybrid vehicle engines shut down during stops.

While the AEO Reference Case assumption that hybrid batteries last the life of the vehicle is applicable for light-duty hybrids, it is questionable for heavy-duty hybrid vehicles, considering their 1.5 million mile life cycle. It would also be appropriate to include higher maintenance costs for light-duty hybrids, since battery replacement costs may be quite high.

Figure 8-24 also shows AEO2010 results for diesels. As with hybrid electric vehicles, diesel shows a large reduction in fuel consumption while prices decrease. This trend is open to question, particularly with the high costs of diesel aftertreatment required to meet tighter emissions standards. The AEO Reference Case does not include cost assumptions for meeting future diesel emissions regulations. Figure 8-24 also includes a projected break-even price of fuel consumption reductions, assuming $4/gallon gasoline (somewhat higher than the Reference Case) and the payback formula used in the Manufacturers' Technology Choice Model. In this projection, consumers would be willing to pay about $40 per percent reduction in fuel consumption, considerably less than the $75 per percent reduction based on technology costs in the AEO Reference Case.

The fuel economy numbers discussed result from certification tests used to measure compliance with fuel economy regulations. It has been recognized for some time that on-road fuel economy is lower than that from these test methods. The AEO2010 uses factors to discount test fuel economy to on-road fuel economy, which is needed for demand projections. However, the assumed discount factors of 80 to 85% are inconsistent with the latest EPA discount factors of 70 to 75%.

Although AEO2010 bases GHG emissions for transportation on tailpipe emissions only, well-to-wheels GHG emissions would better reflect the emissions of the fuel-vehicle transportation system.

Finally, a larger share of flexible-fuel vehicles (FFVs) than projected in the AEO Reference Case would provide flexibility for customers to choose E85 in the future, when its price and availability may be favorable. The Reference Case shows biofuels falling short of 36 billion gallons by 2022 regulation, but reaching 36 billion gallons by 2030. The projected number of FFVs in the Reference Case contributes to a demand shortfall, as would FFV owners not choosing E85 because of its lower driving range. Adding a category for hybrid FFVs to the AEO would also provide a more comprehensive projection of fuel demand.

## HEAVY-DUTY ENGINES/VEHICLES

### Heavy-Duty Engines/Vehicles Commentary

The AEO2010 Reference Case projects a 37% increase in energy demand for heavy-duty vehicles, including freight trucks and buses. This increase assumes slow improvement in fuel economy and modest growth in industrial output. While the AEO2010 does not include a detailed discussion of heavy-duty technology or the heavy-duty vehicle market, the accompanying technology tables represent various truck technologies through their efficiency improvement, cost, and timing. Relative to other public sources, the tables are conservative in projecting the effect of technology advances for medium- and heavy-duty vehicles to 2035.[12] The potential advances would result in incremental and step-change improvements to new vehicle fuel economy rather than the modest gains in the AEO2010 Reference Case (Figure 8-25). The potential technology advances would also reduce energy consumption and GHG emissions for the medium- and heavy-duty sector relative to the AEO Reference Case.

#### *Legislation and Regulation*

The AEO Reference Case assumes that current laws and regulations affecting the energy sector remain unchanged during the projection period. Fuel economy standards reflect current law through model year 2011. Fuel economy standards for 2012–2016 incorporate proposed NHTSA and EPA standards. For model years 2017–2020, the Reference Case assumes that light-duty vehicle combined fuel economy achieves 35 mpg by model year 2020. Fuel economy standards for model years 2021–2030 are constant at 2020 levels, with any additional fuel economy improvements based on economic cost benefit analysis. The AEO2010 Reference Case assumes that laws and regulations in effect at the end of October 2009 will remain unchanged through 2035, unless the establishing legislation calls for them to end or change.

#### *Fuel Taxes and Credits*

State fuel taxes are calculated on the basis of a volume-weighted average for diesel, gasoline, and

12 National Research Council of the National Academies, *Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles,* 2010.

