Appendix E. Transportation Sector Assumptions

The Transportation solutions in this report are divided into three categories: vehicle technology, fuels, and opportunities to reduce travel through smart growth. In most cases, input assumptions adopted for this study were based on the Reference or Transportation High Technology cases of the Annual Energy Outlook (AEO) 2008 report (EIA 2008). This appendix highlights the areas where we either used the Transportation High Technology case assumptions or modified assumptions directly. All other assumptions are based on the AEO 2008 Reference case (see EIA 2008 for more information).

Vehicle Technology Modeling

The vehicle technologies investigated include fuel economy improvements to passenger vehicles (cars and light trucks up to 10,000 pounds gross vehicle weight), fuel economy improvements to medium- and heavy-duty trucks, and improved air-conditioning systems.

Passenger Vehicle Fuel Economy

For the version of NEMS used in AEO 2008 two sets of assumptions were available for the cost and effectiveness of technologies that can be applied to cars and trucks, referred to here as "AEO 2008 Reference" and "AEO 2008 High Tech." In choosing between the two, we developed cost curves and compared them to cost curves from a variety of studies.

Two of the cost curves for the studies were taken from Kliesch 2008 (a UCS study: Friedman 2003; and a study from the National Research Council: NRC 2002). A third is based on data from an MIT study from Bandivadekar et al. 2008. These cost curves represent the most cost-effective path for fuel economy improvements under each study.

The cost curves for the AEO 2008 assumptions, however, do not represent the most cost-effective paths. Instead, they include the cost of diesel, flex-fuel, hybrid, and plug-in vehicles that may be brought into the market at quicker or slower rates than are cost-effective due to consumer preferences and vehicle or fuel standards. As a result, the cost curve for UCS-NEMS is based on a combination of the AEO 2008 High Tech assumptions and our assumptions for plug-in costs and different penetration rates of flex-fuel vehicles and diesels. We therefore refer to this cost curve as the "UCS-NEMS High Tech" case.

The values for the UCS-NEMS High Tech case were developed by exercising the model with tight fuel economy standards, and comparing the resulting fleet-wide fuel economy and technology costs for cars and trucks to those in the baseline year, 2006. We then applied the fixed 54/46 car/truck split used in Kliesch 2008 for model year 2006. These UCS-NEMS costs have gasoline, hybrid, and diesel technologies built in and are slightly different than the actual cost of improved fuel economy from technology alone because UCS-NEMS showed small shifts in fleet mix within cars and within trucks.

As shown in Figure E.1, the values from the UCS-NEMS High Tech case fall in between the range defined by the 2002 National Research Council study on the high-cost end and the 2008 Bandivadekar et al. study on the low-cost end. The UCS-NEMS High Tech case was also closer to the 2003 UCS fuel economy study (Friedman 2003). Based on this comparison, we chose the UCS-NEMS High Tech case as being closest to the findings of the more recent studies.

Figure E.1. Comparing Fuel Economy Improvement Costs
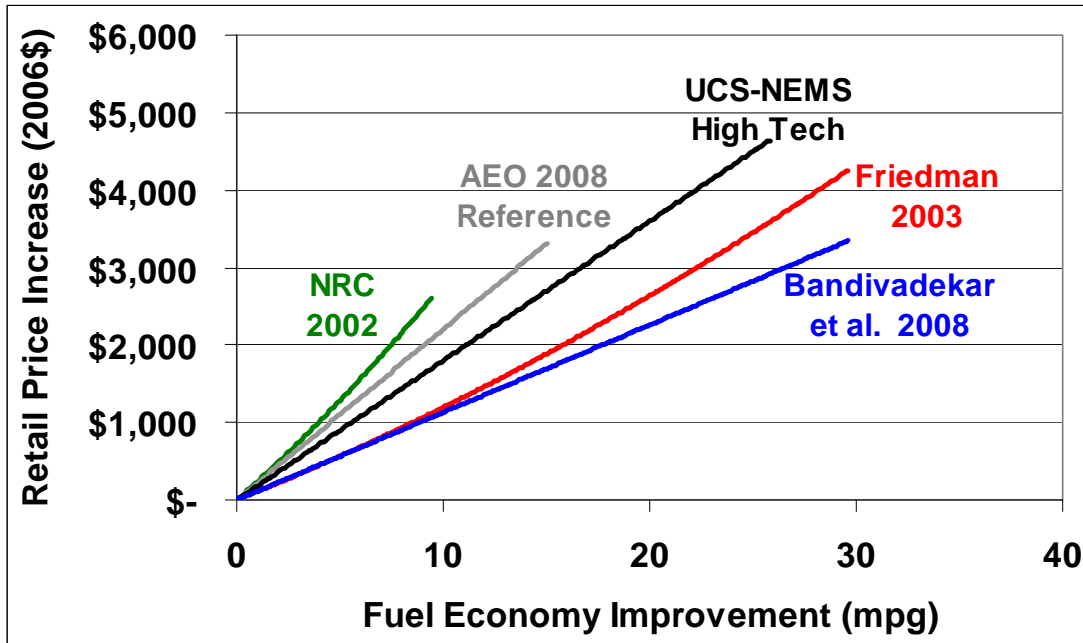
As noted above, the cost and penetration of plug-in hybrids is already built into Figure E.1. To simplify modeling in our study, plug-ins are used as a proxy for any electric vehicle technology (e.g., battery-electric vehicles, fuel-cell vehicles, and plug-ins themselves). While this does induce some error, the environmental performance of plug-ins is expected to be similar to what might be expected from fuel-cell vehicles in this timeframe

