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Scenarios for Benefits Analysis of Energy Research, Development, Demonstration and Deployment

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Publication Date
2005-09-07

LBNL-58009

Scenarios for Benefits Analysis of Energy Research, Development, Demonstration and Deployment

Prepared for the
Office of Planning, Budget and Analysis
Assistant Secretary for Energy Efficiency and Renewable Energy
U.S. Department of Energy

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August 2005

This work described in this paper was funded by the Assistant Secretary of Energy Efficiency and Renewable Energy, Office of Planning, Budget and Analysis of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

Acknowledgements

The work described in this report was funded by the Assistant Secretary of Energy Efficiency and Renewable Energy, Office of Planning, Budget, and Analysis (PBA) of the U.S. Department of Energy (DOE) under Contract No. DE-AC03-76SF00098. The authors would like to thank our program manager for this work, Brian Unruh, and the overall director of this activity, Darrell Beschen, both of PBA. Additionally, thanks to our counterparts at the National Energy Research Laboratory, Charles Drummond, Rodney Geisbrecht, and Frank Shaffer who, under the direction of the Office of Fossil Energy of DOE, collaborated with Berkeley Lab on the specification of the scenarios described herein. The authors have special appreciation to our colleagues, Frances Wood of OnLocation and Paul "Chip" Friley of Brookhaven National Laboratory, who are the downstream users of these scenarios. Their patience and encouragement was charming and inspiring. Our perennial National Energy Modeling System (NEMS) colleagues at Berkeley Lab, Kristina Hamachi LaCommare and Peter T. Chan, supported this work on many levels. The Energy Information Agency analysts, Joseph Benneche, Paul Kondis, Han-Lin Lee, Dan Skelly, and Dana Van-Wagener were instrumental in clarifying the proper parts of NEMS to examine for this work and in resolving some model errors encountered. The authors also appreciate the careful review done by our colleague Charles Goldman.

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Acronyms and Abbreviations

AEO – Annual Energy Outlook, annual EIA generated NEMS report
DOE – U.S. Department of Energy
EE – Energy Efficiency and Renewable Energy, Office of DOE
EIA – Energy Information Administration of DOE
FE – Office of Fossil Energy at DOE
GPRA – Government Performance and Results Act
LBNL – Ernest Orlando Lawrence Berkeley National Laboratory or Berkeley Lab
LNG – liquefied natural gas
MtC –million metric tons of carbon
NEMS – National Energy Modeling System, EIA's model
NEMS-LBNL – Berkeley Lab's version of NEMS
NETL – National Energy Technology Laboratory
NRC – National Research Council
RD^3 – research, development, demonstration, and deployment
tcf – thousand cubic feet

Definitions

Baseline Case – a NEMS-LBNL forecast assuming that certain EE RD^3 is not implemented
Berkeley Lab - LBNL
Case – a unique setup of the NEMS code, including all initial and boundary conditions placed on NEMS, and a corresponding setup of any other analytic tools
Convergence – EIA's measure of how little oscillation there is in solution variables. Solution values are compared between iterations and cycles, and the less oscillation the better the model converges.
Berkeley Lab scenarios – the Reference, High Fuel, and Carbon Cap Scenarios specified by the Working Group and implemented by Berkeley Lab into NEMS
Program Case – a NEMS-LBNL forecast assuming that EE RD^3 is implemented
Reference Scenario – a specific recognized EIA reference forecast. In this report it refers to the version of NEMS which has all the source code, inputs and parameters set up as for the Analysis of S. 1844, the Clear Skies Act of 2003; S. 843, the Clean Air Planning Act of 2003; and S. 366, the Clean Power Act of 2003 Reference Scenario
Scenario – an abbreviated description of a set of key conditions regarding environmental and energy parameters
Scenario 0 – reference scenario forecast, EIA prepared for FE in January 2005
Scenario 1 – Clear Skies forecast, EIA prepared for FE in January 2005
Scenario 2 – Climate Change Initiative forecast, EIA prepared for FE in January 2005
Scenario 3 – Severe Carbon Cap forecast, EIA prepared for FE in January 2005
Scenario 4 – High Fuel Price forecast, EIA prepared for FE in January 2005
Scenario 5 – Higher Oil Price forecast, EIA prepared for FE in January 2005
Static Case – a NEMS-LBNL forecast without any DOE RD^3 changes, i.e. keeps all Reference Scenario parameters except those that distinguish the Scenario from Reference Scenario
Working Group – the EE-FE group that specified the joint scenarios

Abstract

For at least the last decade, evaluation of the benefits of research, development, demonstration, and deployment (RD^3) by the U.S. Department of Energy has been conducted using deterministic forecasts that unrealistically presume we can precisely foresee our future 10, 25, or even 50 years hence. This effort tries, in a modest way, to begin a process of recognition that the reality of our energy future is rather one rife with uncertainty.

