Appendix K – GPRA07 Alternative Scenarios

Background

There is inherently considerable uncertainty in long term energy projections such as those underlying the EERE GPRA benefits analysis. In fact, uncertainty about future energy demand, supplies and prices is one of the motivations for Federal investment in R&D, so that the nation might be better prepared in the face of potentially adverse world energy markets. As a result, the benefits of some of EERE programs may be greater under other conditions than the reference or business-as-usual (BAU) projections used in the main report. The prospective benefits framework developed by the National Research Council (NRC)[1] recognizes this in their recommendation of assessing benefits for several "global scenarios."

The Office of Fossil Energy (FE) and EERE have jointly developed alternative scenarios to capture two of the key uncertainties impacting future energy: energy prices and climate policy. The scenarios were used on a pilot basis, internally within EERE, with respect to its FY06 GPRA analysis, and were more fully implemented for FY07. As all of the R&D offices within DOE's Office of Energy Science and Environment (ESE) work toward developing a common GPRA benefits analysis methodology, it is anticipated that these alternative scenarios, as well as potentially other scenarios, will be used.

The use of alternative scenarios that project other possible futures address just one type of uncertainty; and, in this case, along two dimensions of market uncertainty. Model risk is still embedded in the scenarios in that energy models are abstractions of reality and may contain biases in their abstractions.

Programmatic success is another major area of risk that is not addressed through these scenarios. All the EERE Portfolio cases assume that the programs meet their goals. Work is ongoing within EERE and other DOE R&D offices to account for technological and programmatic risk in the GPRA benefits process.

The two alternative market scenarios that were developed for GPRA07 are a high fuel price case and a case with a constraint on national energy-related carbon emissions. Baseline cases, without EERE programs, and portfolio cases, with representation of all the EERE programs, were created for these alternative cases. The benefits of the programs are then evaluated as the difference between each pair of portfolio and base cases, using a similar methodology as for the BAU GPRA07 benefits. However, the resulting benefits are not always comparable to the BAU benefits. For one, the alternative scenarios have different underlying macroeconomic assumptions and demands for energy services (such as light, travel, industrial steam, etc.) due to the higher energy prices. In other words, the energy system is smaller; and, therefore all else equal, the benefits (of reduced energy or avoided emissions) in absolute terms would be smaller. In addition the definition of the climate policy as a cap on energy related carbon emissions leads

[1] National Research Council, Prospective Evaluation of Applied Energy Research and Development at DOE (Phase One), 2005

to reduced emissions to the cap level in both the baseline and EERE portfolio cases. Hence there are no carbon emission reductions attributable to the EERE portfolio of programs. The primary benefit is that the EERE programs help reach that cap at lower cost.[2]

The off-line analyses that support the benefits analysis were not revised for the alternative scenarios. Thus for programs whose inputs to the integrating models are "outcomes" (such as market penetration rates or energy savings), this potentially leads to an overstatement of benefits, especially in the carbon constraint scenario, because there would likely be greater efficiency investments in the Base case and therefore reduced savings resulting from the EERE technologies. For all programs, the baseline was not revisited, except to the extent that the models will endogenously project reactions to the scenarios. The program analysts were not asked to consider how the sectors in which their programs' technologies have an effect would react in absence of DOE research, development, and deployment (RD3) and in the presence of the scenario constraints. In other words, the baseline technology characteristics for EERE technologies for the most part remain the same under all the scenarios.

As in the benefits analysis shown in the main body of the report, two integrated energy models were used for the scenarios analysis: NEMS-GPRA07 and MARKAL-GPRA07. The former provides the mid-term projections (to 2025), while the latter is used to extend them out to 2050. In most cases, the two models show similar results in the mid-term period, so both sets are not shown. However, there are inter-temporal dynamics in the carbon constraint scenario that necessitate showing the full projection period for MARKAL-GPRA07.

High Fuel Price Scenario Definition

The High Fuel Price scenario is predicated on a future in which the supply of natural gas and oil are more limited, and as a result significantly higher fuel prices occur.[3] The world oil price follows the trajectory of the AEO2005 High B price case (the higher of the two high oil price cases). As seen in Figure 1, oil prices start off higher than the reference case in 2005 and rises to $48 (2003 dollars[4]) per barrel by 2025 and then to $70 by 2050. Natural gas supply in the GPRA High Fuel Price case was restricted in order to cause natural gas prices to reach and remain above $5 by 2015. They continue to rise and reach $8.25 by 2050. The restrictions on gas supply included limiting the ability of new LNG terminals to be constructed, delaying the Canadian and Alaska gas pipelines until after 2025, and reducing assumed Canadian resources. Coal price assumptions were not explicitly changed, but coal prices rise by up to 12 percent due to the increases in other prices.

[2] One might argue that the presence of EERE technologies that allows for more rapid adoption of technologies that reduce carbon emissions might influence climate policy, however carbon caps, including the one modeled here, usually specify a time-path for reductions. The level of emissions reductions and the timing of the reductions are thus dictated by the scenario, and not influenced by the technologies in this construct.

[3] In hindsight the oil price path turns out to be very similar to the more current view of prices as represented by the *Annual Energy Outlook 2006*.

[4] Unless otherwise stated, all prices are given in 2003 dollars.

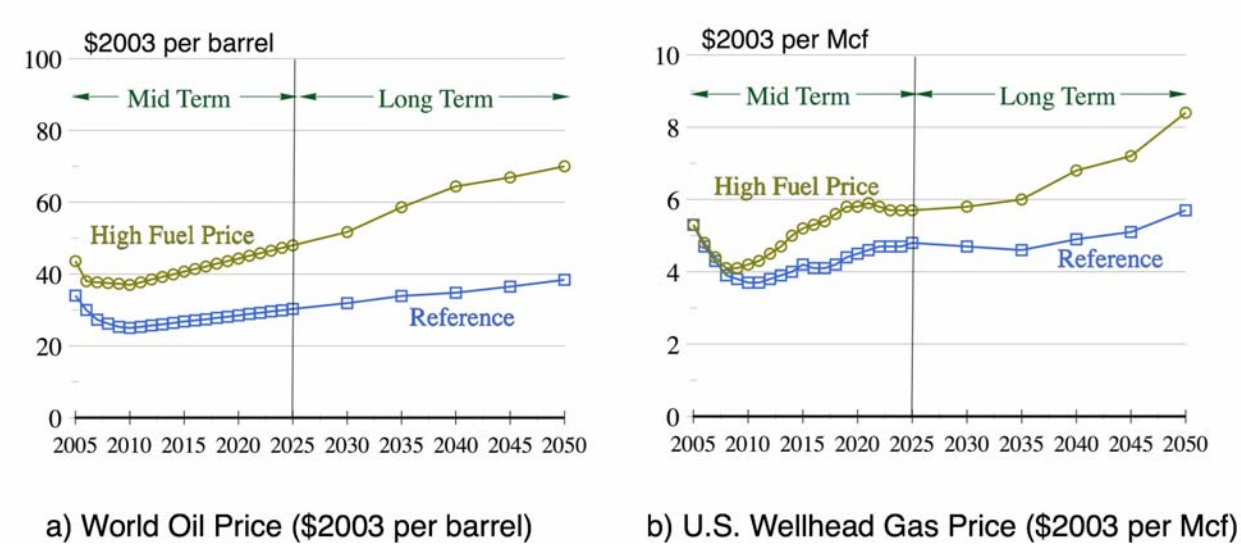

Figure 1. Projected World Oil and Wellhead Natural Gas Price

Carbon Constraint Scenario Definition

A second scenario was designed to examine the implications of EERE benefits under a cap on energy-related carbon emissions. The cap is imposed beginning in 2008 and drops to 1,580 million metric tons of carbon equivalent (MMTCE) by 2017, which is roughly the level of emissions in 2003. After 2017, the cap is assumed to remain constant at that level. An economy-wide trading system is assumed where the lowest cost reductions will occur first. The price of the carbon allowances indicates the marginal cost of compliance.

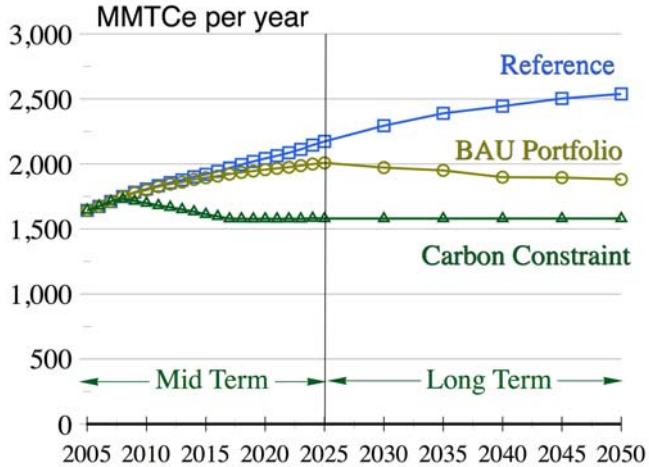

Figure 2. Carbon Emissions

Benefits Under High Fuel Prices

Changes in Primary Non-Renewable Energy Consumption

Figure shows the impacts of EERE's technology portfolio under business-as-usual and high fuel price scenarios.