For this study, the input assumptions for plug-ins are as follows:

30-mile all-electric range. This is the value used in a 2008 MIT study from which we draw our long-term costs (Bandivadekar et al. 2008). Given that there are a wide variety of plug-in configurations under consideration, this seemed a reasonable and convenient compromise.

50 percent all-electric vehicle miles traveled (VMT). This value is based on a survey of utility factors in a variety of studies (EPRI 2007; Tate, Harpster, and Savagian 2008; Komatsu et el. 2008; Santini and Vyas 2008). Early adopters may likely get more use, but likely charging patterns are unknown.

All-electric efficiency. We assume that a plug-in operating on electricity from the grind has two times the efficiency of a conventional hybrid.

Plug-in Car incremental cost vs. hybrid-electric vehicle (HEV). $12,000 in 2010 and $3,400 in 2030 (see Figure E.2). The 2030 cost is based on the 2008 MIT study (Bandivadekar et al. 2008). The near-term cost is very roughly derived from press accounts of $40,000 for the Chevy Volt plug-in hybrid with 40 miles all-electric range compared with about $24,000 for a similar conventional hybrid (Honda Civic Hybrid or Toyota Prius), which yields $16,000, which is then reduced by 20 percent for a plug-in hybrid with a 30 mile all-electric range.

Plug-in Truck incremental cost vs. HEV. $18,000 in 2010 and $5,100 in 2030 (see Figure E.2). The 2030 cost is based on the 2008 MIT study (Bandivadekar et al. 2008). The truck near-term cost is very roughly derived from the fact that the car near-term cost is 3.5 times higher than the car long-term cost.

Figure E.2. Learning Curve for Plug-In Hybrid Costs
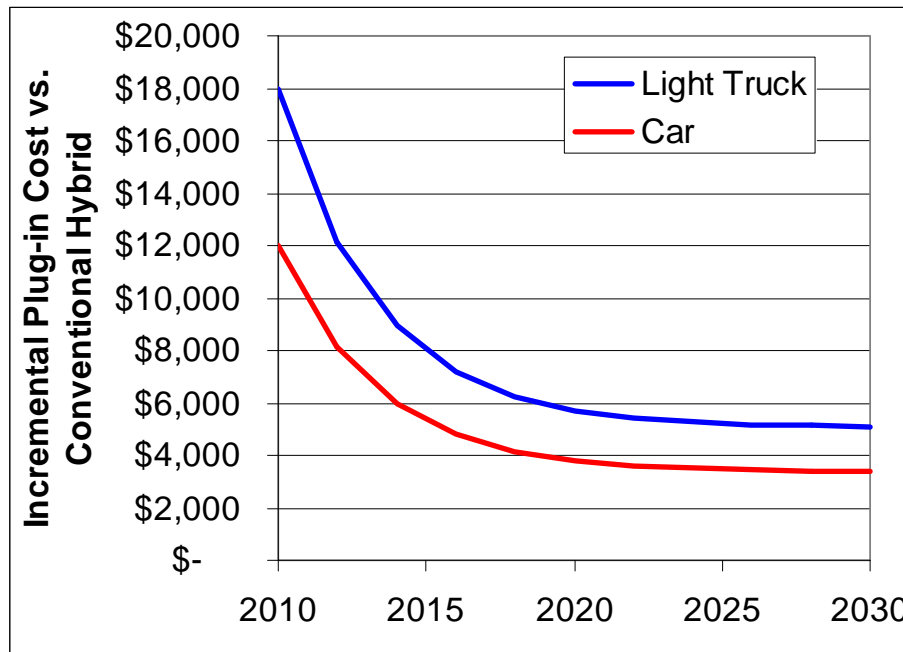
Medium- and Heavy-Duty Vehicle Fuel Economy

We also began with the AEO 2008 High Tech case for medium- and heavy-duty freight truck efficiency improvements. These assumptions are based on work by Argonne National Laboratory (Vyas, Saricks, and Stodolsky 2002). However, since this work was completed in 2002, UCS modified some parameters to better reflect the current state of the technology, based on Anair 2008 and conversations with authors of a forthcoming study on truck efficiency technology (Cooper et al. forthcoming).

Anti-idling: Long-haul heavy-duty trucks can use auxiliary power units (APUs) to avoid idling. Other heavy-duty trucks that do not have sleeper berths can use integrated starter generators (ISGs). A cost estimate of $4,025 is based on a weighted average of costs for

APU systems for long-haul trucks[1] and the AEO 2008 Reference case cost assumptions for ISG for medium-duty trucks. We assume 15 percent of heavy-duty trucks could benefit from APUs while the remainder could benefit from ISG technology. A weighted average 4 percent fuel economy improvement is assumed for anti-idling technology.