The National Energy Modeling System (NEMS) is used by the Department of Energy's Office of Energy Efficiency and Renewable Energy (EE) and Fossil Energy (FE) for their RD^3 benefits evaluation. In order to begin scoping out the uncertainty in these deterministic forecasts, EE and FE designed two futures that differ significantly from the basic NEMS forecast.

A *High Fuel Price Scenario* and a *Carbon Cap Scenario* were envisioned to forecast alternative futures and the associated benefits. Ernest Orlando Lawrence Berkeley National Laboratory (LBNL) implemented these scenarios into its version of NEMS, NEMS-LBNL, in late 2004, and the Energy Information Agency created six scenarios for FE in early 2005. The creation and implementation of the EE-FE scenarios are explained in this report. Both a Carbon Cap Scenario and a High Fuel Price Scenarios were implemented into the NEMS-LBNL. EIA subsequently modeled similar scenarios using NEMS.

While the EIA and LBNL implementations were in some ways rather different, their forecasts do not significantly diverge. Compared to the Reference Scenario, the High Fuel Price Scenario reduces energy consumption by 4% in 2025, while in the EIA fuel price scenario (known as Scenario 4) reduction from its corresponding reference scenario (known as Scenario 0) in 2025 is marginal. Nonetheless, the 4% demand reduction does not lead to other cascading effects that would significantly differentiate the two scenarios.

The LBNL and EIA carbon scenarios were mostly identical. The only major difference was that LBNL started working with the AEO 2004 NEMS code and EIA was using AEO 2005 NEMS code. Unlike the High Price Scenario the Carbon Cap scenario gives a radically different forecast than the Reference Scenario.

NEMS-LBNL proved that it can handle these alternative scenarios. However, results are price inelastic (for both oil and natural gas prices) within the price range evaluated. Perhaps even higher price paths would lead to a distinctly different forecast than the Reference Scenario. On the other hand, the Carbon Cap Scenario behaves more like an alternative future. The future in the Carbon Cap Scenario has higher electricity prices, reduced driving, more renewable capacity, and reduced energy consumption. The next step for this work is to evaluate the EE benefits under each of the three scenarios. Comparing those three sets of predicted benefits will indicate how much uncertainty is inherent within this sort of deterministic forecasting.

1. Introduction

During 2004, Berkeley Lab together with the National Energy Technology Laboratory (NETL) developed three common scenarios for the annual modeling of program benefits done by the Department of Energy (DOE). This analysis is conducted to comply with the Government Performance and Results Act 1993 (GPRA) and the National Research Council (NRC) suggestion that DOE use common assumptions and methods to model and evaluate their research, development, demonstration, and deployment (RD^3) portfolio.[1] The Office of Management and Budget has requested that DOE's Offices of Energy Efficiency and Renewable Energy (EE) and Fossil Energy (FE) use the same scenarios and approach for their currently separate benefits analyses.

This report outlines the assumptions and methods EE uses for the scenarios forecasted with National Energy Modeling System (NEMS) through 2025, and Markal through 2050. In this report, *Scenario* will refer to a particular NEMS-LBNL forecast specified by variations in a few major energy and environmental parameters. Within a Scenario, variations are called *Cases*.

EE benefits are measured as the difference between the forecast for the case with continued EE RD^3 funding (*Program Case*) and for the case without continued RD^3 funding (*Baseline Case*). One of the more challenging aspects of this analysis is determining technology characteristic improvements for Baseline Cases because envisioning a future without Federal research is harder than one with ongoing RD^3 programs continued. This effort focuses on the development of the Scenarios rather than the benefits estimation or development of the Cases.

This project required EE and FE agreement on a common starting point (Reference Scenario), and common alternative future scenarios. The alternative scenarios were each designed to incorporate a major change to the business-as-usual future incorporated in the Reference Scenario. Berkeley Lab NEMS team had many discussions with the NETL NEMS team, eventually arriving at mutually agreeable definitions of the scenarios. This agreement is described in detail throughout this report. FE-NETL used similar scenarios to the ones Berkeley Lab implemented in NEMS-LBNL for test runs in the GPRA-06 budget cycle.