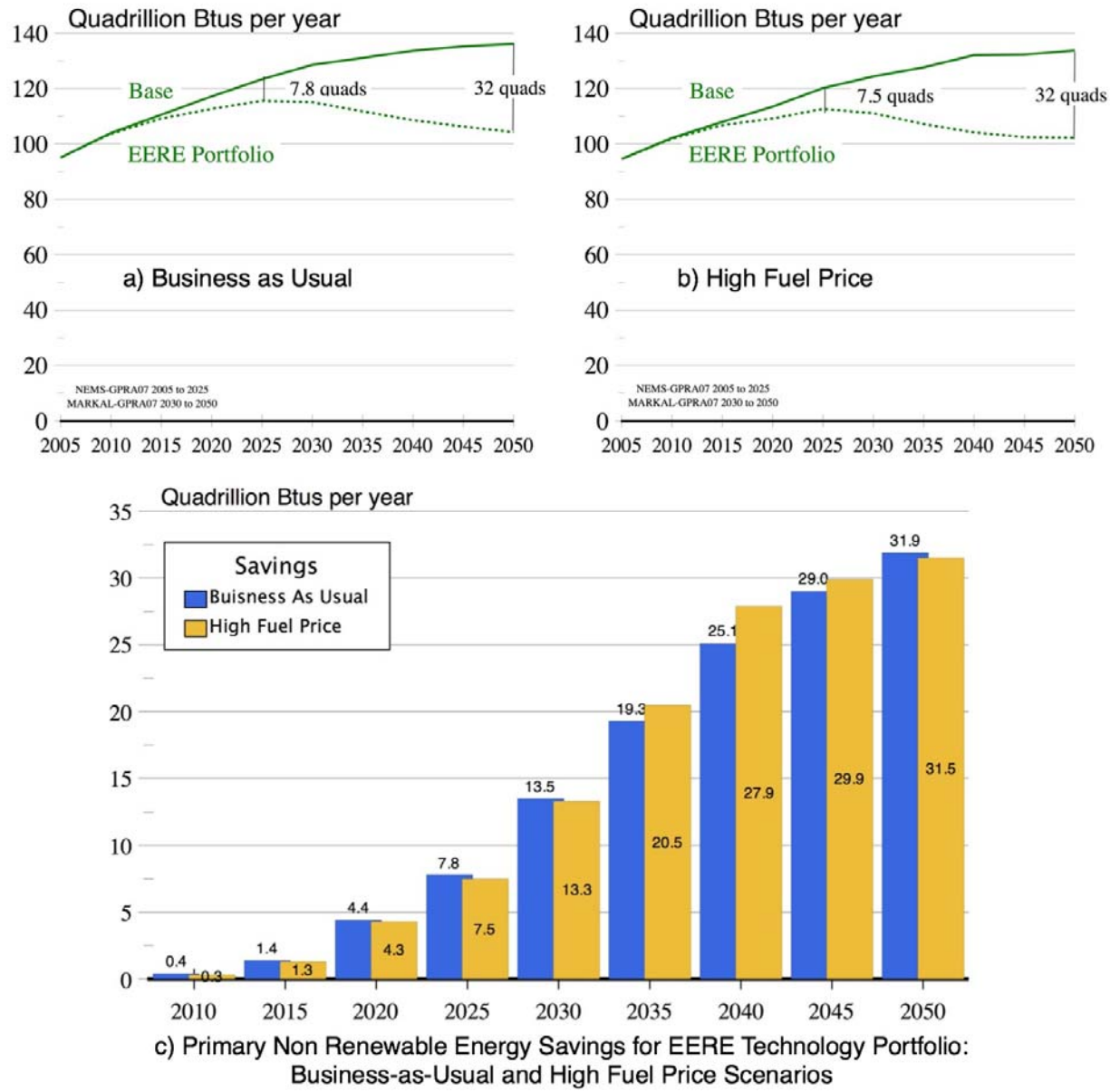

Figure 3. Primary Nonrenewable Energy Use Under Alternative Fuel Price Scenarios

The benefits of EERE's portfolio of programs, as measured by the traditional GPRA metrics, are generally lower under the high fuel price conditions than under the reference conditions. One of the key determinants of how the benefits change under high fuel price conditions is the baseline projection, given that benefits are defined as the difference between the baseline and the

portfolio cases. Higher prices shrink the demand for energy. In part, this is due to lower demand for energy services as a result of slightly lower incomes and economic output, and behavioral responses to higher prices such as turning down thermostats and driving less. Higher energy prices also stimulate greater investment in energy efficient and renewable technologies even in the absence of technology improvements resulting from the EERE R&D and deployment programs. In the Portfolio case, with advanced technologies available, greater adoption of these technologies is expected. The net result is somewhat smaller primary non-renewable energy savings resulting from the EERE portfolio in most years as shown in Figure 3.

Sector- Specific Effects

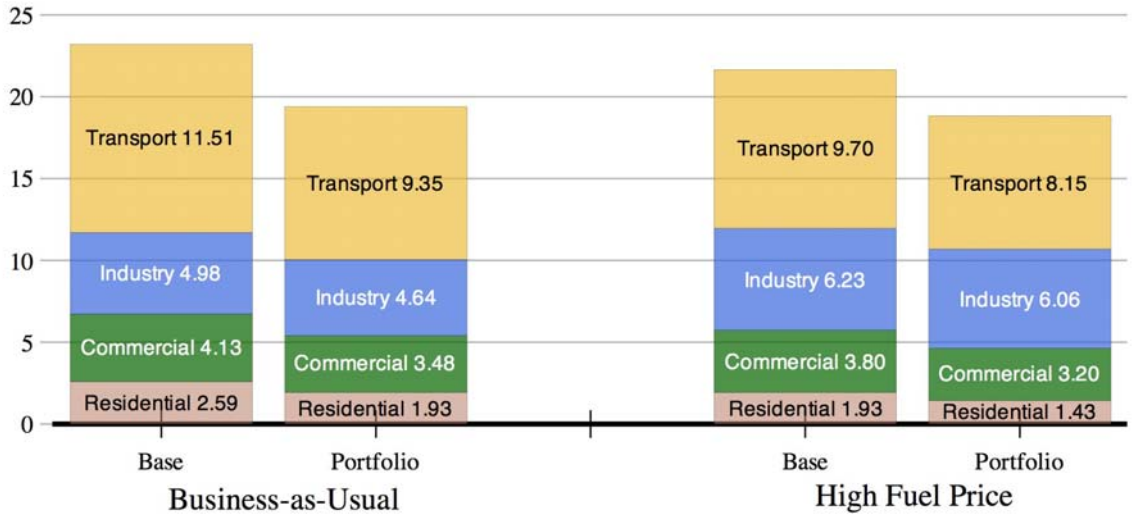

Figure 4. Growth in End-Use Energy Consumption from 2005 to 2025: Business-as-Usual and High Fuel Price Scenarios

The most significant reduction in energy consumption with high prices occurs in the transportation sector (see Figure 4), where higher gasoline and diesel prices lead to reduced vehicle miles traveled and higher vehicle efficiencies. Both of these factors reduce the opportunity for savings from the FreedomCar and hydrogen fuel cell vehicles, even though higher prices make these vehicles more attractive.

Similarly, in the residential and commercial sectors, higher prices reduce energy consumption, primarily oil but also natural gas and electricity to a less extent, through behavioral changes as well as equipment efficiencies. Overall, the buildings energy demand reduction resulting from the EERE Portfolio is roughly 15 percent smaller with higher fuel prices in 2025. The industrial sector's energy use actually increases in the high price case, due to increased consumption of coal for coal-to-liquids production.

The base case reduction in service demands and increased efficiency in the High Fuel Price scenario relative to the BAU scenario leads to a reduction in incremental delivered energy consumption in the buildings sector of 9 percent and 4 percent in 2030 and 2050 respectively.

The addition of EERE technologies in the Portfolio Case reduces delivered energy consumption in the buildings sector for both the BAU and high fuel price scenarios. This reduction in delivered energy consumption in the EERE Portfolio Cases is attributable to improved buildings shell packages, highly efficient space conditioning technologies and improved and highly efficient solid state lighting technologies. Figure 5 shows the incremental buildings delivered energy consumption for the Base and EERE Portfolio cases in the long term in both the BAU and High Fuel Price scenarios.

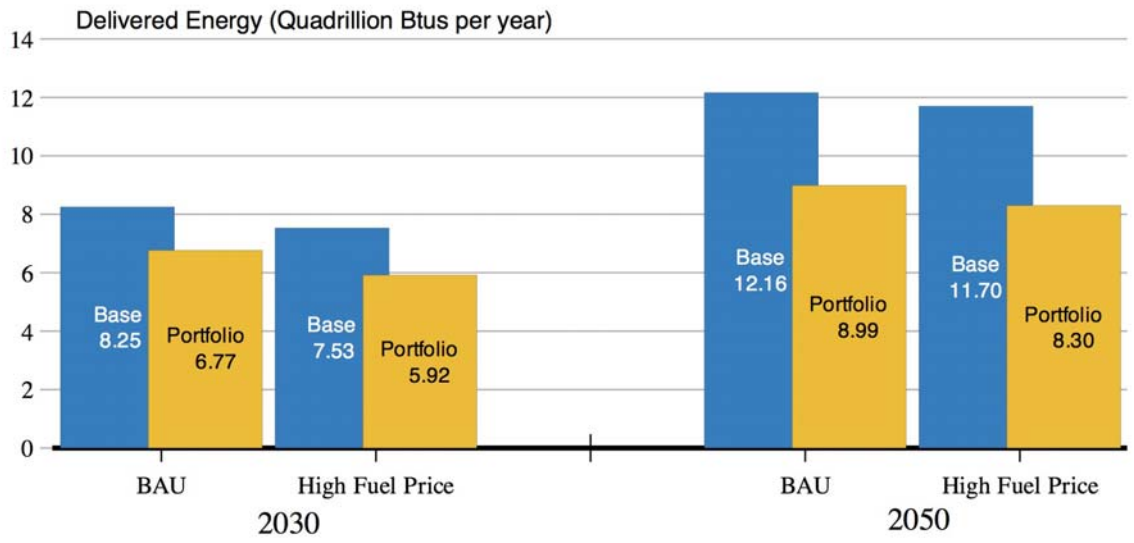

Figure 5: Buildings-Sector Delivered Energy Consumption: 2030 and 2050

In the transportation sector, service demands are lower and efficiency is increased. Light duty vehicle (LDV) vehicle miles traveled (VMT) fall by about 5 percent between the BAU and high fuel price scenario. Furthermore, the Base case average LDV stock efficiency increases by 9 percent and 30 percent in 2030 and 2050 in the high fuels scenario relative to the BAU scenario. Over the long run, the increase in LDV stock efficiency is due to a dramatic increase in hybrid vehicle penetration in the High Fuel Price Base case. Also, with the higher oil prices coal-to-liquids (CTL) technologies become cost-effective and ethanol consumption increases in the High Fuel Price Base case relative to the BAU Base case. The increased uses of these substitute fuels further reduce base case oil consumption in the High Fuel Price scenario.