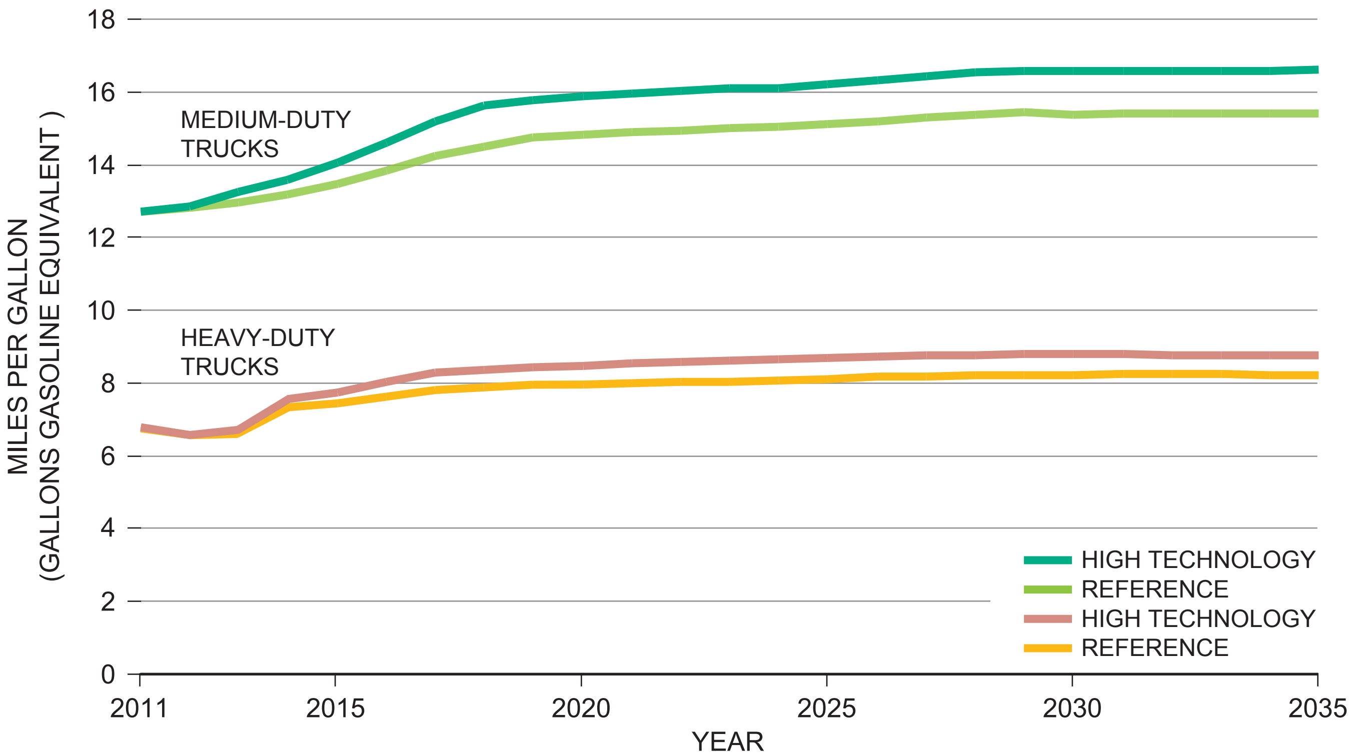



***Figure 8-25.*** *AEO2010 Fuel Efficiency Projections for New Trucks*

jet fuels. The state fuel taxes were updated as of July 2009 and are held constant in real terms to 2035. No changes have been made in the treatment of biofuels taxes and credits in AEO2010 relative to the previous AEO.

### *Low-Carbon Fuel Standard*

The AEO2010 does not include California's Low-Carbon Fuel Standard rules intended to reduce the carbon content of transportation fuels sold in California, since the regulations had not been formulated as of October 2009.[13]

### *CAFE Standards*

The AEO2010 assumes that CAFE standards will be increased, so that the combined fuel economy of new light-duty vehicles will meet the required minimum of 35 mpg by 2020. The Reference Case does not include potential effects of increasing CAFE standards on fuel demand or vehicle miles traveled.