Hybrids: Hybrids in heavy-duty applications would see benefits in urban and suburban driving, and in applications such as utility trucks and waste haulers. UCS assumes mature hybrid technology could achieve a 40 percent fuel economy improvement in these applications.[2] The incremental cost of such a system is assumed to be $18,900.[3] A 2010 introduction of hybrids is assumed with a maximum market penetration of 15 percent for heavy-duty trucks. For medium-duty trucks, maximum market penetration is 100 percent.

Advanced tractor-trailer aerodynamics: Applying technologies such as pneumatic blowing and full tractor-trailer gap closure, we assume a 13.5 percent improvement at a cost of $16,500 with initial introduction in 2015, and a maximum potential market share of 50 percent.[4,5]

Additional assumptions: For medium-duty and heavy-duty trucks, conventional technology engine improvements and application of low rolling resistance tires are assumed to have a maximum potential market of 100 percent. Tractor-only aerodynamic improvements are also assumed to have a maximum potential market share of 100 percent for heavy-duty vehicles.

Vehicle Air-Conditioning Systems

NEMS does not model vehicle air-conditioning systems. We therefore added on a reduction of 8 grams of carbon dioxide (CO_2) equivalent emissions per mile at a cost of $50 per vehicle.[6] Replacing HFC-134a with HFC-152a, reducing connections, and other steps to reduce leaks can cut direct heat-trapping emissions by 95 percent. Total heat-trapping emissions leakage, including two lifetime service intervals, is about 6.6 grams per mile of carbon dioxide equivalent at 15,000 miles per year (Bedsworth 2004). A 95 percent reduction will save about 6.3 grams per mile (Bhatti 1999; Vainio 2003). A variable-speed compressor motor can help waste less energy, overcoming the increased energy demand from HFC-152a and even improving efficiency overall, cutting indirect heat-trapping emissions (about 15 grams per mile of carbon dioxide equivalent) by about 10 percent, saving about 1.5 grams per mile. Given that average mileage is actually less

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[1] Cost estimates based on diesel-powered and battery-powered APUs. See EPA 2009.

[2] 40 percent improvement for urban application heavy-duty hybrids is based on medium-duty assumptions in Vyas, Saricks, and Stodolsky 2002.

[3] Based on conversations with authors of a forthcoming heavy-duty vehicle study (Cooper et al. forthcoming).

[4] Testing of pneumatic blowing alone has shown improvements of up to 12 percent (see *http://gtresearchnews.gatech.edu/newsrelease/truckfuel.htm*). Preliminary results from Southwest Research Institute simulation modeling estimates long-haul tractor-trailer improvements of 20 to 30 percent are possible in the 2017 timeframe.

[5] Based on conversations with authors of the forthcoming heavy-duty vehicle study (Cooper et al. forthcoming).

[6] Based on data from Hill 2003 and Pettersen 2003.

than 15,000 miles per year, we round up the sum of 6.3 and 1.5 to 8 grams per mile. Moreover, new refrigerants continue to be developed; the refrigerant HFO1234yf, for example, has a remarkably low heat-trapping potential of just four times that of CO_2, while still allowing for efficient air conditioner compressor operation (SAE 2008).

For simplicity, we applied the same value to medium- and heavy-duty trucks. These vehicles have larger air-conditioning systems and more service intervals, driving up emissions, but they travel more, driving down per-mile values. Further analysis is needed for these larger vehicles.

Vehicle Policy Modeling

The UCS-NEMS transportation sector model cannot directly model the vehicle-related climate policies in the Blueprint case. As a result, we used existing tools where possible and offline analysis when necessary to implement or verify our Blueprint policies in the transportation sector.

Blueprint Light-Duty Vehicle Global Warming Emission Standards

Because NEMS does not include the ability to model comprehensive vehicle global warming emission standards, we split up the impacts from vehicle technologies and fuels into separate areas. As with California's standards, our standards can be met through improvements in vehicle efficiency, improvements in air-conditioning systems, and the use of cleaner fuels. This section discusses the vehicle efficiency and air-conditioning technology approaches.

Vehicle efficiency: If all vehicles used only one single fuel and did not have air-conditioning systems, the tailpipe global warming emissions could be known simply by knowing the fuel economy. In UCS-NEMS, all vehicles are represented by their "gasoline equivalent" fuel economy, so UCS-NEMS effectively assumes all vehicles are using gasoline for the sake of applying fuel economy standards and is therefore really applying an efficiency standard. As a result we can use the UCS-NEMS "fuel economy" standards as representing the efficiency portion of our global warming emission standards. It should be noted, however, that UCS-NEMS does not contain all the details of how fuel economy standards, as implemented by the National Highway Traffic Safety Administration (NHTSA), actually work. Those standards provide extra credit for flex-fuel and dedicated alternative-fuel vehicles in an attempt to represent reductions in oil use. These reductions in oil use, however, are not achieved through efficiency, so NHTSA's fuel economy standards should not be seen as a proxy for efficiency.