By 2050, both the BAU and High Fuel Price EERE Portfolio cases, the LDV fleet is comprised entirely of EERE hybrids and fuel cell vehicles, although the proportion of fuel cell vehicles increases in the high fuels scenario. The EERE Portfolio cases lead to reduced petroleum consumption due to the increased market share of highly efficient EERE hybrid and fuel cell vehicles. Also, increased production of cellulosic ethanol further displaces petroleum consumption. Figure 6 shows the LDV stock market shares.

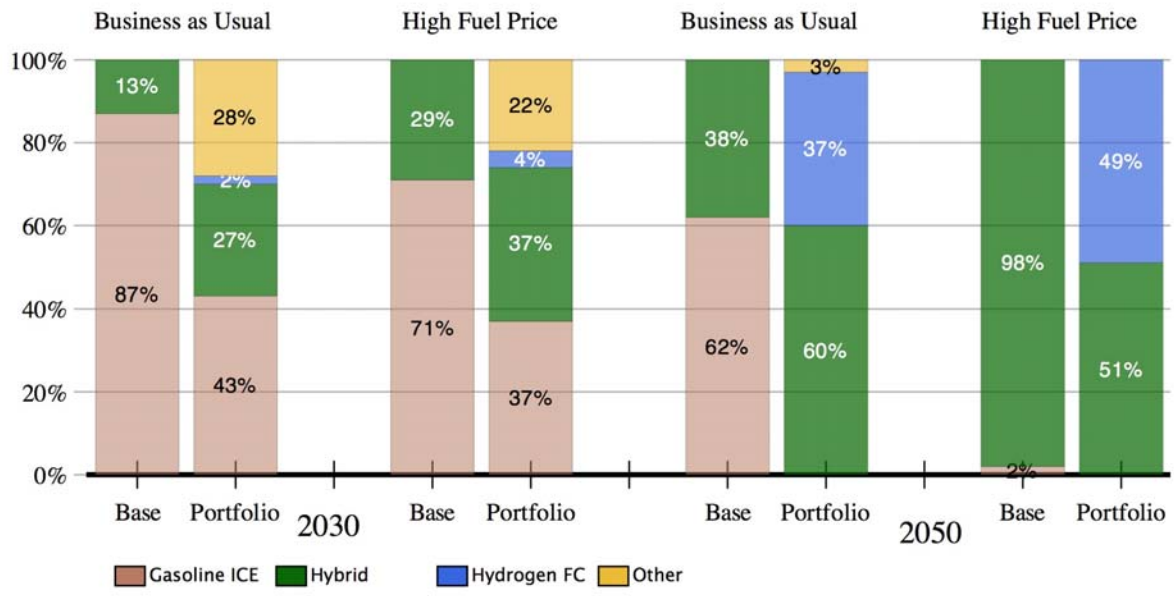

Figure 6: Light Duty Vehicle Stock Market Shares, 2030 and 2050

Electricity Generation and Capacity Effects

The mix of electric generation capacity shifts away from natural gas fired technologies (combustion turbines and combined cycles) and toward coal (steam coal and integrated gasification (IGCC)) and renewable capacity in the High Fuel Price Base relative to the BAU Base. The EERE Portfolio stimulates a greater amount of renewable capacity in the High Fuel Price scenario and displaces a greater proportion of coal than occurs with the BAU scenario.

The shifts become even more pronounced over the long term. By 2050, coal-fired capacity is 40 percent higher in the high fuels base case than in the BAU base case, while renewable generation capacity shows a more modest 8 percent increase. With the inclusion of the EERE portfolio technologies, by 2050 IGCC and natural gas combined-cycle capacity decrease 63 percent and 41 percent, respectively, relative to the High Fuel Price Base case. The decreases are attributable to both improved renewable generation technologies and end-use efficiency. The impacts for the mid and long-term are shown in

There is a corresponding shift in the fuels used for electric generation with generally more coal and less oil and gas when fuel prices are higher. Total generation decreases in the EERE Portfolio Case due to greater adoption of energy efficient equipment. (Figure 8)

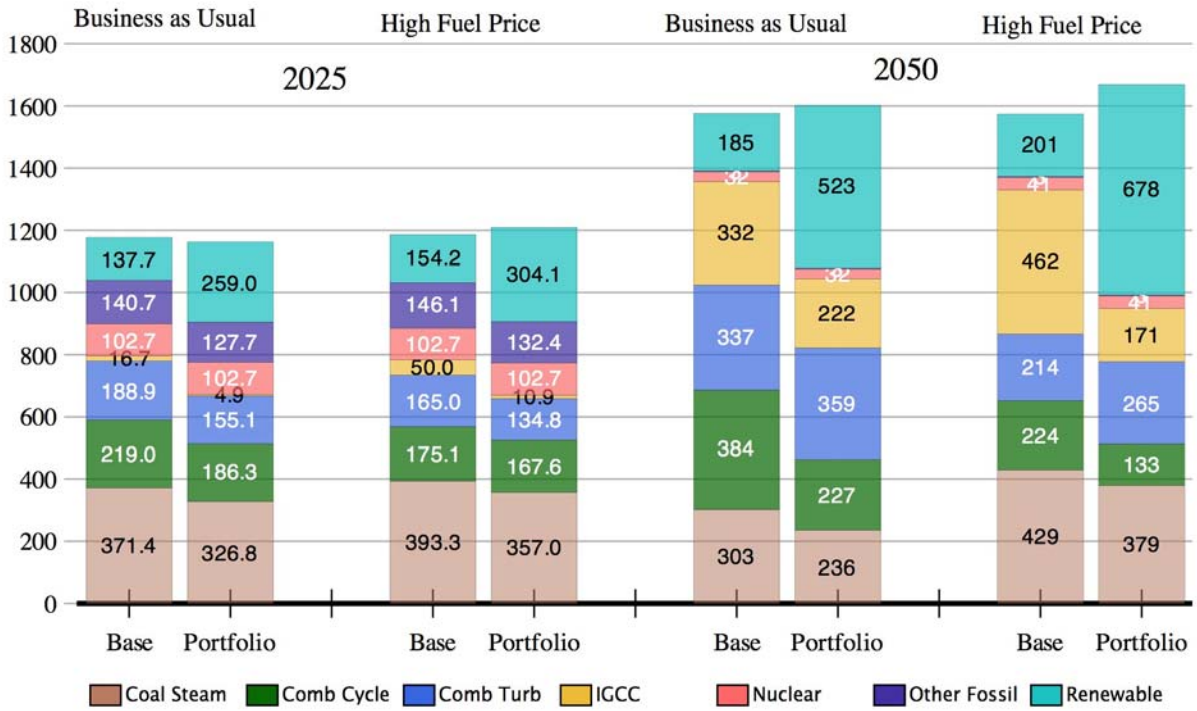

Figure 7. Gigawatts of Electric Generation Capacity in 2025 and 2050 Business-as-Usual and High Fuel Price Cases

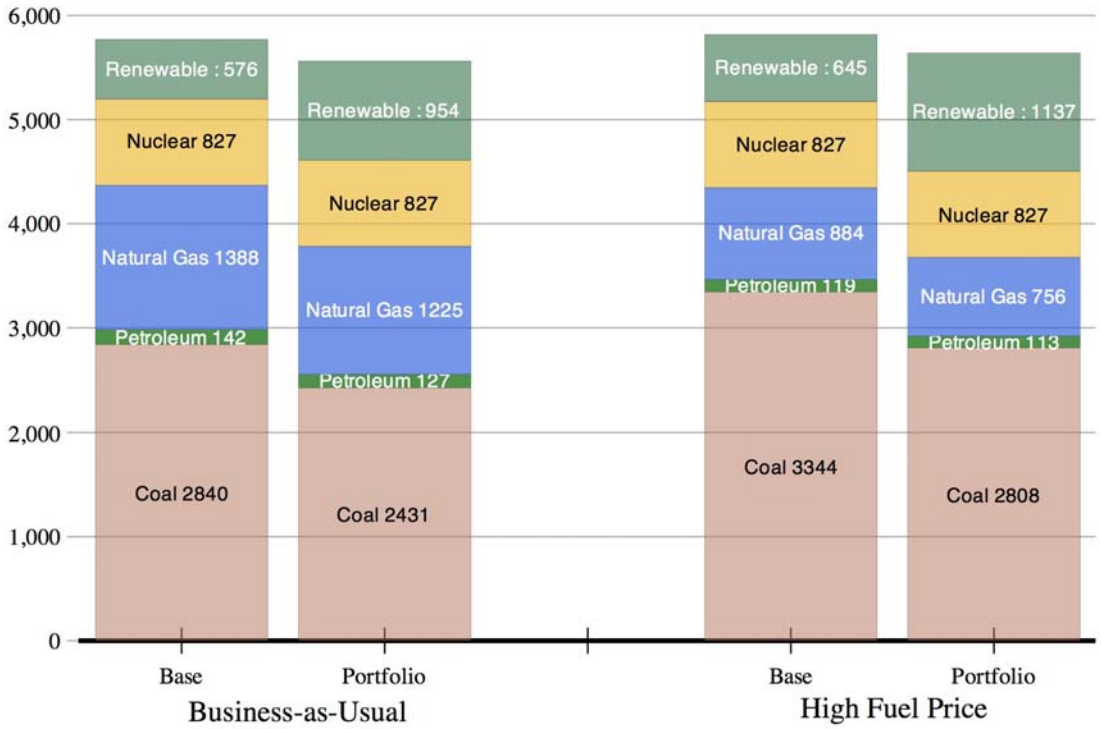

Figure 8. TWh of Electricity Generation in 2025: Business-as-Usual and High Fuel Price Cases

As in the BAU scenario, wind and solar PV technologies increase substantially in the High Fuel Price Portfolio case, reflecting the R&D success in lowering costs and improving performance. The effect is magnified with higher fuel prices, even though more is adopted in the base (no R&D) case as well. The mix of generation is similar, although PV and wind are intermittent technologies and therefore provide less generation than other technologies that can be operated all the time.