### *Carbon Capture and Storage*

The AEO2010 Reference Case assumes that an additional one gigawatt of coal-fired capacity with carbon capture and storage (CCS) will be built by 2017. The assumption is based on ARRA Title IV provision of $3.4 billion for additional research and development of fossil energy technologies, including $800 million to fund projects focused on capture and sequestration of GHGs. Reference Case projections do not include future regulation of CCS in the power sector. The Reference Case does not assume any CCS in the refining sector.

## GREENHOUSE GAS EMISSIONS

The Reference Case assumes no explicit regulations to limit GHG emissions beyond recent vehicle GHG standards. On average, projected GHG emissions grow by 0.3% annually from 2008 to 2035—to 6,320 million metric tons, which is 6% above

13 The EIA anticipated that baseline carbon intensities for gasoline, diesel fuel, and their substitutes would be calculated in a full-life-cycle fuel analysis by the end of 2010, including indirect land-use effects for certain biofuels.

2007 and 9% above 2008. Petroleum accounts for 42% of the emissions total in 2008 and 41% in 2035. Figure 8-26 shows projected $CO_2$ emissions specifically for transportation.

The AEO2010 Reference Case does not include net emissions from biomass and assumes that biomass energy consumption is $CO_2$ neutral. The uptake of carbon when feedstock is grown balances the release of carbon from biomass combustion, resulting in zero net emissions over time. Including direct emissions from biomass in the Reference Case would increase total projected 2035 energy-related $CO_2$ emissions by 12.9% or 813 million metric tons. The Reference Case does not include "indirect land use change" calculations when projecting GHG emissions.

## 2005 Emissions Baselines

As requested by the Secretary of Energy, this study considers options for achieving a 50% reduction in transportation sector GHG life-cycle emissions by 2050 relative to a 2005 baseline. The NPC used the Energy Information Administration's AEO2008 as the source for this baseline, as summarized in Table 8-2 and Figure 8-27.

### *EIA vs. EPA GHG Inventories*

While GHG emissions in the EIA's Annual Energy Outlook are similar to those in the EPA's GHG inventory, there are accounting differences. The NPC used the AEO2008 for the 2005 baseline because it provides consistent GHG emissions data that are publicly available, updated annually, and the basis for the 2010–2035 Reference Case. Since the EPA GHG inventory is considered by some as the official inventory for the United States, it is useful to understand the relevant accounting differences. Figure 8-28 compares $CO_2$ emissions in the EPA and AEO2008 inventories for 2005.

EIA figures are higher than the EPA's due to methodological differences in the treatment of non-energy fuel use (such as coking coal) and bunker fuels in the transportation sector. The EPA subtracts emissions resulting from non-energy fuel use and bunker fuels and allocates these emissions to other categories. One area where the EPA