As noted in Chapter 6, the efficiency portion the tailpipe emission standards is the equivalent of 42 miles per gallon (mpg) of gasoline by 2020 and 55 mpg by 2030, so standards were set to these levels for the Blueprint. However, because automakers can opt out of meeting fuel economy standards by paying a fine of $5.50 per 0.1 mpg below the standard per vehicle sold, initial modeling runs did not meet the standard. The fines were then doubled and indexed to inflation. The 2030 goal, however, was still not quite met, leading to a 2030 efficiency equivalent of 52 mpg.

Air conditioning: We assume that all new vehicles adopt low-leak HFC-152a systems with more efficient motors/compressors by 2015 and add the reductions in a post-processing spreadsheet.

Reference Case and No Complementary Policies Case Vehicle Policy Application

The Reference and No Complementary Policies cases include the minimum fuel economy standards that are required under the 2007 Energy Independence and Security Act (EISA) as modeled in AEO 2008. This act requires a minimum fuel economy of 35 mpg for the fleet of new cars and trucks sold in the United States in 2030 and "ratable" progress along the way.

This has a major impact on the findings in this report because all of the costs and benefits of the necessary fuel economy technologies are embedded in the Reference and No Complementary Policies cases. This significantly lowers the contribution of the transportation sector to reducing further heat-trapping emissions through 2030. It also significantly lowers the costs of solutions in the transportation sector because only those costs for going above 35 mpg are included.

These facts highlight the importance of getting the modeling of fuel economy policy correct. However, NEMS has historically over-predicted the adoption of technology that improves fuel economy as price changes. This could be due to an assumption of too little demand for power and size, the inability of the three-year payback with a 15 percent discount rate adoption model to capture manufacturer and consumer decisions, or both.

Increases in gas prices will clearly have an impact on consumer decisions around fuel economy. To test whether the Reference and No Complementary Policies case modeling runs over-predict fuel economy we compared the initial results from modeling these two cases to the results we would have expected from using a long-run price elasticity of vehicle fuel intensity (e.g., gallons per mile) ranging from 0.2 to 0.4 (based on Small and Van Dender 2006; Espey 2004; Goodwin, Dargay, and Hanly 2004; Dahl 1993; and Brons 2006). We assumed a baseline gas price of $1.50 per gallon, consistent with the relatively stable fuel economy levels and gas prices in the early 2000s.

Reference case: Gasoline prices averaged $3.37 per gallon between 2020 and 2030 under the Reference case. Assuming the highest elasticity noted above (0.4), fuel economy would reach about 35 mpg at this price.[7] UCS-NEMS, however, predicted a higher fuel economy in this timeframe. To make the results more realistic, we adjusted the discount rate used in the three-year payback model to keep fuel economy from growing significantly above 35 mpg, which is also the minimum required standard of 35 mpg post-2020 under the EISA.

No Complementary Policies case: Gasoline prices averaged $4.21 per gallon between 2020 and 2030 under the No Complementary Policies case. Assuming the same elasticity (0.4), fuel economy would reach about 38 mpg at this price, so we adjusted the discount

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[7] Assumes fixed household income. Consumers would also purchase fewer vehicles and drive less due to the higher prices.

rate used in the three-year payback model to keep post-2020 fuel economy no higher than that level.

Blueprint Medium and Heavy-Duty Vehicle Global Warming Emission Standards

Unlike light-duty vehicles, UCS-NEMS has no fuel economy standards for medium- and heavy-duty vehicles to serve as a proxy for the efficiency contribution to global warming emission standards. As a result, there are only two potential tools available. The first is manipulation of the discount rate used in the simple payback method used for determining efficiency technology adoption. This approach is ineffective because the discount rate is not set up to be changed year by year, and determining annual adjustment values would be difficult.

The second alternative is to modify the variable that controls the speed of technology adoption (the time to reach 50 percent market share). We therefore started with the Reference case technology adoption rates and then changed the technology adoption rates of any slower technology times to meet the technology potential of 8 mpg by 2020 and 9.5 mpg by 2030 for heavy-duty vehicles and 11 mpg by 2020 and 16 mpg by 2030 for medium-duty vehicles.

Reference and No Complementary Policies Case Medium and Heavy-Duty Vehicle Policy Application

While the EISA does include a requirement for fuel economy standards for medium- and heavy-duty trucks, no minimum values are specified. Furthermore, no structure is specified for those standards, which would apply to a wide variety of vehicle applications. Perhaps because of this, NEMS has not to date had the ability to model fuel economy standards for trucks and only includes a fuel price response.

As with light-duty vehicles, NEMS has historically over-predicted the adoption of efficiency technology for larger vehicles. A similar payback method is used to evaluate technology adoption, but there is no consumer choice model that could replicate behavior, such as demand for retro-trucks that have poor aerodynamics but look "cool." Complicating matters further, there is no good literature on the price elasticity of fuel intensity for medium- and heavy-duty vehicles.

Lacking other resources, we used our judgment and adjusted both technology introduction rates and penetration rates per our assessment of historical adoption in the absence of standards.