In the long run, the most significant increase in both renewable capacity and generation in the High Fuel Price Portfolio case relative to the High Fuel Price Base case is for central solar thermal generation and distributed photovoltaics. These generation sources provide power during periods of peak electric demands and thus reduce the need for gas-fired combustion turbines. Figures 9 and 10 show non-hydro renewable generation and capacity for the mid and long-term.

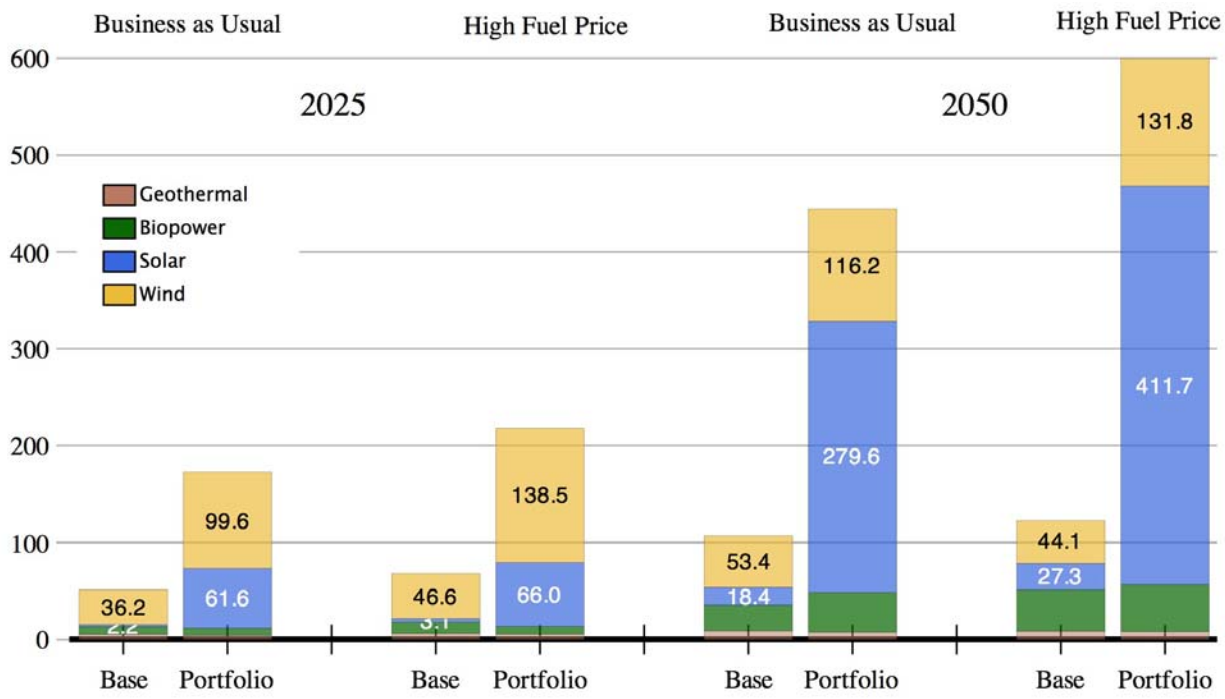

Figure 9. Gigawatts of Non-Hydro Renewable Generation Capacity, 2030 and 2050, Business-as-Usual and High Fuel Price Cases

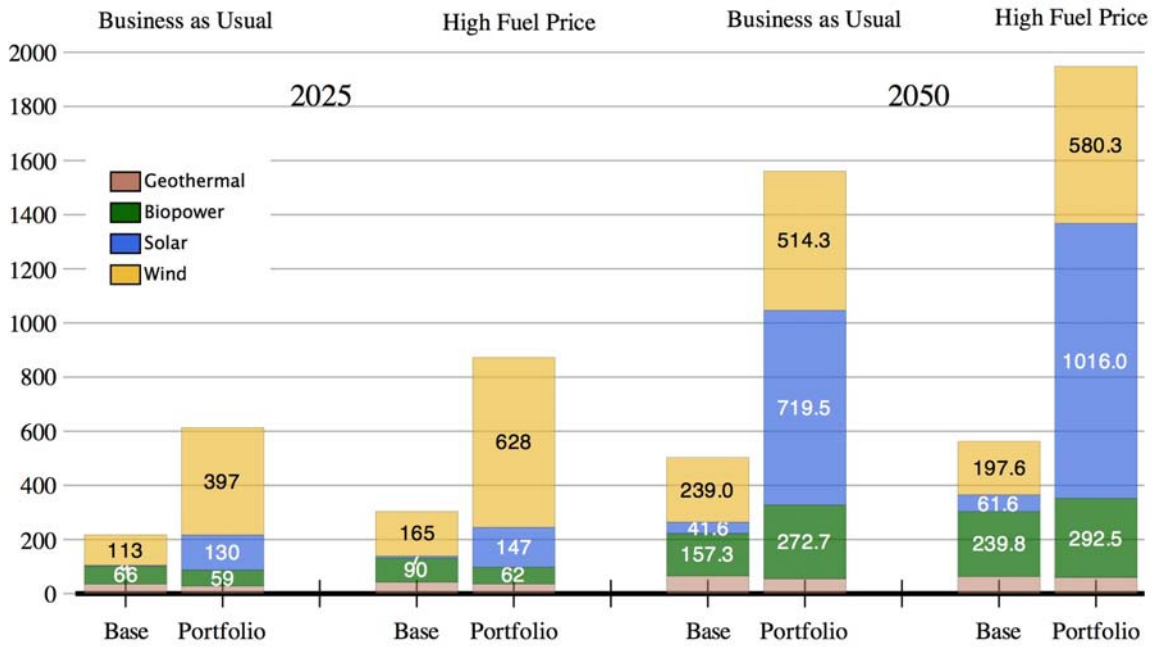

Figure 10. TWh of Non-Hydro Renewable Electric Generation in 2025 and 2050 in the Business-as-Usual and High Fuel Price cases

Carbon Emission Reductions

In the mid-term, carbon emission reductions resulting from the EERE Portfolio under high prices are higher in some years and lower than others relative to the BAU. Because the baseline projects a greater reliance on coal-fired generation, electricity generation displaced by efficiency and renewable generation in the portfolio case is more carbon intensive. On the other hand, energy savings are slightly lower. In the long-term, the coal displacement effect dominates and results in greater carbon emission reductions. Thus, as increased buildings efficiency and improved and less costly renewable generation technologies penetrate the market, a higher proportion of carbon intensive coal-fired power generation being displaced in the high fuels EERE scenario.

Economic Benefits

Energy expenditure savings, as measured in the mid-term projections, are greater due to higher fuel prices. Each unit of energy saved has a higher value. In addition, the impact of reduced consumption has a greater impact of reducing prices, especially natural gas, in the high price case. Energy system cost savings, as measured in the long-term projections, also increase due to the reduction in increasingly more expensive fossil fuels.

Benefits Summary

Table 1. FY07 Annual Benefits Estimates for the EERE Portfolio Under High Fuel Prices (NEMS-GPRA07)

Benefits	2010	2015	2020	2025
Energy Displaced				
Non-Renewable Energy Savings (quadrillion Btu/year)	0.3	1.2	4.3	7.5
Economic				
Energy Expenditure Savings (billion 2003 dollars/year)*	1	26	89	152
Environmental				
Carbon Savings (million metric tons carbon equivalent/year)	7	24	89	167
Security				
Oil Savings (million barrels per day)	0.03	0.2	0.7	1.3
Natural Gas Savings (quadrillion Btu/year)	0.1	0.4	0.9	0.7
Program-Specific Electric Capacity (gigawatts)	2	14	95	155
Program-Specific Generation (terawatt-hours/year)	2	39	314	515

Table 2. FY07 Annual Benefits Estimates for the EERE Portfolio Under High Fuel Prices (MARKAL-GPRA07)

Benefits	2030	2040	2050
Energy Displaced			
Non-Renewable Energy Savings (quadrillion Btu/year)	13	28	31
Economic			
Energy-system net cost savings (billion 2003 dollars/year)*	89	203	307
Environmental			
Carbon Savings (million metric tons carbon equivalent/year)	286	626	698
Security			
Oil Savings (million barrels per day)	6	9	13
Natural Gas Savings (quadrillion Btu/year)	1	1	2
Program-Specific Electric Capacity (gigawatts)	160	337	479
Program Specific Generation (terawatt-hours/year)	525	1,066	1,396

* Midterm energy-expenditure savings only include reductions in consumer energy bills, while long-term energy-system net cost savings also include the incremental cost of the advanced energy technology purchased by the consumer.

Benefits Under a Carbon Emissions Constraint

Changes in Primary Nonrenewable Energy Consumption

Figure 11 shows the primary nonrenewable energy consumption for the base and EERE cases under both the BAU and Carbon Constraint scenarios as projected by NEMS-GPRA07 and MARKAL-GPRA07. The imposition of the carbon cap has a profound impact on the energy system. By 2025, the cap requires a 27 percent reduction in emissions from the BAU Baseline and a 21 percent reduction from the BAU Portfolio case.