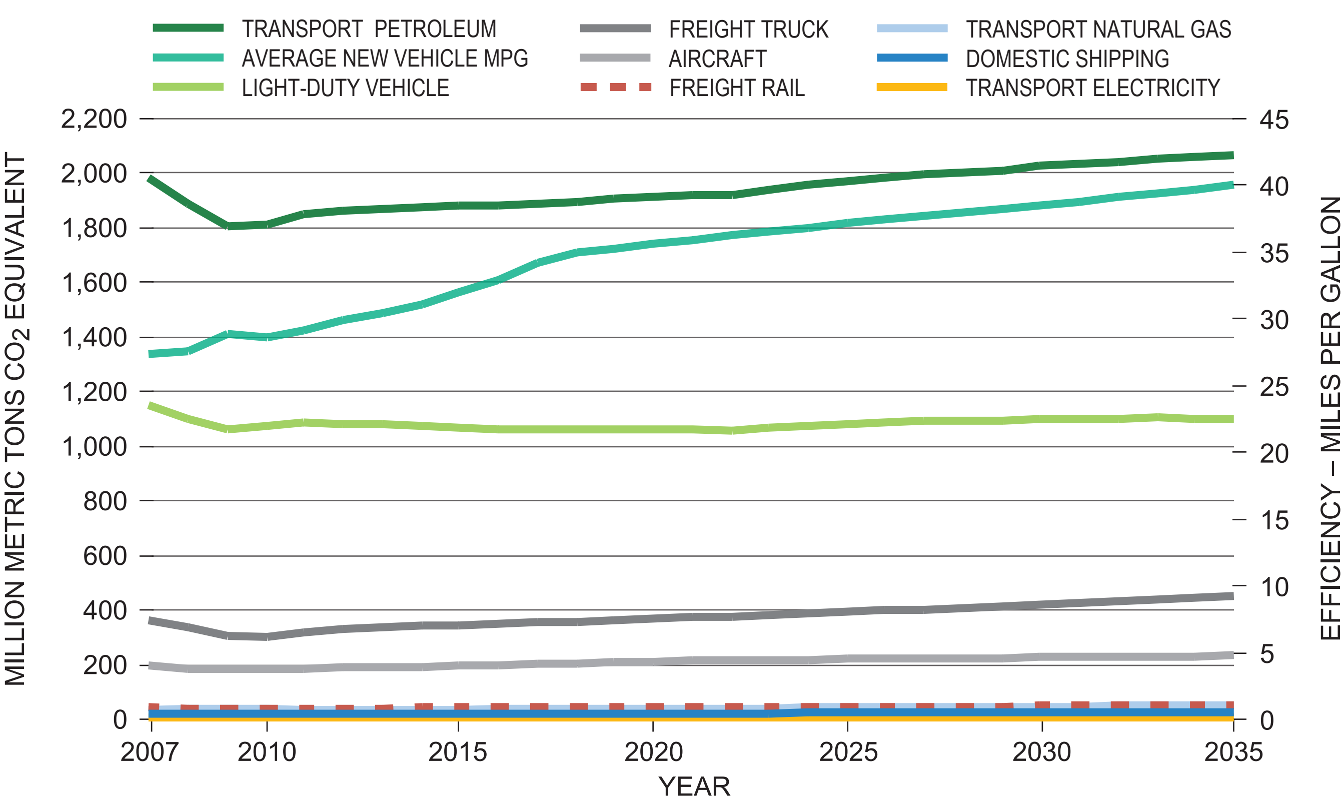
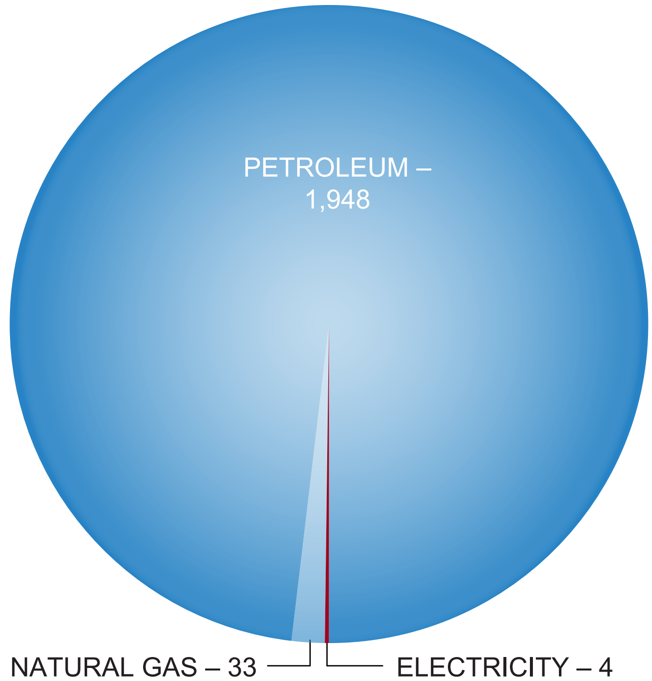



***Figure 8-26.*** *Transportation Sector $CO_2$ Emissions*

| Grouping | 2005 Baseline | |
|---|---|---|
| Energy-related $CO_2$ | Electric power | 2,397 |
| | Transportation | 1,985 |
| | Industry | 1,004 |
| | Commercial | 225 |
| | Residential | 365 |
| Non-energy-related $CO_2$ and other GHGs | Methane | 692 |
| | Non-energy $CO_2$ | 103 |
| | Nitrous oxide | 304 |
| | Fluorinated gases | 158 |
| **Total** | | **7,231** |