Introduction date of advanced technologies: The introduction date of heavy-duty truck advanced technologies (including aerodynamics, rolling resistance improvements, engine waste-heat recovery, and lightweight materials) were shifted farther into the future to better reflect their likely entrance into the heavy-duty market.

Pneumatic blowing to reduce rolling resistance and aerodynamic drag is an advanced technology that is still in the early stages of development. The introduction of these technologies is assumed to begin in the 2015 (aerodynamic improvements) and 2020

(rolling resistance) timeframes. Similarly, waste-heat recovery from engine exhaust gases is a promising technology also in the development stage. The current stage of development will likely push commercialization into the 2017 timeframe unless standards are in place to accelerate them. The introduction date of advanced weight-saving technology was pushed to 2015 from 2007.

Maximum market penetration: For all of these technologies, maximum market share in the Reference case was cut in half from the AEO 2008 High Tech case because of the complexity of the systems and likely market barriers. These barriers are exacerbated in the case of tractor trailers in which investments in fuel economy improvements of trailers have lagged far behind tractors, potentially affecting the introduction of advanced aerodynamics, rolling resistance, and weight savings. Medium-duty truck assumptions were unchanged in the Reference case scenario.

Fuel Technology Modeling

UCS-NEMS makes available a wide variety of transportation fuels, but because it has only limited policy tools related to fuels and carbon emissions, our focus for low-carbon fuels is on biofuels, electricity (also operating as a proxy for hydrogen), and cleaner gasoline and diesel. Within biofuels, UCS-NEMS includes ethanol, biomass-to-liquids (BTL), and biodiesel. Only the technology assumptions for cellulosic ethanol are modified in UCS-NEMS; those for BTL and biodiesel remain unchanged from the AEO 2008 High Energy Project Cost case.

Ethanol Technology

UCS-NEMS includes potential supplies of ethanol made from corn, sugarcane, and cellulosic material. The model also allows for the importation of ethanol made either from cellulosic material or from non-cellulosic material (assumed to be either corn or sugarcane). For the Climate 2030 Blueprint, we did not modify any of the technology assumptions for corn ethanol or imported non-cellulosic ethanol beyond the adoption of any changes associated with the use of the AEO 2008 High Energy Project Cost case. We did modify the share of cellulosic to non-cellulosic imports (from 88 percent for 2022 and beyond in AEO 2008 to 44 percent in UCS-NEMS), which helps to minimize potential land-use changes associated with these imports.[8] All other ethanol technology modifications were limited to domestically produced cellulosic ethanol and are primarily based on work by NREL and Lynd (Anden et al. 2002; Phillips et al. 2007; Lynd, Elander, and Wyman 1996).

UCS-NEMS limits biofuel resources to agricultural residues and energy crops and excludes forest and urban wood and mill residue. While technology is being investigated to process forest and other wood residues into ethanol, the process is more complex and, given uncertainties surrounding the technology, we accepted the current model limitation.

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[8] Before 2022, the cellulosic to non-cellulosic ratio is an exponential function that climbs from about 0.1 percent in 2010 to 20 percent in 2020 and 35 percent in 2021.

For more information on the size of this resource and land-use exclusions used in this report, see Appendix G.

For cellulosic ethanol production, changes were made to production efficiency, capital costs of plant construction, and fixed and variable production costs for processing feedstock into fuel. Table E.1 shows both the AEO 2008 assumptions and the changes made for UCS-NEMS.

Table E.1. Assumptions for Cellulosic Ethanol Production

	AEO 2008	UCS-NEMS		AEO 2008	UCS-NEMS
Initial Capital Cost (2006$ per gallon of capacity)			Initial Growth Rate Capacity Year		
2015	$5.24	$3.31	-	2017	2017
2016	$5.05	$3.13	Fixed Production Costs (2006$ per gallon)		
2030	$3.25	$1.99	-	$0.27	$0.128
Ethanol Yield (gallons per short ton)			Non-Feedstock Variable Production Costs (2006$ per gallon)		
2010	80	80	2010	$0.68	$1.11
2015	85	87.5	2015	$0.68	$0.43
2030	85	110	2030	$0.68	$0.17

The 2015 figures are based primarily on the results from the National Renewable Energy Laboratory's (NREL's) work on estimated capital and operating costs for both biological and thermochemical processing (Anden et al. 2002; Phillips et al. 2007). These estimates are based on continued research through NREL's the Advanced Energy Initiative, with a goal of cost-competitive ethanol by 2012. We assume that a three-year learning curve would allow production-sized plants to be built in 2015 at the cost estimated in the studies for 2012.

2030 estimates are based on consolidating biological processing in the production of cellulosic ethanol based on work by Lynd 1996, Sheehan 2007, and Greene et al. 2004.

Capital costs: Cellulosic ethanol plant construction is $2.85 (in year 2000 dollars) per gallon of annual plant capacity in 2015 based on the enzymatic hydrolysis process described in NREL's 2002 analysis (Anden et al. 2002). The cost assumptions are based on mature technologies and those that are under development and presumed to be viable in 2010. We assume the proposed capital costs are not reached until 2015 to account for the expected higher capital cost of the earliest plants.