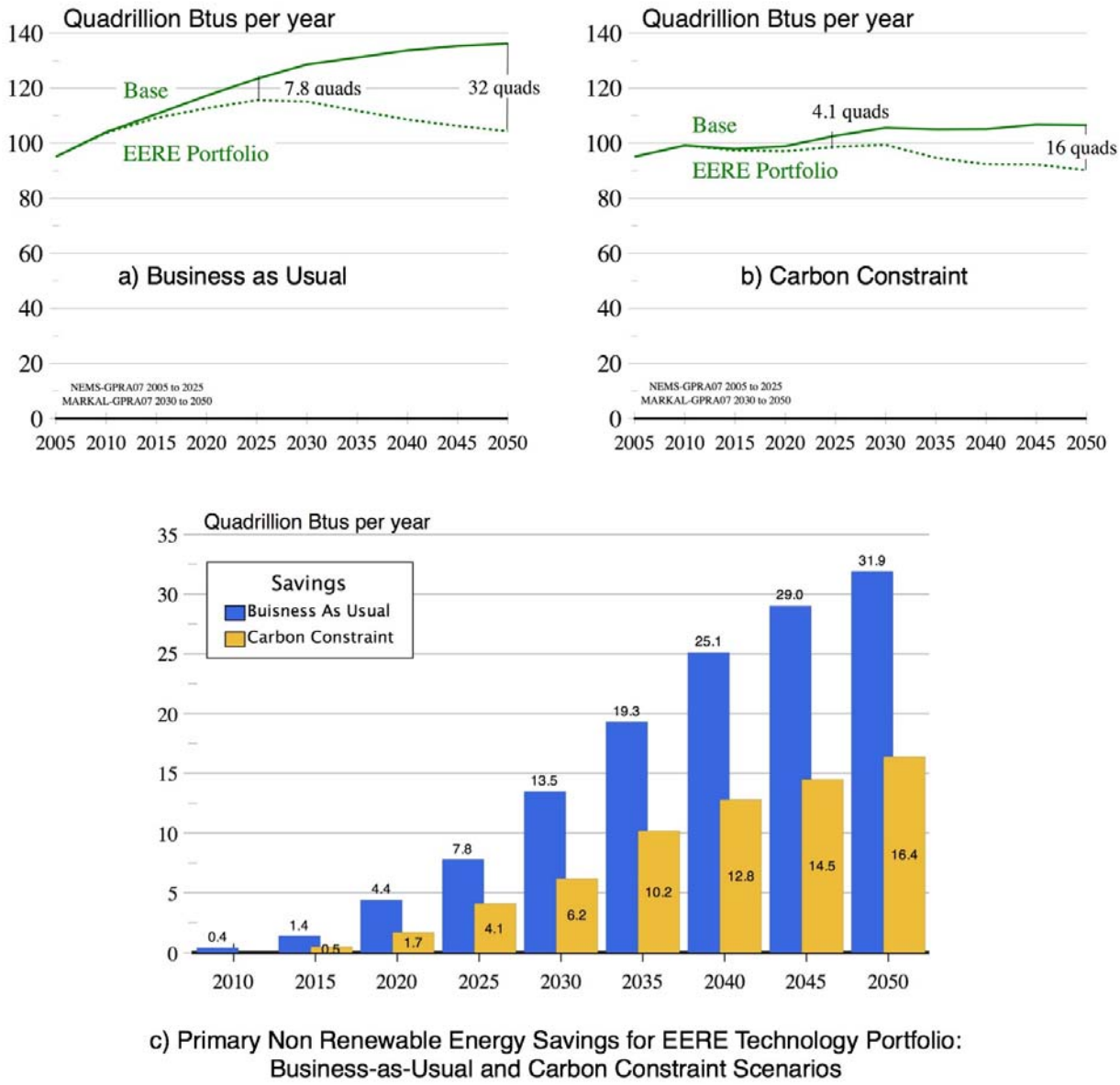

Figure 11. Primary Nonrenewable Consumption in the BAU and Carbon Constraint Cases, through 2050

These emission reductions are achieved through a combination of energy service demand reductions, increased efficiency, and fuel switching to less carbon intensive energy sources. In the Carbon Constraint Base case, without EERE R&D, primary fossil energy use drops in 2025 by 21 percent relative to the BAU, and primary nonrenewable energy is reduced by 17 percent. Because meeting the cap requires such a significant shift in consumption, only slightly greater reductions occur in the EERE Portfolio case.

The most dramatic changes occur during the transition period between 2010 and 2020 when the carbon cap is being phased-in, before it reached the cap level of 1580 MMTCE that is then held constant. During the transition period, a large amount of carbon-intensive steam coal electric generation capacity is replaced with carbon free nuclear and renewable generation. At the same time, lower service demands and increased end-use sector efficiency result in lower demands for electricity

Carbon Reductions and Carbon Allowance Prices

By definition, carbon emissions are at the specified cap in the carbon cases, and take place on a specified schedule, with or without EERE technologies.[5] Therefore no carbon emission reductions are expected that would be attributable to the EERE programs, unless the cap becomes non-binding as occurs in the very long term. Nevertheless, there is a significant reduction in the cost required to meet that cap when the EERE advanced technologies are available.

In the midterm, the carbon allowance price that is necessary to reduce emissions to the cap level falls from a maximum of $200 per metric ton of carbon equivalent in the Base to $165 per ton in the Portfolio case. From 2015 to 2015, NEMS-GPRA07 projects an average price drop of $35 per ton with the EERE portfolio relative to the Base case without the R&D.

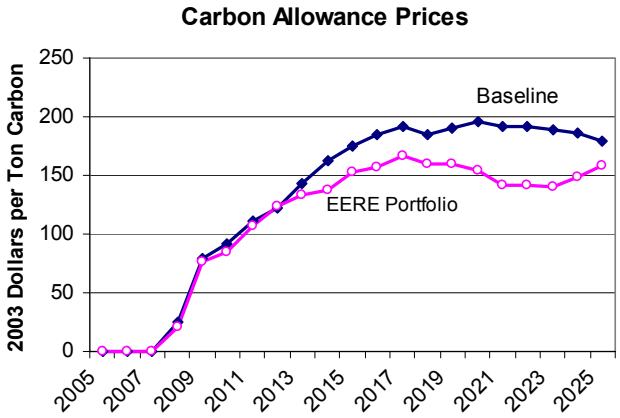

Figure 12. Carbon Allowance Prices through 2025 in the Base and EERE Portfolio Cases

[5] No banking of allowances was included in the scenario.

The expenditures that consumers pay for energy are higher due to the carbon allowances that are embedded in energy prices. The reduction in the carbon allowance price in the EERE portfolio case, along with a reduction in energy consumption due to greater energy efficiency opportunities, leads to greater energy expenditure savings from the EERE portfolio than in the BAU case – 85 percent higher in 2020 and 51 percent greater in 2025.

The longer term effects are driven in large part by the energy system's reaction during the transition period. Specifically, the introduction of a large stock of highly efficient and/or carbon free capital stock during the transition period frees the energy system to make only incremental investments in additional efficiency and carbon free capital stock in future periods in order stay under the carbon cap while meeting increased demand for energy services. Thus, in the Carbon Constraint Base case, the marginal value of carbon falls dramatically from about $250 per metric ton of carbon in 2015 to stabilize at roughly $100 per metric ton after 2030.

The differences between model projections for carbon allowance prices are attributable to at least three fundamental factors:

- MARKAL's design includes perfect foresight and thus "optimizes" over the entire model horizon, while different NEMS-GPRA07 modules have different foresight formulations (myopic and simulation-based for the demand sectors; close to perfect foresight and optimizing for the electric generation sector). Because the carbon cap is instituted in 2012, MARKAL makes an optimal decision early, but with respect to the shape of the energy system through 2050. NEMS-GPRA07 only "sees" through 2025, and only its supply modules optimize over the time frame.
- The version of MARKAL employed for GPRA07 does not include elastic service demands. As relative prices change, the demand sectors continue to demand the same amount of energy services as under the original prices.[6] In NEMS-GPRA07, the demand sectors can lower their energy demands in the short-term in response to higher real energy prices; in MARKAL the only mechanism is through adoption of new technologies[7].
- MARKAL runs in five-year time steps, while NEMS runs in one-year time steps. While this distinction is usually not very significant for long-term models, the timing of the carbon cap in our scenario makes the time-step issue quite important. The carbon cap starts in 2008 and becomes more stringent in 2017. In MARKAL, this translates into 2010 and 2015, and the change occurs in one time step. In NEMS, the additional resolution of annual time periods allows the energy system to respond more gradually; in MARKAL, the new stringency is a one-period shock to the system.

With the addition of the EERE technologies in the Carbon Constraint Portfolio Case, the energy system carbon emissions fall below the cap after 2030, and the value of carbon (expressed as the allowance price) drops to zero. There are several reasons for this result. As noted above, the

[6] Energy demand is generally quite inelastic in the short term, reflecting the existing capital stock, but more elastic in the long-term as fuel switching and capital retirements and replacements become more economic and have time to occur. EERE expects to implement an elastic service demand version of MARKAL in future GPRA reports.
[7] For these scenarios, some of the service demands, such as VMT, were adjusted to reflect the response from NEMS-GPRA07.

version of MARKAL being used has fixed service demands, thus consumers are not responding to a drop in the value of carbon (and the resulting decrease in fuel prices) by demanding more energy services. The introduction of more efficient and low/no carbon capital stock during the transition period has a lasting effect on carbon emissions throughout the projection period. Finally, the introduction of EERE technologies further reduces the cost of reducing carbon emissions. In fact, in the BAU scenario without any climate policy, the EERE portfolio emissions drop to about 1890 MMT of carbon by 2050. This is about two-thirds of the required savings from the BAU baseline needed to meet the carbon cap. The marginal value of carbon (allowance prices) and total carbon emissions as projected by MARKAL-GPRA07 are shown in Figures 13 and 14.