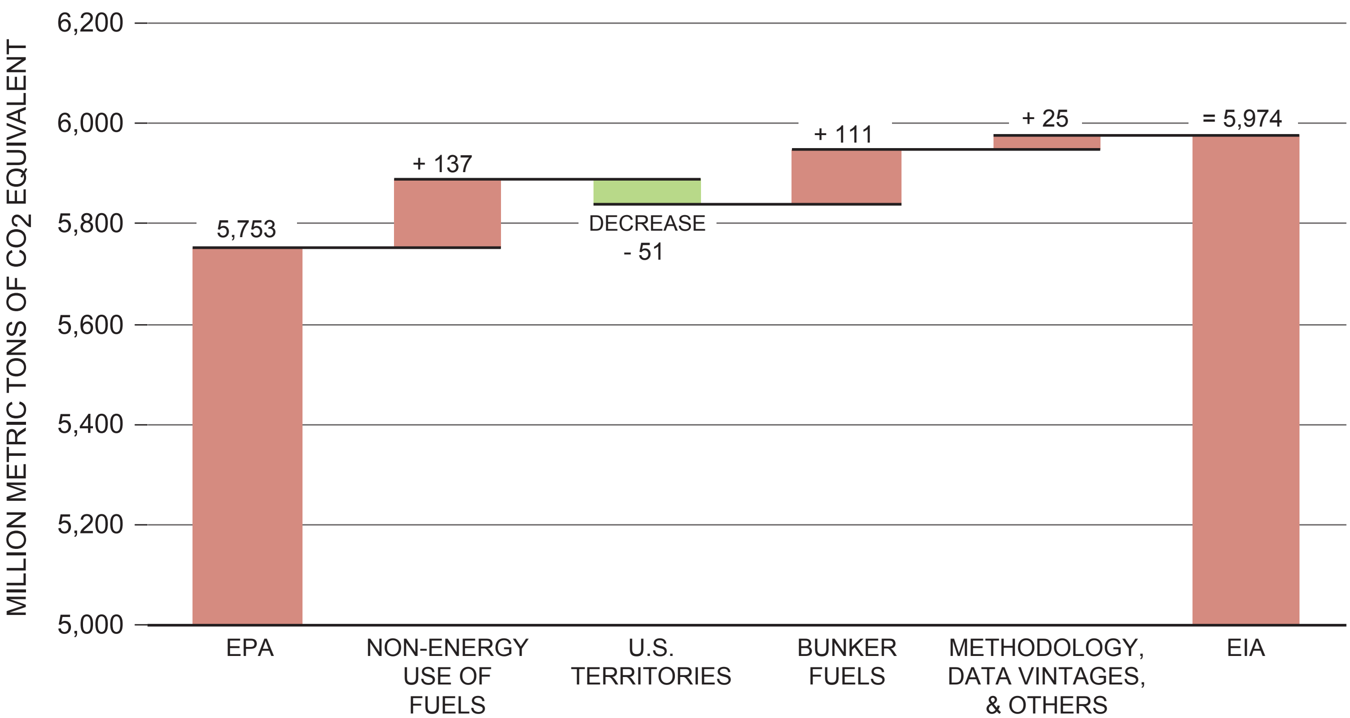
Source: U.S. Energy Information Administration, *Annual Energy Outlook 2008*.

***Table 8-2.*** *2005 Baseline GHG Emissions (Million Metric Tons of $CO_2$ Equivalent)*




Source: U.S. Energy Information Administration, *Annual Energy Outlook 2008*.

***Figure 8-27.*** *2005 Transport Emissions by Fuel Type (Million Metric Tons of $CO_2$ Equivalent)*




Source: U.S. Energy Information Administration, *Annual Energy Outlook 2008,* and U.S. Environmental Protection Agency, *2010 Greenhouse Gas Inventory Report*.

***Figure 8-28.*** *Comparison of EPA and EIA Energy-Related 2005 $CO_2$ Emissions* includes emission categories not included in the EIA is emissions from U.S. Territories. The remaining difference is based on methodology and the time frames used for data.