These capital costs are assumed to drop 40 percent by 2030 through consolidated processing, higher yields, and larger plants enabled by high-yield energy crop production. The NREL 2007 analysis of thermochemical production of cellulosic ethanol showed similar capital costs (Phillips et al. 2007).

The 2015 and 2030 capital cost values represent a nearly consistent 38 percent drop compared with the AEO 2008 values using their initial cost and learning curve function. We therefore kept the AEO 2008 learning curve and simply reduced the initial year capital cost by 38 percent.

Variable production costs: The 2015 value is based on the Anden et al. 2002 study results ($0.32 per gallon, in 2000 dollars). This is an updated source as the AEO 2008 modeling is currently based on older work by NREL. For 2030, the Sheehan 2007 analysis indicated the potential for a 66 percent cost reduction compared with 2015, but we chose a more conservative value of a 50 percent reduction.

Production efficiency: For 2015, the production efficiency for the enzymatic hydrolysis process is assumed to be 89.7 gallons of ethanol per ton of corn stover based on the NREL 2002 study (Anden et al. 2002). For 2030, production efficiency is assumed to reach 110 gallons ethanol per ton of biomass based on thermal efficiencies indicated in Lynd, Elander, and Wyman 1996; as well as in the Greene et al. 2004 and Sheehan 2007 analyses. This represents a 30 percent increase in process efficiency from 2015. In the actual modeling the values are slightly lower due to the use of an exponential decay curve to simplify representation.

Initial capacity growth rate year: Because cellulosic ethanol is a new technology, a Mansfield-Blackman diffusion curve is applied in UCS-NEMS to limit the speed of expansion. The curve is applied starting in 2017 when cellulosic ethanol is assumed to be fully commercialized. Before that only a slow rate of growth is allowed to simulate pilot and demonstration plants. Figure E.3 illustrates the maximum cellulosic production allowed assuming growth reaches the maximum amount of production in each year. If production is less than the maximum, then the constraint shifts outward in time. (Note: it is possible that the start year could be delayed due to the recent recession.)

Figure E.3. Maximum Cellulosic Ethanol Production
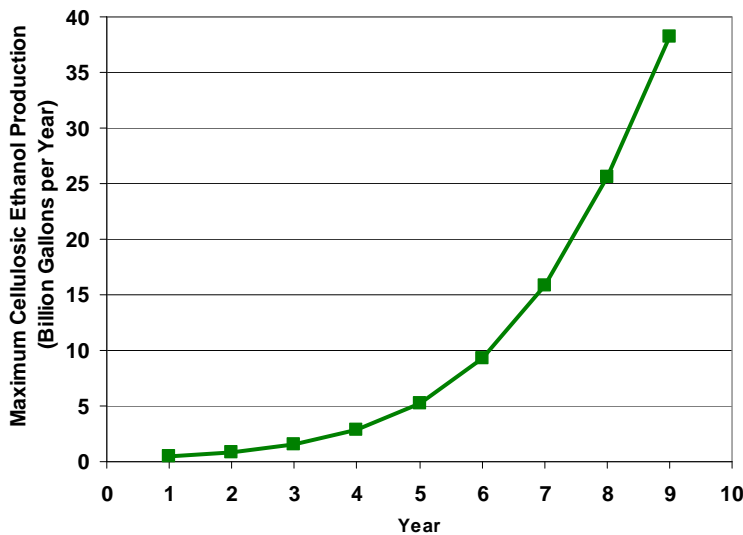
Biofuel Carbon Emissions

Recent research points to the importance of including the full life cycle global warming emissions of all fuels, including those that involve land-use changes or other offshore emissions impacts. The issue is most acute for food-based biofuels. To address this issue and simplify the modeling, we assume that all food-based biofuels provide no net carbon benefit compared with gasoline. We also assume that all biofuels produced from waste or energy crops completely lead to a 100 percent reduction in carbon emissions compared with gasoline.

Because AEO 2008 assumes that tailpipe emissions from all biofuels are offset by growing the plants, the latter assumption for waste and energy crops simplifies our modeling and requires no changes in UCS-NEMS. For food crops, we add back in emissions equal to the claimed reductions that would occur without the inclusion of land-use changes. The values used are 20 percent of conventional gasoline carbon emissions for corn ethanol and 50 percent for biodiesel.

Biofuel Vehicle Technology

Under both the Reference case and the Blueprint case, the combination of low-carbon and other biofuel consumption reaches the ethanol equivalent of about 40 billion gallons per year by 2030. While some of this biofuel can be mixed in with gasoline or diesel in existing vehicles, the majority must be consumed by vehicles that can run on high blends of ethanol (e.g., E85), requiring sufficient sales of flex-fuel vehicles.