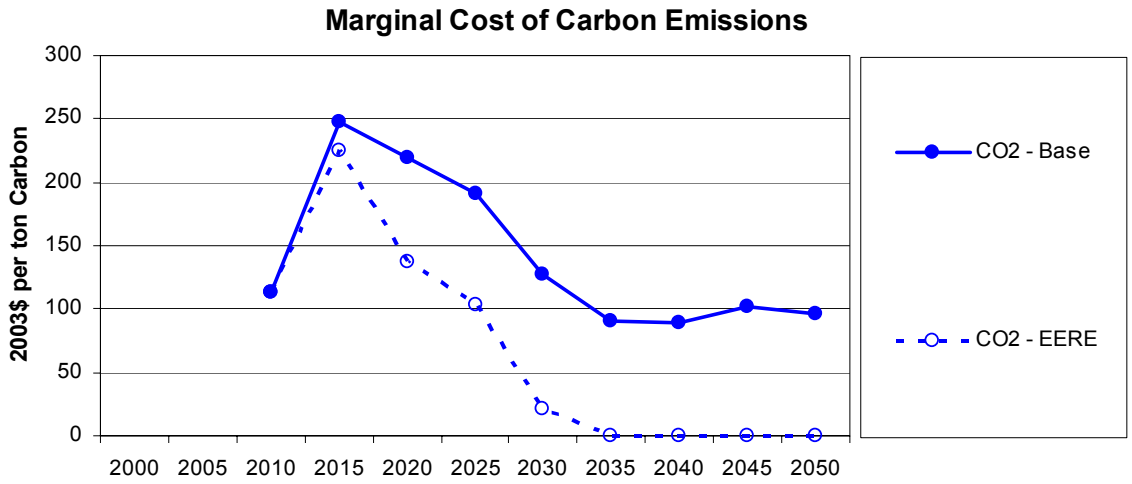

Figure 13. Carbon Allowance Prices through 2050 in the Base and EERE Portfolio Cases

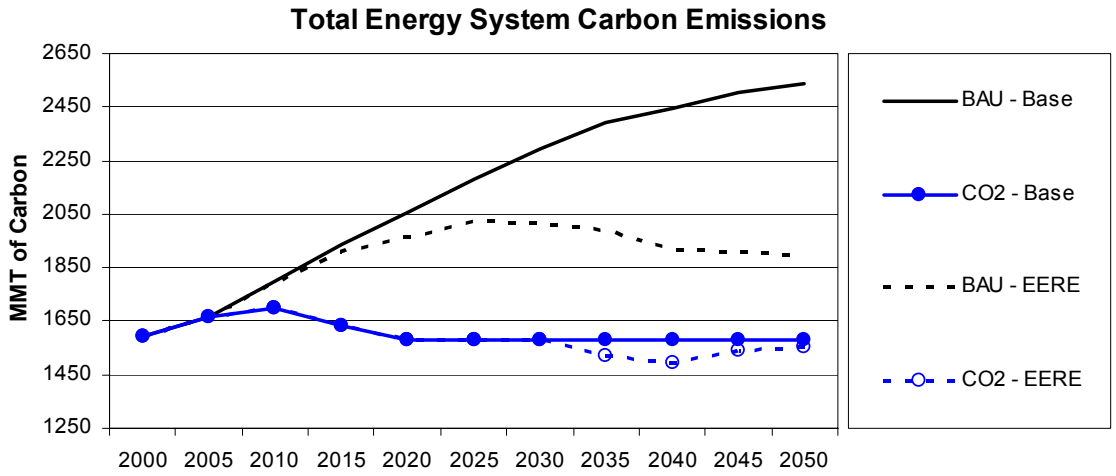

Figure 14. Carbon Emissions through 2050 in the BAU and Carbon Constraint Base and EERE Portfolio Cases

Generation and Capacity Effects

In both time periods and models, the greatest shifts in energy use patterns occur in the electric power sector. A significant portion of existing coal-fired power plants retire, and nuclear, sequestered coal, and renewable capacities increase. With the EERE Portfolio, an additional 121 GW of renewable capacity is added by 2025 compared to the carbon constraint baseline. This is very similar to the incremental amount that was added in the BAU Portfolio relative to the BAU Base although the mix of renewable types is different, as will be shown later. In the BAU scenario, the additional renewable capacity displaces a mix of gas and coal capacity. In the Carbon Constraint scenario, the displaced capacity includes nuclear and sequestered coal, as well as conventional gas and coal capacity. In 2025, total capacity is projected to be higher in the Carbon Constraint case despite lower electricity demand due to the increasing share of intermittent wind capacity that leads to greater capacity reserve requirements.

In the long-term projections, the inclusion of the EERE Portfolio technologies lowers the total generation capacity. Here the impact of reduced electricity demand due to increased efficiency in the end-use sectors leads to lower capacity overall. There is a shift away from existing coal and towards carbon free generation capacity, such as nuclear or IGCC with sequestration. However, with the EERE Portfolio of technologies, there are more cost-effective opportunities for reducing carbon emissions and the carbon allowance price declines significantly (shown in Figure 13). Therefore, the system's use of carbon-free generation sources declines and more unsequestered IGCC capacity is added at the end of the forecast period. The decline in the carbon allowance price also reduces the economic incentive to build large amounts biomass-fired and wind-powered generation capacity. However, the wind turbines built in the Portfolio Case have higher capacity factors than those built in the Base Case, and the decrease in wind generation between the Carbon Constraint Base case and EERE portfolio case is lower than the reduction in capacity. The decline in nuclear capacity occurs as no new nuclear plants are built after 2025 due to both the decline in the carbon allowance price, the reduction in electricity demand, and improvements in renewable generation technologies relative to the base case. Total electric generation capacity is shown in Figure 15 and nuclear generation capacity is shown in Figure 16.

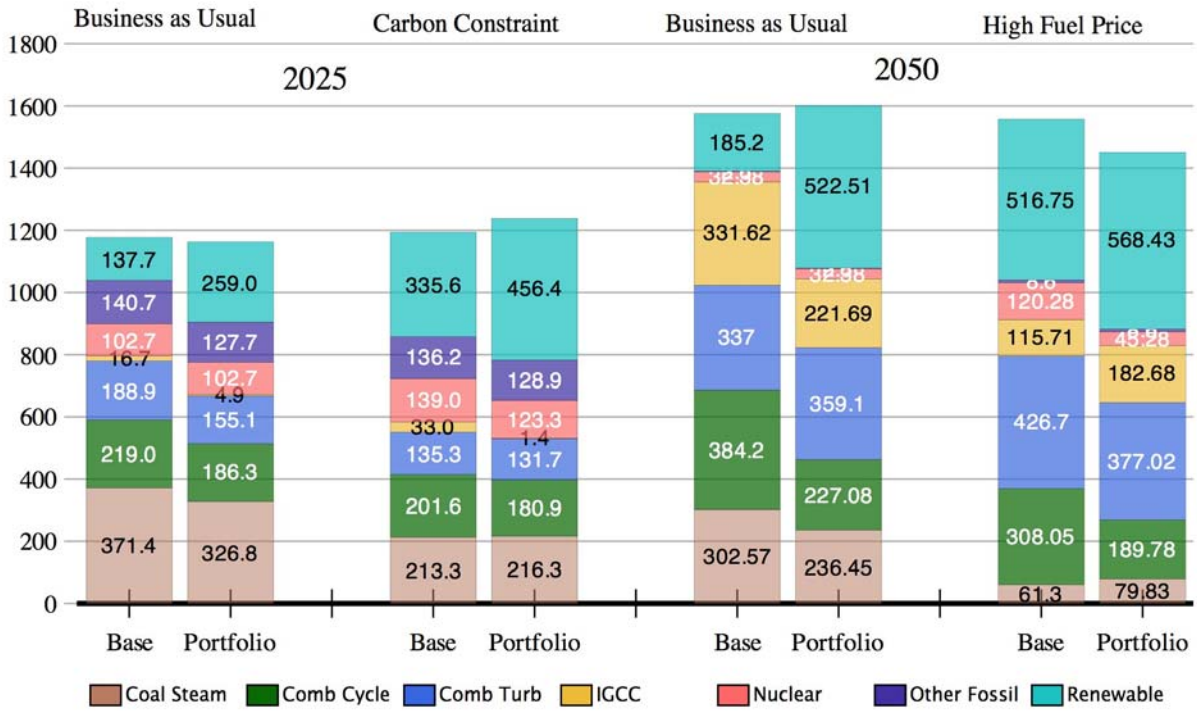

Figure 15. Electric Generation Capacity in 2025 and 2050 Business-as-Usual and Carbon Constraint Cases