## 2005 Non-GHG Baseline Emissions

Consistent with the NPC's *Prudent Development: Realizing the Potential of North America's Abundant Natural Gas and Oil Resources* study, this study includes environmental factors such as criteria air pollutants from the transportation sector. Since the Annual Energy Outlook does not report criteria pollutants for the transportation sector, the NPC extracted the data from EPA's National Emissions Inventory. Table 8-3 summarizes 2005 criteria pollutant emissions from on-road vehicles and non-road vehicles, planes, ships, and trains. Table 8-3 does not include criteria pollutant emission levels associated with other elements of the transportation fuel supply chain including oil production, manufacturing, bulk storage, and distribution. This study evaluates potential reductions of these criteria pollutants through 2050 against the 2005 baseline data.

| Criteria Air Pollutant | On-Road & Non-Road Vehicle Emissions (Million Tons) |
|---|---|
| Nitrogen Oxides | 8.5 |
| Sulfur Dioxide | 0.5 |
| Particulate Matter (10 Microns) | 0.5 |
| Particulate Matter (2.5 Microns) | 0.5 |
| Volatile Organic Compounds | 7 |
| Ammonia | 0.5 |
| Carbon Monoxide | 71 |

Source: U.S. Environmental Protection Agency, "Documentation for the 2005 Mobile National Emissions Inventory, Version 2," December 2008. ftp://ftp.epa.gov/EmisInventory/2005_nei/mobile/2005_mobile_nei_version_2_report.pdf.

***Table 8-3.*** *2005 Baseline Emissions: Mobile Criteria Pollutants*

## EXTRAPOLATIONS TO 2050

The study's 2050 endpoint required extrapolations of AEO2010 Reference Case data for the 2035–2050 period. These extrapolations complete the FTF Reference Case: AEO2010 Reference Case + 2050 Extrapolation + 2005 GHG baseline. The 2035–2050 extrapolations are neither provided nor endorsed by the Energy Information Administration. They have been generated solely for comparative and analytical purposes in this study.

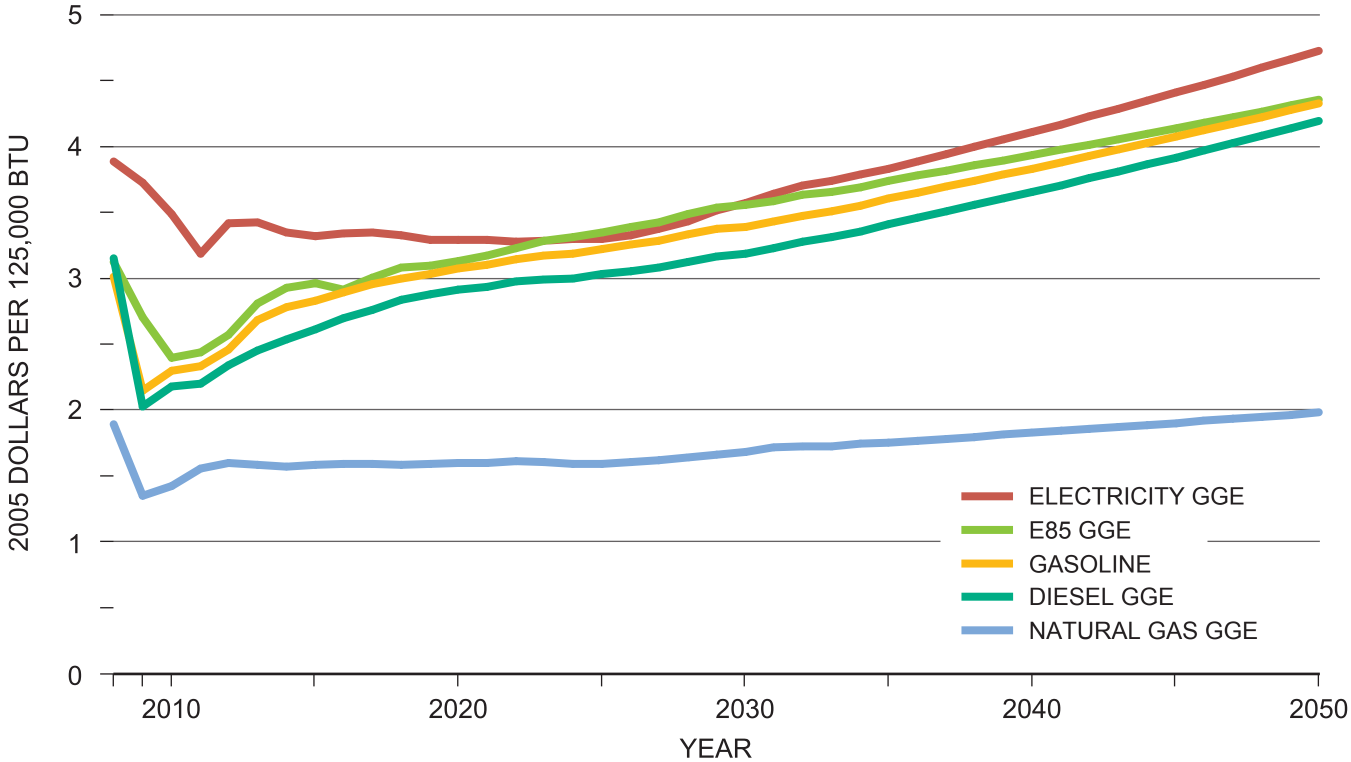
Generally, this study used the Department of Energy's VISION model, which was developed to estimate potential energy use, oil use, and carbon emission impacts to 2050 of various vehicle technologies and fuels.[14] The VISION model was used because it considers a set of input parameters, with default values taken from the AEO Reference Case. In instances where the VISION model did not contain data for a certain fuel and application (e.g., CNG in medium-/heavy-duty vehicles) or transport mode (e.g., air), the NPC developed trend lines from AEO2010 data based on guidance from EIA and Argonne National Laboratory.