However, in keeping with their standard practice, FE formally requested that the Energy Information Administration (EIA) implement these scenarios in NEMS. EIA completed these cases in February 2005. One major difference between these scenarios and the ones defined previously is that the EIA-FE scenarios use many standard NEMS files that are 9 months more current than NEMS-LBNL. EE and FE conduct their GPRA work on quite different schedules, with the FE effort taking place earlier in the budget cycle. Because the FE scenarios are similar to the jointly established Berkeley Lab ones, and they have been implemented in the AEO 2005 version of NEMS, they are available for use by EE in its current GPRA-07 budget cycle.

Section 2 briefly describes the joint approach to benefits analysis of the EE-FE Working Group, how the two offices worked together to specify common scenarios, and the challenges associated with implementing them in NEMS-LBNL.

[1] National Research Council, 2001.

Section 3 explains the Reference Scenario chosen. Unlike most NEMS-LBNL work, the most recent Annual Energy Outlook (AEO) Reference Scenario was not the starting point; rather, a reference scenario published a few months after the release of AEO 2004 was used.

Section 4 explains the High Fuel Price Scenario. This scenario reflects a future in which the supply of natural gas and oil are restricted, causing significantly higher fuel prices.

Section 5 explains the Carbon Cap Scenario as implemented by Berkeley Lab. This scenario caps annual U.S. carbon emissions at 2003 levels, approximately 1580 million metric tons of carbon (MtC). The carbon cap is implemented through a simple cap-and-trade regime. This limit reduces projected carbon emissions by more than 600 MtC, or about 29%, by 2025.

Section 6 discusses the three emissions scenarios and two fuel price scenarios that EIA created for FE. Results are presented to highlight differences among the EIA scenarios.

Section 7 compares the EIA-FE scenarios with the Berkeley Lab scenarios.

Section 8 summarizes the main conclusions of this work while Section 9 goes over EE and Berkeley Lab's next steps for evaluating how alternative scenarios fit into model forecasting.

2. Joint Scenarios for EE and FE

During 2004, the EE-FE Working Group defined a common Reference Scenario and two alternative scenarios to potentially serve as common scenarios for the two offices. The central challenge was merging different analysis perspectives into a unified approach. Initially, the two DOE offices explained and exchanged their existing approaches, and then the Working Group negotiated new scenarios in detail that would satisfy both EE and FE's requirements. Finally, the implementation of these scenarios and the benefits analysis was discussed in detail to reach a common starting point for as many of the small yet potentially divergent assumptions as possible. While the Working Group determined the specifications for the scenarios, Berkeley Lab was responsible for the actual implementation into NEMS-LBNL.

Each scenario will have versions, or cases. The case for each scenario that incorporate none of the baseline or program characteristics are herein called the *static case*. The intent of the Working Group is that the three scenarios' Static Cases should be almost identical and will be used for comparison between EE and FE. However, the actual benefit analyses will be done separately using the common scenarios but different analysis approaches. EE and FE will both end up with at least nine cases, laid out in Table 1.

For EE's analysis, each scenario's Static Case will be run along with a Baseline Case and Program Case. In all scenarios, each office keeps the other's programs constant throughout all three cases. In other words, there has been no effort to date to develop a common analysis method, or to jointly conduct one. However, that will change soon, as EE, FE, as well as the Office of Nuclear Energy, Science and Technology and Office of Electric Delivery and Energy Reliability try to develop joint Cases and estimates starting with GPRA-08 budget request.

Table 1 List of Cases used for Scenario Benefits Analysis

Scenarios	Identical EE-FE Cases	Separate Cases Developed Using Different Method by EE
Reference	Static Reference Case	Baseline & Program Reference Cases
High Fuel Price	Static High Fuel Case	Baseline & Program High Fuel Price Cases
Carbon Cap	Static Carbon Case	Baseline & Program Carbon Cases

2.1 Extreme Scenario Limitations

NEMS is intended to produce the annual AEO Reference Scenario, and scenarios that fall outside this range are not easily implemented and are not guaranteed by EIA. Specifically, surprise scenarios with unexpected shocks cannot be readily implemented. The surprise factor is reduced by NEMS's various look-ahead assumptions that soften the blow of coming change. Also, the model can become unstable if sudden extreme changes are encountered. The scenarios chosen, therefore, should not be interpreted as discontinuous surprises, but rather as significant deviations from the Reference Scenario path.