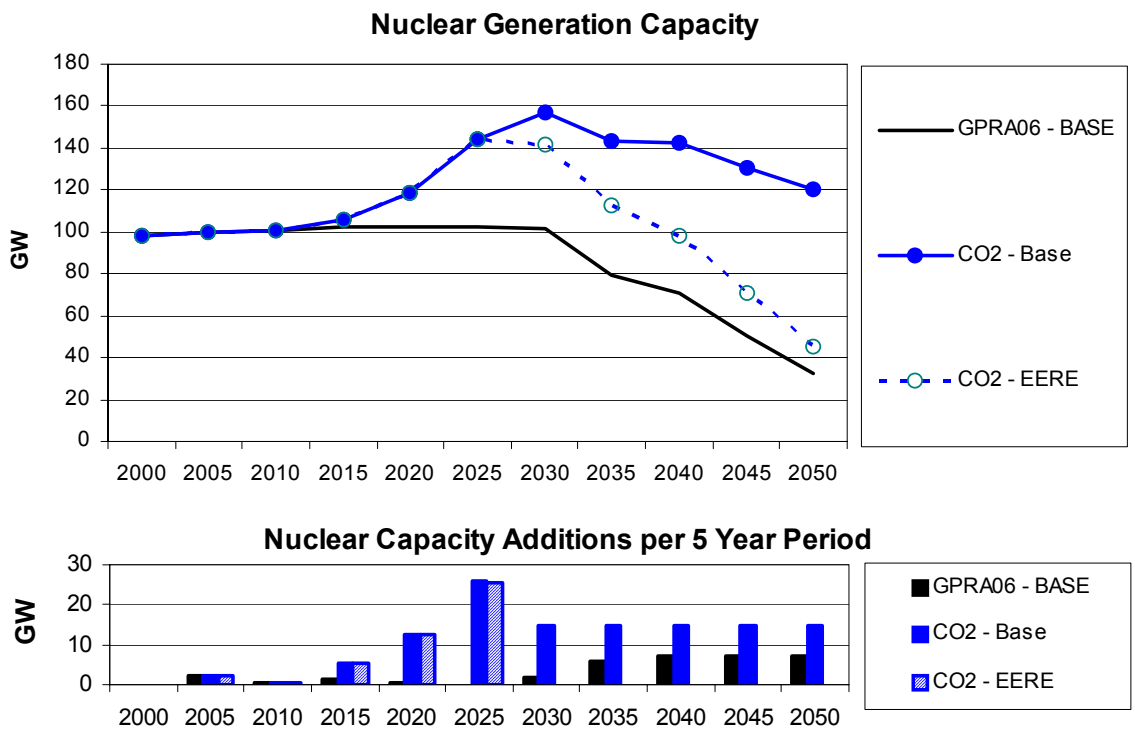

Figure 16: Nuclear Generation Capacity

In the Carbon Constraint case, the drop in coal generation is even greater than the decrease in capacity as existing coal plants become more expensive to operate. The EERE portfolio provides more cost-effective renewable generation, and nuclear and natural gas generation decline relative to the base. Total generation is slightly lower as well due to greater adoption of energy-efficient technologies.

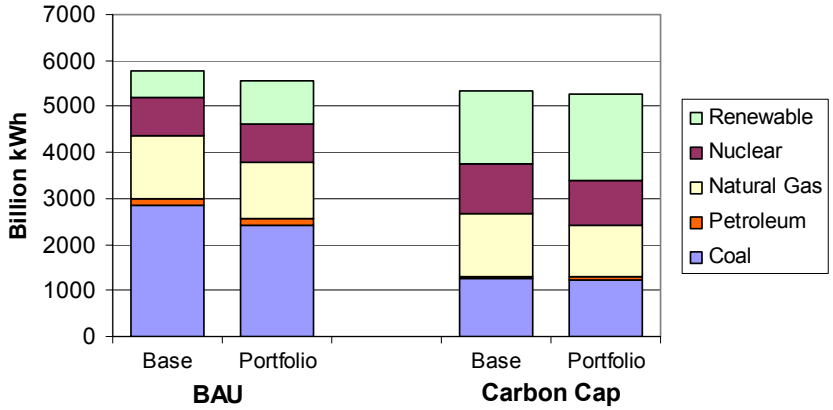

Figure 17. Electricity Generation in 2025 in the BAU and Carbon Constraint cases

With the EERE portfolio technologies, non-hydro renewable generation capacity increases in both the BAU and Carbon Constraint scenarios. However, the composition of this capacity changes dramatically in the Carbon Constraint scenario. In the Carbon Base case, the largest increase is in biomass and wind generation and capacity. In the EERE portfolio case, wind and solar technologies make significant additional contributions to carbon emission reductions in the midterm period. Dedicated biomass power, which is not in the EERE R&D portfolio, is greater in the Carbon Base case, but shrinks as the wind and solar technologies improve in the EERE Portfolio case.

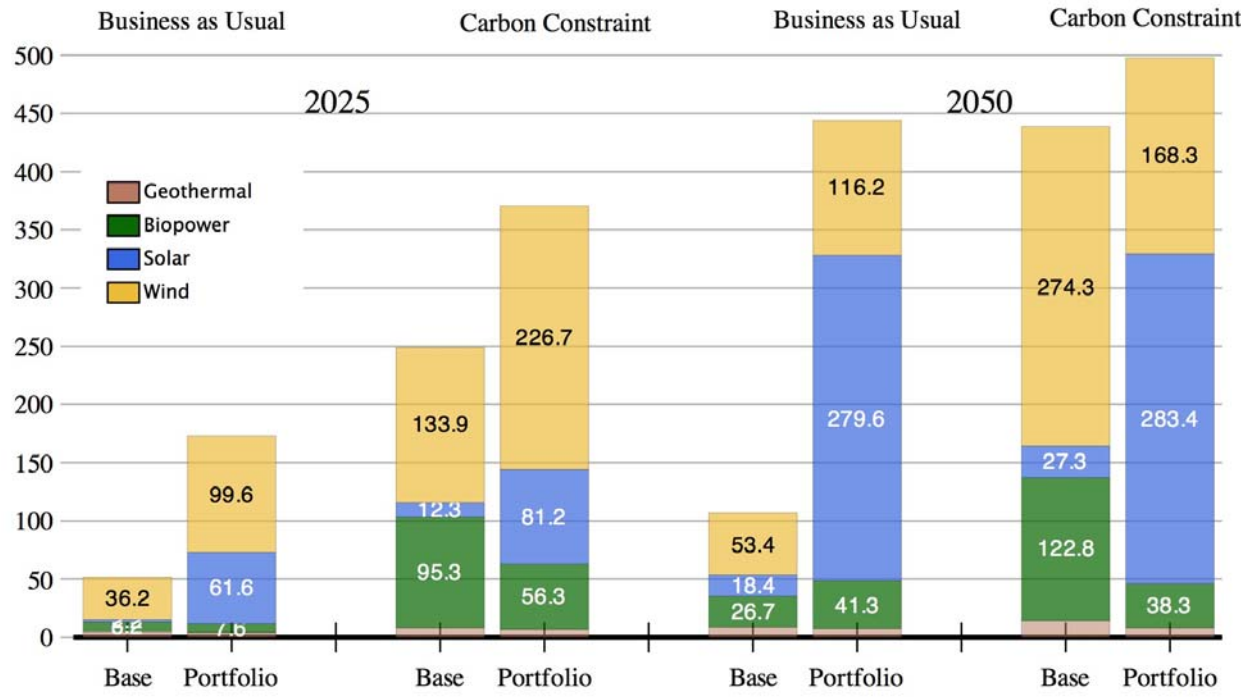

Figure 18. Non-Hydro Renewable Electric Generation Capacity in 2025 and 2050 Business-as-Usual and Carbon-Constraint cases

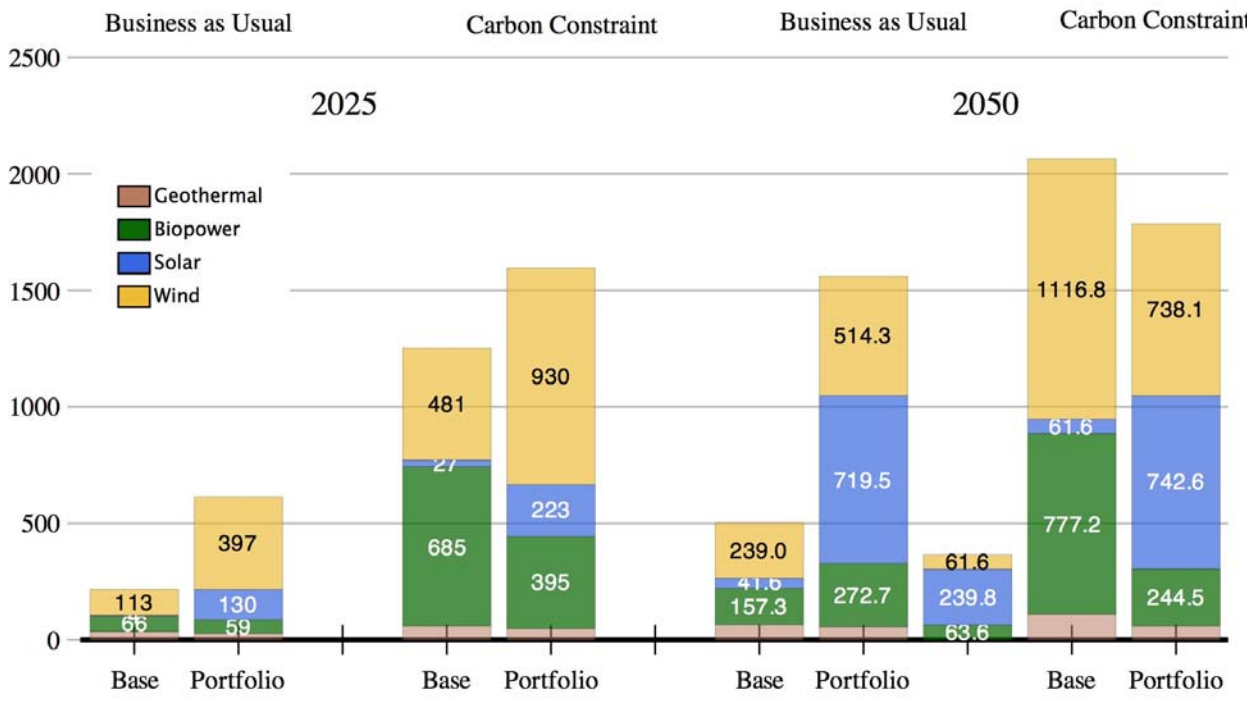

Figure 19. Non-Hydro Renewable Electric Generation in 2025 and 2050 Business-as-Usual and Carbon Constraint cases

In the long run, the largest increase is in solar generation relative to the carbon base case. In the carbon base case, biomass and wind generation were among the most cost effective options in reducing carbon emissions. However, with the introduction of the EERE technologies, end-use efficiency in both the buildings and transportation sectors are very cost effective in reducing carbon emissions. Furthermore, the EERE solar technologies show relatively higher cost and performance improvement over their base case levels.