In the VISION 2010 model, the "Model Input" parameters match the values published in and/or underlying the AEO2010 Reference Case through 2035. The inputs post-2035 are based on assumptions made in this study. In some cases, the inputs are extensions of the AEO values, generally relying on 2025–2035 growth rates estimated in the AEO Reference Case. In other cases, the inputs may be held constant at the AEO 2035 values, or the projections may be made to fit a logit curve. See the Methodology sections of Chapter Two, "Light-Duty Vehicles," and Chapter Three, "Heavy-Duty Vehicles," for a detailed description of calculations and formulas.

### Example VISION Model Extrapolation

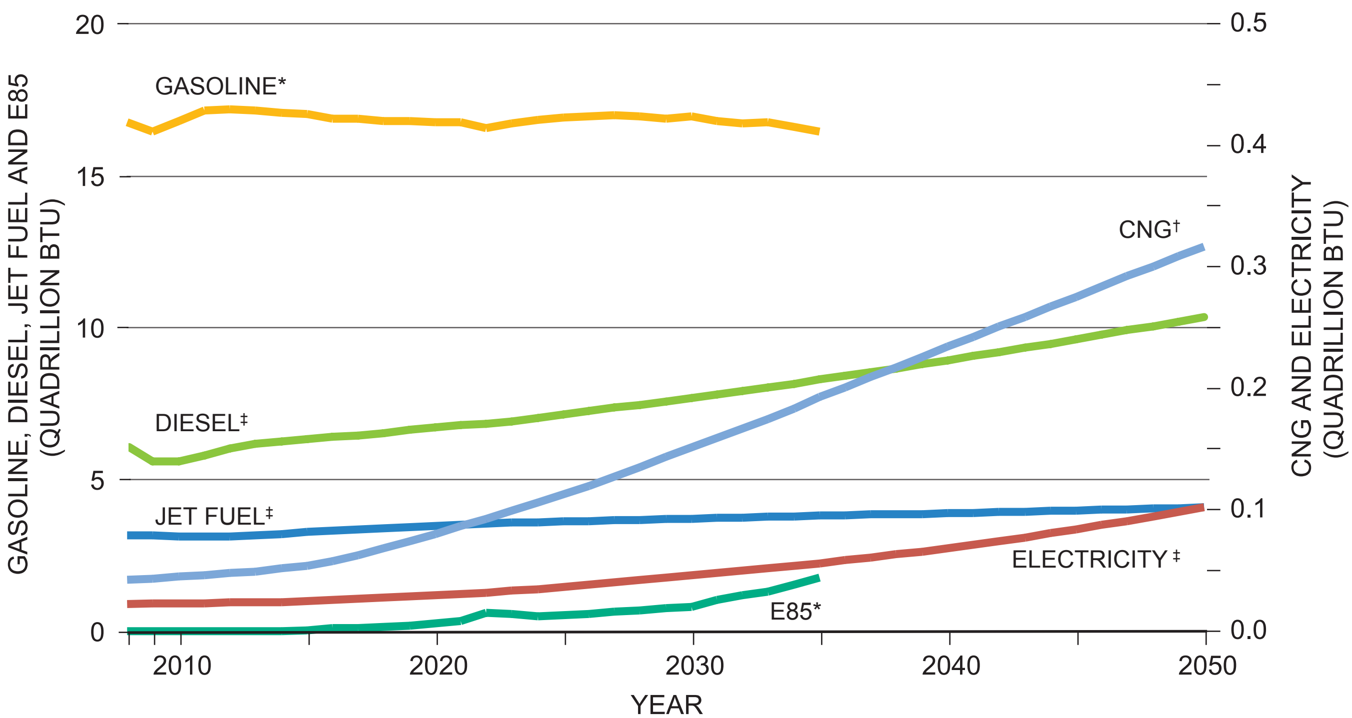
Figure 8-29 is a VISION linear extrapolation from AEO2010 Reference Case inputs for gasoline gallon equivalent 2005 dollar price per 125,000 BTU. The example uses AEO2010 data for the years

14 For a full description of the VISION model, see the U.S. Department of Energy's Argonne National Laboratory website: Transportation Technology R&D Center: Modeling Simulation: VISION, "The VISION Model," www.transportation.anl.gov/modeling_simulation/VISION/.




Note: GGE = gallon gasoline equivalent.

***Figure 8-29.*** *VISION Model Extrapolation of AEO2010 Data to 2050*




Source: * VISION Model; † AEO 5-Year Linear; ‡ AEO 5-Year Exponential.

***Figure 8-30.*** *AEO2010 Extrapolation to 2050 of Consumption of Fuels by the Transportation Sector*

2008–2035 and a linear calculation from VISION for the years 2035–2050.