A separate analysis was conducted by Berkeley Lab to compare the scenarios chosen with other scenario analyses that have been done. The authors concluded that the High Fuel Scenario is reasonable though perhaps the price increases were too conservative. The Carbon Cap Scenario was described as “less aggressive than” some others found in the literature, “…[yet] aggressive in the near term, and may explore the limits of NEMS…”[2].

2.2 Overcoming Other Challenges to Using NEMS-LBNL

Developing the High Fuel Price and Carbon Cap Scenarios was tricky. Dreaming up alternative paths was one thing, but making NEMS-LBNL follow them was something else entirely. In NEMS, fuel prices are solutions not input values, except for the price of oil, which is set by world supply and demand. Other fuel prices are determined by domestic supply and demand forecasts.

In order to attain the particular natural gas wellhead prices elaborated on in Section 4, the resource base for Canadian and Liquefied Natural Gas (LNG) imports had to be carefully calibrated. All of these calibrations and other corrections took 24 runs, 77 cycles,[3] over the course of six weeks, trying 14 different versions of the natural gas input file, *ngmisc*. Eventually, with the help of EIA analysts, all of the problems were eliminated and the price targets were hit.

The Carbon Cap Scenario, in contrast to High Fuel Price Scenario, merely involved changing inputs to NEMS-LBNL. However, carbon capped scenarios in NEMS-LBNL are much harder to solve and converge.[4] The NEMS-LBNL work refining the Carbon Cap Scenario took approximately 30 runs, 630 cycles, over six weeks. Each carbon scenario cycle took between 45 and 80 minutes to execute. Originally an annual carbon cap of 1480 MtC was envisioned for this scenario but after a month and hundreds of hours without approaching EIA’s convergence criterion, the carbon cap target was eased to 1580 MtC.

The Working Group believes that the extensive number cycles needed for convergence is due to the limited options for reducing carbon emissions. Limited options cause the model to oscillate between reduction strategies; and results that oscillate significantly cannot be considered converged.

[2] Wiser, R., and M. Bolinger, 2004.
[3] A “cycle” in NEMS is a model run from start to finish 1990 - 2025. Most scenarios with small changes converge within a few cycles.
[4] For example, some test carbon cap scenarios never converge satisfactory after three or four days running continuously, a range of 50 to 100 cycles. The actual convergence determination is an extremely complicated calculation. Some of the criteria involve: determining how many variables have different values from cycle to cycle; and the magnitude of these differences. A reference scenario usually converges in two to three cycles.

3. Reference Scenario

Normally, Berkeley Lab uses EIA's latest AEO version of NEMS as its Reference Scenario for most all of its NEMS-LBNL related analysis. This is updated once a year after the new AEO is published. For these joint scenarios, however, the AEO 2004 Reference Scenario was deemed an inadequate starting point. At the outset of the project, both EE and FE analysts were using code updated post-AEO 2004. Therefore the Working Group chose to start with an EIA published reference scenario from a May 2004 emissions report[5], which will be subsequently called the *Reference* Scenario.

The differences between the two versions of NEMS, the Reference Scenario and AEO 2004 Scenario, include updates, corrections, and a few revised assumptions. According to EIA,[6] most of the changes had minor impacts relative to the AEO 2004 Scenario results. These changes are explained in Appendix A, which was provided by EIA.

Results are essentially similar for the Reference Scenario and the AEO 2004 Scenario. Most of the noticeable differences occur in the short term Natural Gas Wellhead prices, 2004 through 2006, shown in Table 2 below. This change probably results from EIA updating their short-term benchmarking to March 2004 from September 2003. Longer range forecast prices are very similar.

Table 2. Natural Gas Wellhead Price Comparison ($ / tcf)[7]

	2002	2003	2004	2005	2006	2007	2008	2009
Reference	2.95	4.91	4.88	4.62	4.12	3.74	3.63	3.46
AEO 2004	2.95	4.90	3.88	3.54	3.48	3.53	3.64	3.47
% change	0%	0%	26%	31%	18%	6%	0%	0%

[5] This is the version of NEMS from EIA, 2004(a)._
[6] Changes to Reference Case-r2.doc, document supplied by Andy Kydes, EIA, to NETL on May 5th, 2004.
[7] All $ are 2002 $ in this report unless otherwise noted.