Sector- Specific Effects

The growth in end-use consumption is reduced considerably in the Carbon Constraint base case even without the advanced EERE technologies. Part of the drop is due to lower demands for energy services, such as vehicle miles traveled or home heating and cooling, and partly due to greater efficiency. With the inclusion of EERE technologies, energy efficiency improves further, and energy consumption drops a bit more. The incremental reduction due to EERE is smaller in the carbon constraint case, because of overall reduced demand for services and greater efficiency in the base.

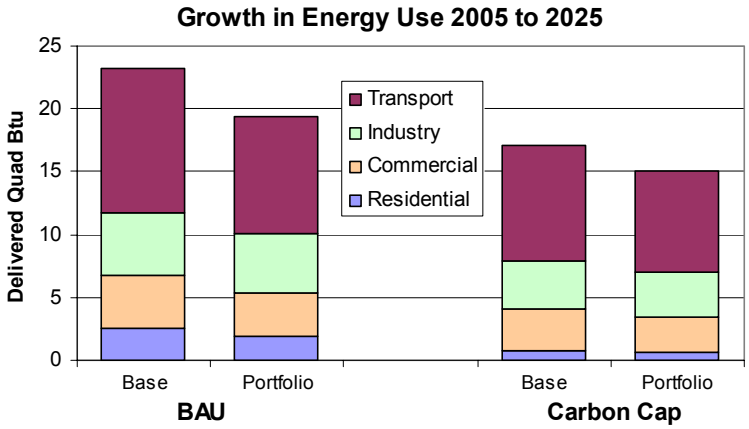

Figure 20. Growth in Energy Consumption from 2005 to 2025 in the BAU and Carbon Constraint cases

In the long term, the carbon constraint continues to reduce delivered buildings energy consumption in the Carbon Constraint Base case relative to the BAU Base. Incremental delivered energy consumption in the buildings sector is roughly 40 percent lower in 2030 and 2050. The inclusion of EERE portfolio technologies further reduces delivered energy consumption in the buildings sector in both the BAU and Carbon Constraint scenarios. The reduction in delivered energy consumption in the EERE Portfolio cases are attributable to improved buildings shell packages, highly efficient space conditioning technologies and improved and highly efficient solid state lighting technologies. Figure 21 shows the incremental buildings delivered energy consumption for the base and EERE portfolio cases in both the BAU and High Fuel Price scenarios.

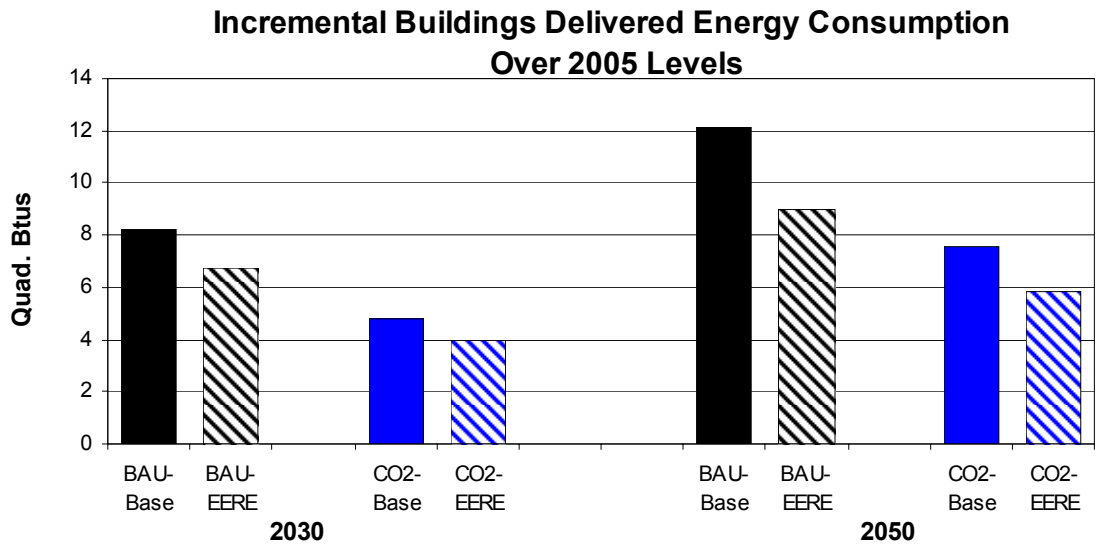

Figure 21. Buildings-Sector Delivered Energy Consumption: 2030 and 2050

The transportation sector reacts to the carbon constraint by reducing service demands and by increasing efficiency. LDV VMTs fall by about 6 percent between the BAU and Carbon Constraint scenario. Furthermore, in the Carbon Constraint scenario the Base case average LDV stock efficiency increases by 8 percent in 2030 and 18 percent in 2050 relative to the BAU scenario. The increase in LDV stock efficiency is due to an increase in hybrid vehicle penetration in the carbon constraint base case. Also, ethanol consumption increases in the Carbon Constraint Base case relative to the BAU Base. The increased use of ethanol further reduces Base case oil consumption in the Carbon Constraint scenario.

By 2050, both the BAU and Carbon Constraint EERE Portfolio cases, the LDV fleet is comprised entirely of EERE hybrids and fuel cell vehicles. The EERE Portfolio cases lead to reduced petroleum consumption due to the increased market share of highly efficient EERE hybrid and fuel cell vehicles. Also, increased production of cellulosic ethanol further displaces petroleum consumption. Figure 22 shows the LDV stock market shares.

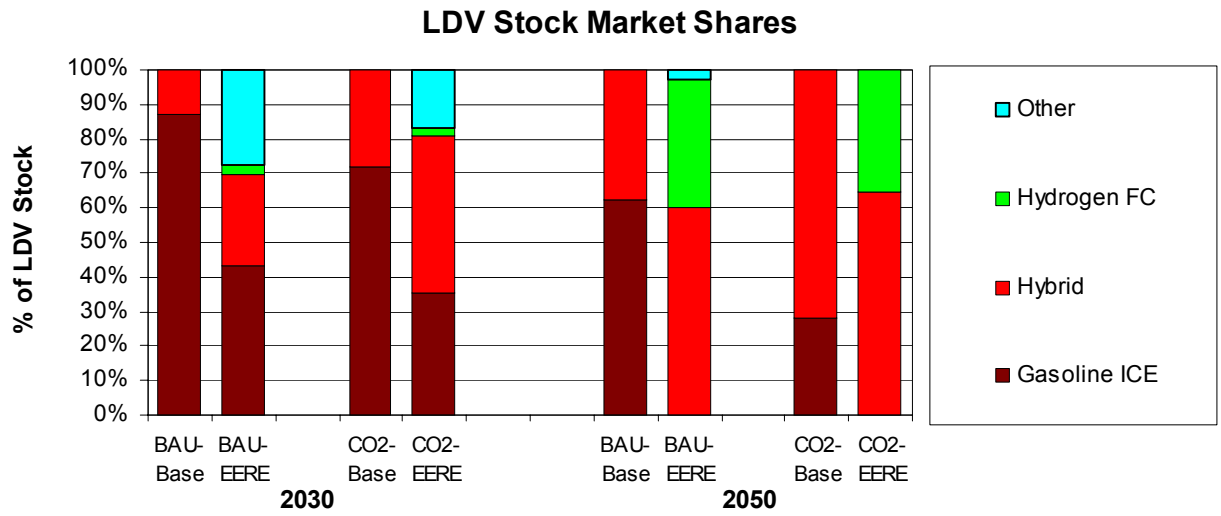

Figure 22: Light Duty Vehicle Stock Market Shares, 2030 and 2050

As noted earlier, many of the benefits estimates for the Carbon Constraint scenario are lower than in the BAU scenario due to the massive changes in the energy system in the Base case that result from the imposition of a carbon cap. Furthermore, the reduction in service demands means that the energy system cost savings are not comparable to those in the BAU scenario. However, the increased buildings and transportation efficiency, as well as improved cost and performance of renewable technologies still lead to significant benefits relative to the base case.

Benefits Summary

Table 3. FY07 Annual Benefits Estimates Through 2025 for the EERE Portfolio Under a Carbon Constraint (NEMS-GPRA07)

Benefits	2010	2015	2020	2025
Energy Displaced				
Non-Renewable Energy Savings (quadrillion Btu/year)	0.01	0.4	1.6	3.9
Economic				
Energy Expenditure Savings (billion 2003 dollars/year)*	13	55	129	162
Environmental				
Carbon Savings (million metric tons carbon equivalent/year)	ns	ns	ns	ns
Security				
Oil Savings (million barrels per day)	0.1	0.2	0.5	0.9
Natural Gas Savings (quadrillion Btu/year)	0.2	0.6	1.5	1.0
Program-Specific Electric Capacity (gigawatts)	ns	25	116	163
Program-Specific Generation (terawatt-hours/year)	ns	94	423	575

Table 4. FY07 Annual Benefits Estimates Through 2050 for the EERE Portfolio Under a Carbon Constraint (MARKAL-GPRA07)

Benefits	2030	2040	2050
Energy Displaced			
Non-Renewable Energy Savings (quadrillion Btu/year)	6	13	16
Economic			
Energy-system net cost savings (billion 2003 dollars/year)*	67	130	185
Environmental			
Carbon Savings (million metric tons carbon equivalent/year)	ns	83	29
Security			
Oil Savings (million barrels per day)	3	6	8
Natural Gas Savings (quadrillion Btu/year)	3	3	4
Program-Specific Electric Capacity (gigawatts)	62	85	139
Program Specific Generation (terawatt-hours/year)	269	291	260

* Midterm energy-expenditure savings only include reductions in consumer energy bills, while long-term energy-system net cost savings also include the incremental cost of the advanced energy technology purchased by the consumer.