Core data for this example are found in the AEO2010 Transportation Sector Data, Table 3: Energy Prices by Sector and Source (2008 dollars per million BTU). Using the EIA Implicit Price Deflator (Appendix D: Table D1 from the Annual Energy Review 2009), the VISION model converted the 2008–2035 data into 2005 dollars with a 2008 price deflator (1.08483). These values were then converted into dollars per gasoline equivalent by dividing the million BTU by 8 to calculate 2005 dollars per 125,000 BTU.

The VISION data set can be found in the VISION Model Input Tab under the Fuel Price Option Table, located on the NPC website.

## Example AEO2010 Extrapolation

VISION does not include data on several transport modes within the scope of this study, such as air, rail, bus, and waterborne shipping. VISION also has limited fuel options for medium-/heavy-duty vehicles. As a result, VISION cannot be used to extrapolate the AEO's projected demand for jet, CNG, diesel, and electricity in these transportation modes. This discrepancy in transport mode creates accounting differences when summarizing total projected fuel consumption. VISION, for example, does not track CNG consumption by medium- and heavy-duty trucks, whereas AEO assumes significant growth of CNG use by heavy-duty trucks. As a result, VISION's projections for CNG use in the transportation sector are effectively zero.

For extrapolation of variables not included in VISION, the NPC developed trend lines based on guidance from EIA and Argonne National Laboratory. In Figure 8-30, the AEO projections for electricity, diesel, and jet fuel are exponentially extrapolated with an average annual compound growth rate from the last five years of AEO data. The AEO projection for CNG is linearly extrapolated from a linear best fit to the last five years of AEO data.

The report continues with Chapter 9 in Part 2