4. High Fuel Price Scenario

This scenario was designed to represent a future with fuel prices significantly higher than the Reference Scenario's fuel prices. Prices begin to deviate from the Reference Scenario around 2010. The natural gas supply is restricted to cause natural gas prices to reach a minimum of \$5.00 by 2015, \$5.50 by 2025, and \$7.50 by 2050 (all in 2002 \$)[8]. Oil prices reach a minimum of \$40 by 2025, and \$50 by 2050 (in 2002 \$)[9].

The fuel prices reached in this scenario are compared with what is found in the Reference Scenario below in Figures 1 and 4. Coal prices through 2025 are not manipulated, and reach whatever level that NEMS-LBNL determines, given the target natural gas and oil prices.

4.1 Oil Prices

The change needed to reach the oil price path was straightforward. The world oil price used in NEMS is exogenous, so the price path was merely redefined. World oil price is made to increase significantly from 2010 to 2019 and then level off, as shown in Figure 1. A few other code changes were made that are consistent with those changes made by EIA to create their High World Oil Price Case.[10]

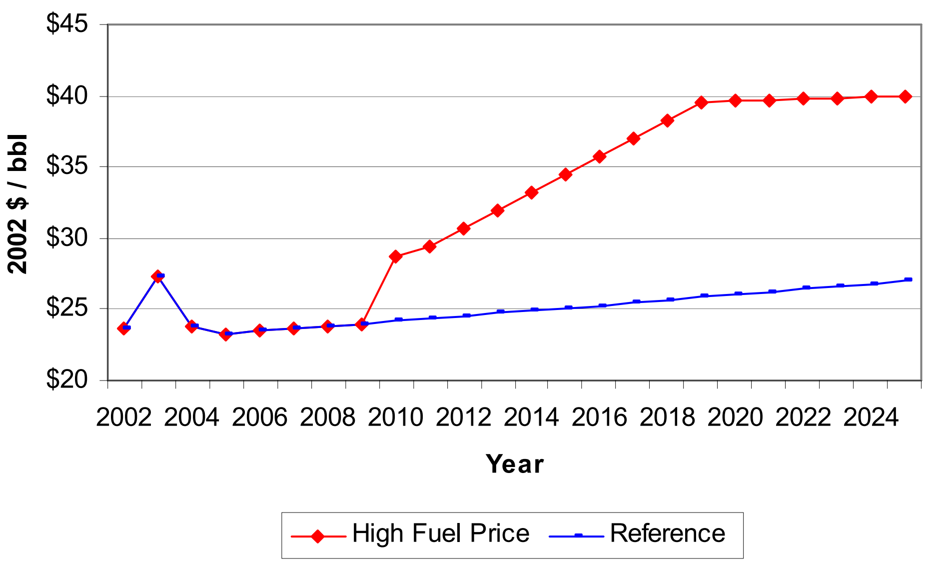

Figure 1. World Oil Price Trajectory Comparison

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[8] Natural gas prices quoted herein are wellhead price in year 2002 U.S. dollars per thousand cubic feet. (1000 equivalent ft^3 contains roughly 1.05 GJ of energy). Using a 2.5% discount rate, in real dollars, this translates to \$3.60 in 2015, \$3.07 in 2025, and \$2.22 in 2050.

[9] Oil prices herein are annual average world oil price in 2002 U.S. dollars per barrel. Using a 2.5% discount rate in real dollars, this translates to \$22.34 in 2025 and \$14.83 in 2050.

[10] These changes were identified by comparing the AEO Reference Scenario options to the High World Oil Price Scenario options.

Figure 2 shows how the world oil price modification affects U.S. oil demand. The elasticity of oil demand relative to world oil price can be seen below in Figure 3. Price elasticity of demand is defined as the absolute value of the percent change in demand divided by the percent change in price. U.S. petroleum demand is mostly inelastic to price according to the model within the price range shown in Figure 1; since a 50% price increase reduces demand by less than 7 % from 2020-2025.