Under the Reference case, in which hybrid vehicles reach less than 20 percent of the light-duty vehicle market by 2030, UCS-NEMS forecasts the combination of flex-fuel vehicle sales (20 percent of non-hybrid vehicle sales) and conventional vehicle sales as sufficient to consume all of the ethanol available. However, under the Blueprint case, rising sales of hybrids (which NEMS does not configure as flex-fuel vehicles) and the overall reduction in fuel demand lead to insufficient sales of conventional flex-fuel vehicles to consume the ethanol. To fix this problem, UCS-NEMS was adjusted to assume sufficient flex-fuel vehicle sales by setting one-third of hybrid sales as flex-fuel vehicles by 2030.

Electricity and Hydrogen Technology

For simplicity, we only look at electricity as an option for low-carbon fuels but consider it as a proxy for the use of hydrogen, which would have similar environmental and cost characteristics in this timeframe. Costs and emissions associated with electricity come from the electricity module. For more information, see Appendix D.

Cleaner Gasoline Technology

In 2000, the petroleum industry put together a technology vision that pointed to the potential for a 10 percent improvement in refinery efficiency by 2020 (API 2000). A 2005 study by Lawrence Berkeley National Laboratory pointed to pathways to improve the efficiency of refineries across the country by 10 to 20 percent while saving money (Worrell and Galitsky 2005). Based on current refinery efficiency levels of about 90 percent (Wang 2008), a 10 to 20 percent improvement in efficiency would lead to a 1 to 2

percent reduction in global warming emissions from gasoline.[9] In this study, we took the lower end of this range as a conservative assumption of the potential for improvements by 2030. Because of the potential for saving money or integrating these changes during regular upgrades and maintenance, we assume no costs for these improvements.

Fuel Policy Modeling

The UCS-NEMS transportation sector model cannot directly address any of our fuel-related climate policies. As a result, we used existing tools where possible and offline analysis when necessary to implement or verify our Climate 2030 Blueprint policies in the transportation sector.

No Complementary Policies Case

As noted above, the AEO 2008 base assumption is that there are no tailpipe carbon emissions from any biofuels, and, while this was not changed for the actual emissions levels within the model for the UCS scenarios, adjustments to the cap-and-trade accounting were made. Because some emissions are ignored, modeling cap-and-trade in NEMS gives a market advantage to all biofuels over gasoline. As with the actual emissions results, we modify the accounting for cap-and-trade in UCS-NEMS to assume that ethanol made from corn and biodiesel made from food products provide no carbon advantage over gasoline and diesel, respectively. This may still give too much credit to making fuel from food, but appeared as the simplest compromise as we wait for additional research on land-use impacts to emerge.

Low-Carbon Fuel Standards

The only carbon-related policy in UCS-NEMS is the renewable fuel standard (RFS) from the EISA. As a result, we "simulated" a low carbon fuel standard (LCFS) by focusing on progress for different fuels-related areas.

Renewable Fuel Standard: The expected impact of a LCFS on biofuels would be to increase the use of "cleaner" options such as cellulosic ethanol and BTL from cellulosic resources and to decrease the use of food-based biofuels, so we adjusted the RFS in such a manner. Because the Reference case already maxed out production of cellulosic ethanol and BTL, we set the non-food biofuel requirement at 30 billion gallons of ethanol-equivalent fuel. We then increased the overall RFS requirement to 40 billion gallons by 2030. This, however, is actually a reduction from the total level achieved under the Reference case in order to reduce the amount of corn-based ethanol by 40 percent compared with the Reference caseto account for the fact that food-based ethanol would not be encouraged under an LCFS.

Refinery Efficiency: As noted in the technology section, refinery efficiency improvements are phased in and reach 10 percent by 2030. NEMS does not have a specific policy lever that could induce this change, so UCS-NEMS incorporates this policy by forcing in a 10 percent reduction in required process energy inputs.

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[9] Based on 90 percent efficiency, refining is responsible for just under 10 percent of gasoline's life cycle global warming emissions, so a 10 to 20 percent efficiency increase would reduce emissions by 1 to 2 percent.

Vehicle mandate: An LCFS would also encourage the use of electricity and hydrogen, especially that which is made from renewable resources, but the RFS in NEMS does not provide sufficient incentive to bring in increased electricity use in the transportation sector. This would likely be the case for a simple LCFS as well, but the LCFS would give credit to electricity and hydrogen use that was encouraged in other ways.

There are at least two possible ways to require increased use of electricity in transportation. One is an Ultra Low Carbon Fuel Standard that would require that some portion of the LCFS be met by using the cleanest fuels available. This would drive down the price of such fuels, making them more attractive. This, however, still might not be enough to encourage the adoption of plug-in hybrids, battery-electric vehicles, and fuel-cell vehicles.

A complementary approach is to require that the vehicles needing to use ultra-low-carbon fuels be placed into the market, as with California's Zero-Emissions Vehicle Mandate. This report does not define what such a mandate would look like at a national level. Instead, UCS-NEMS includes California's ZEV mandate in the baseline and then adds on a requirement for progressively increasing sales of plug-in hybrids as a proxy for all possible electric vehicles. As shown in Figure E.4, this requirement reaches 20 percent by 2030.