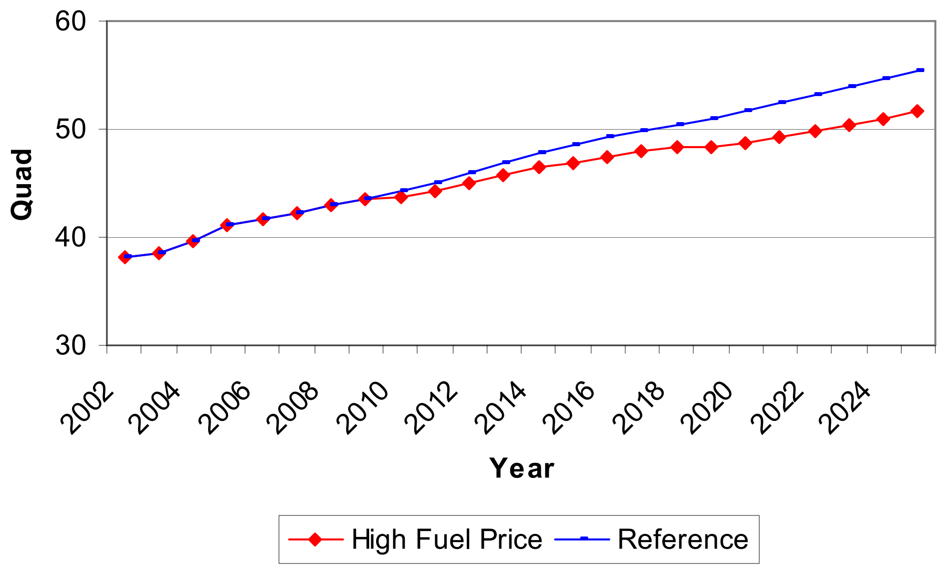

Figure 2 U.S. Petroleum Consumption

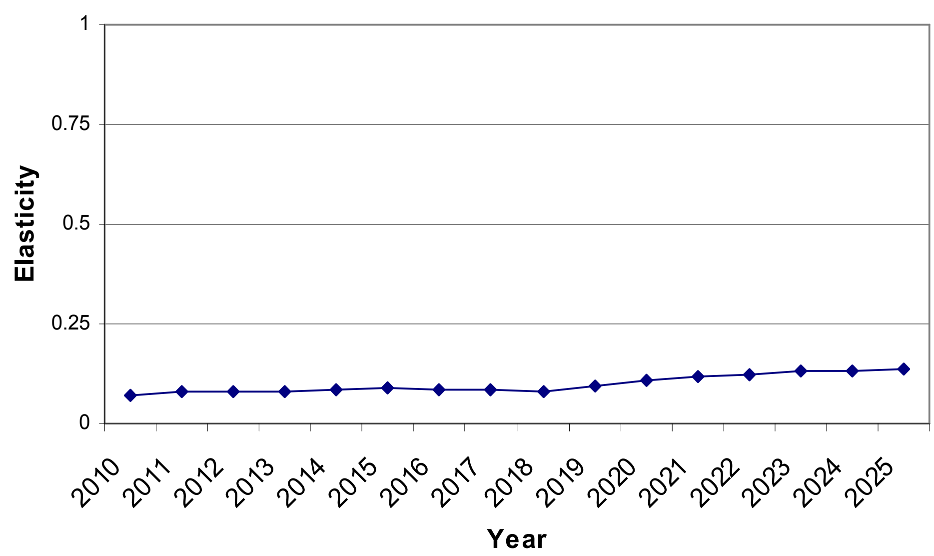

Figure 3 Elasticity of U.S. Petroleum Demand

4.2 Natural Gas Wellhead Prices

Forcing a higher natural gas wellhead price was more difficult. Figure 4 shows the wellhead prices achieved. Prices begin to diverge before 2010. The Working Group agreed that the desired natural gas price trajectory is more important than the means by which the natural gas supply is restricted. Nonetheless, the choice of supply restrictions implemented, as listed below, was in large measure motivated by a desire to inhibit supply primarily from sources outside the contiguous states, thereby disturbing domestic supply assumptions and logic as little as possible.

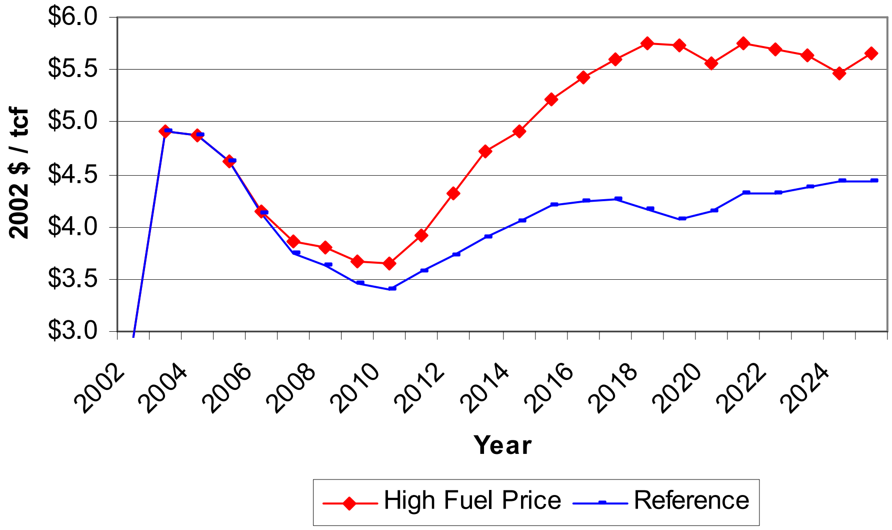

Figure 4. Natural Gas Wellhead Price Comparison

The techniques used to restrict natural gas supplies are as follows:

- Construction of an Alaska natural gas pipeline is assumed delayed and will not be in operation before 2025.
- Western Canadian Sedimentary Basin gas supplies (both conventional and coalbed methane) are reduced by 25 percent relative to the Reference Scenario.
- No new LNG facilities are allowed on U.S. shores except for Region 10, Florida, since it actually represents a planned Bahamas plant.
- The Baja California planned LNG facility is allowed to double in size once built whereas in the Reference Scenario it can triple in capacity.
- The existing four U.S. LNG facilities (Cove Point, Elba Island, Lake Charles, and Everett-DistriGas) are not allowed to expand as much as allowed under Reference Scenario conditions.

Beyond 2025, Arctic and LNG gas supplies are further restricted until the price target is met.

The net result of these restrictions is supply reductions of 0.8 trillion cubic feet in 2015 and 3.4 trillion cubic feet in 2025 as shown in Figure 5. Specifically, LNG supplies are 3 trillion cubic feet less and Canadian imports about 2 trillion cubic feet less than for the Reference Scenario in 2025. With higher prices and limited international supplies, it makes sense that some of the slack is offset by increased domestic production.

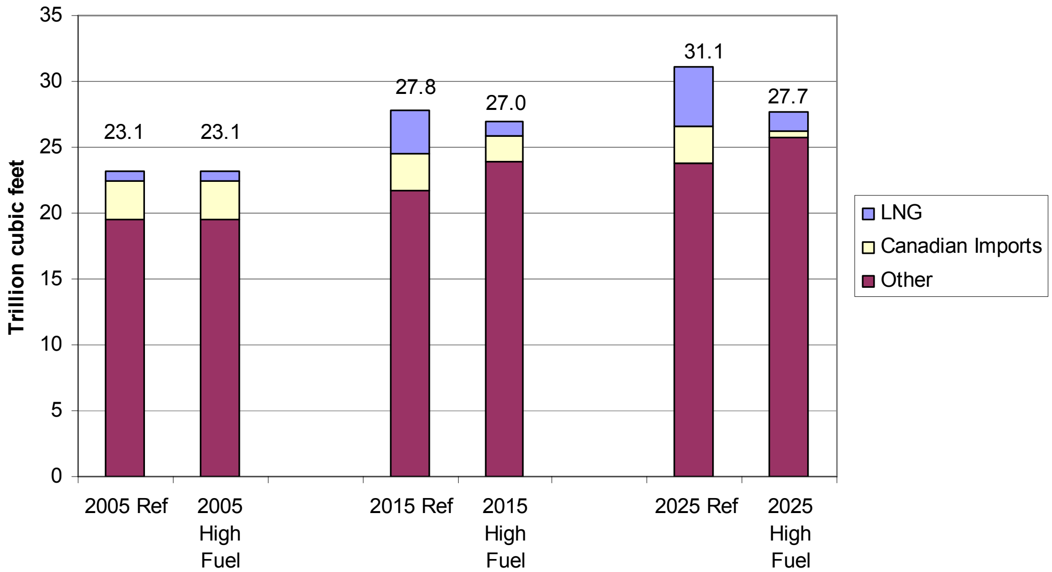

Figure 5. U.S. Natural Gas Supply Forecast

In 2005, imports make up 16% of U.S. natural gas supply. In the Reference Scenario, that share grows to about 22% in 2015 and stays pretty constant through 2025. For the High Fuel Price Scenario, in contrast, imports share of the total is reduced to 11% by 2015 and 7% by 2025.

4.3 Results

4.3.1 Energy Prices and Consumption

Total energy consumption is shown in Figure 6, and unsurprisingly, demand slackens a little bit (4% in 2025) as a result of the higher world oil and natural gas wellhead prices. A comparison of overall non-renewable energy expenses is shown in Figure 7. Total national expenses get as much as 15% higher in the middle of the forecast, though by 2025 that gap narrows back to 10% higher.