Figure E.4. New Vehicle Sales Plug-in Requirement as a Proxy for All Possible Electric Vehicles
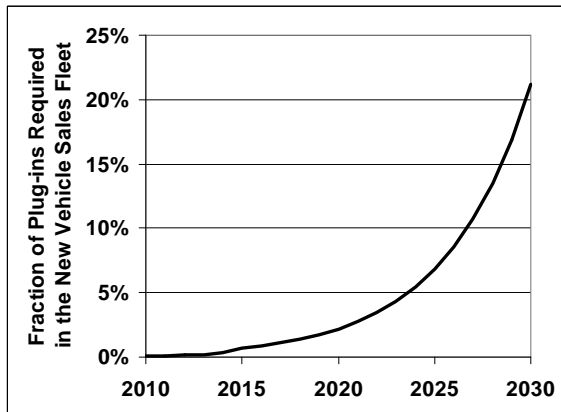
Reference and No Complementary Policies Case Fuels Modeling

The Reference case and the No Complementary Policies case include the RFS passed as part of the EISA. This act requires at least 36 billion gallons of biofuels by 2022, 21 billion of which must be cellulosic or "advanced" biofuels.

As with the inclusion of the EISA fuel economy standards in the Reference case, the inclusion of the RFS has a significant impact on the report findings. Within the model, the requirement of 21 billion gallons of non-corn biofuels moved cellulosic ethanol and BTL along their learning curves, ultimately bringing the costs lower than gasoline,

leading to a self-sustaining market that went beyond the minimum requirements under oil and gasoline price levels in our scenarios.

Smart Growth

While UCS-NEMS does include the ability to model changes in demand for travel based on fuel price, it is not equipped to include the impact of per-mile fees for insurance or congestion mitigation, increased spending on transit, policies to shift freight from truck to rail, policies to adjust zoning, development patterns, and increased urban and suburban densities.

One option would have been to adjust VMT after the fact in a post-processing spreadsheet. This, however, was unnecessary as the UCS-NEMS model was adjusted to force in the expected shifts in travel. This has the advantage of allowing the rest of the model to adjust to the lower demand levels, with corresponding impacts on price and fuel availability.

Modeling travel reductions: We used the approach of adjusting vehicle travel directly in the UCS-NEMS model. This approach was used to implement an average growth rate of 0.9 percent per year in light-duty VMT compared with 1.4 percent per year in the Reference case (and 1.7 percent per year in the AEO 2008 Reference case). It was also used to reduce freight truck travel by 2.5 percent by 2030, which, combined with changes in economic activity and increased fuel prices, lowered the average growth rate of freight truck travel to 1.4 percent per year from 1.7 percent per year.[10]

Modeling mode shifts: Some of the reduced personal travel is absorbed in public transit, which is assumed to double energy demand, and therefore global warming emissions, by 2030. This is a conservative assumption because many transit systems are not at capacity and could expand ridership without significant increases in energy use.

For freight travel, the 2.5 percent shift from freight to rail was modeled by shifting the freight truck miles traveled to increased rail ton-miles traveled at a rate of 11.8 tons per freight mile. This assumes that rail and freight trucks carry the same cargo and that rail is about five times more efficient than freight trucks. As a result, it likely overestimates the actual benefit as the average freight truck load will be less dense than the average rail load.

Modeling pay-as-you-drive (PAYD) costs: For PAYD insurance, the costs include the cost of pilot programs and tax credits to speed up adoption, and the cost of the GPS system needed to monitor and report vehicle mileage, as shown in Table E.2 below. These costs, however, will be defrayed by the potential to save $150 per vehicle per year in reduced accident costs. While the reduced accident costs could more than defray the cost of the GPS system, we still assume that there is a net cost of $50 per new vehicle

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[10] Shifts in the economy and increased fuel prices lowered the average growth rate for freight truck travel to 1.5 percent per year. The added 2.5 percent shift from freight to rail lowered the average growth rate to 1.4 percent.

under the assumption that not all of the savings will directly accrue to consumers. These costs and savings are not implemented directly in UCS-NEMS, but are instead incorporated in post-processing.

Table E.2. Pay-As-You-Drive Costs and Savings

Mileage Monitoring System Cost	$100 per vehicle
Annual Accident Savings	$150 per vehicle
Federal Funding for PAYD Pilot Programs	$3 million per year over 5 years
Tax Credit for PAYD Electronics	$100 million per year over 5 years

Costs associated with increased per mile fees: The cost of increased public transit is covered by a $0.006 per-mile congestion mitigation fee, which will raise about $21 billion per year by 2030. Users will also see a $0.011 per-mile fee by 2030 to maintain the existing transportation system, but we assume that these costs would have to be borne in the Reference case as well, perhaps through increased income or sales taxes. There would be additional costs of implementing these systems and outfitting vehicles to monitor mileage. We assume that the mileage-monitoring system for PAYD insurance can also be used for this system and we currently do not include any implementation costs.

Smart growth costs: We assume that changes to local zoning, full cost coverage of utility expansion, and tying federal highway funds to global warming performance metrics, all of which will lead to increased density and encourage mixed-use neighborhoods, can be done at no cost or a cost savings.

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