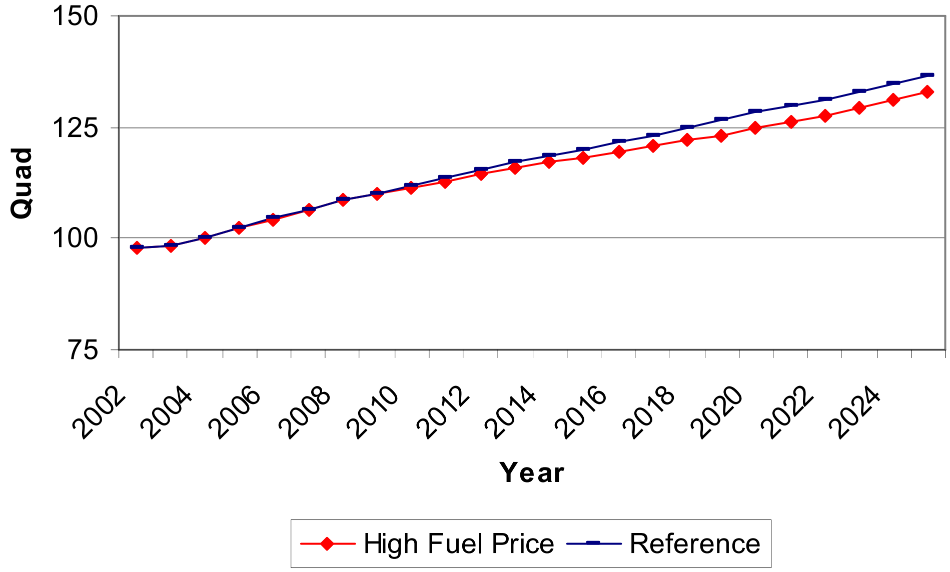

Figure 6 U. S. Total Energy Consumption

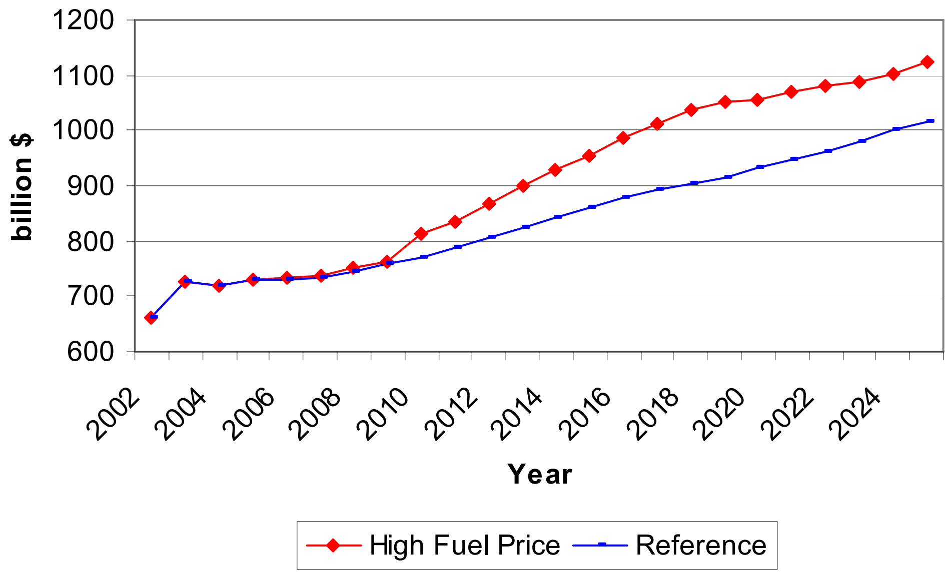

Figure 7 Total Non-Renewable Energy Expenses

4.3.2 Average Electricity Prices

Average electricity prices are nudged higher, mostly as a result of the higher natural gas prices. Figure 8 shows that at its highest point in 2019, average electricity prices reach 10% higher than the Reference Scenario. By 2025, though, the divergence is reduced to just 3%, 7.1 versus 6.9 cents per kWh. Electricity prices diverge more in 2019 than in 2025 because coal and natural gas prices increase more dramatically in the early years, and by 2020 prices start to converge again. Additionally, between 2019 and 2025 in the High Fuel Price Scenario natural gas's share of electric generation falls from 14% (Figure 9) to 11% (Figure 10).

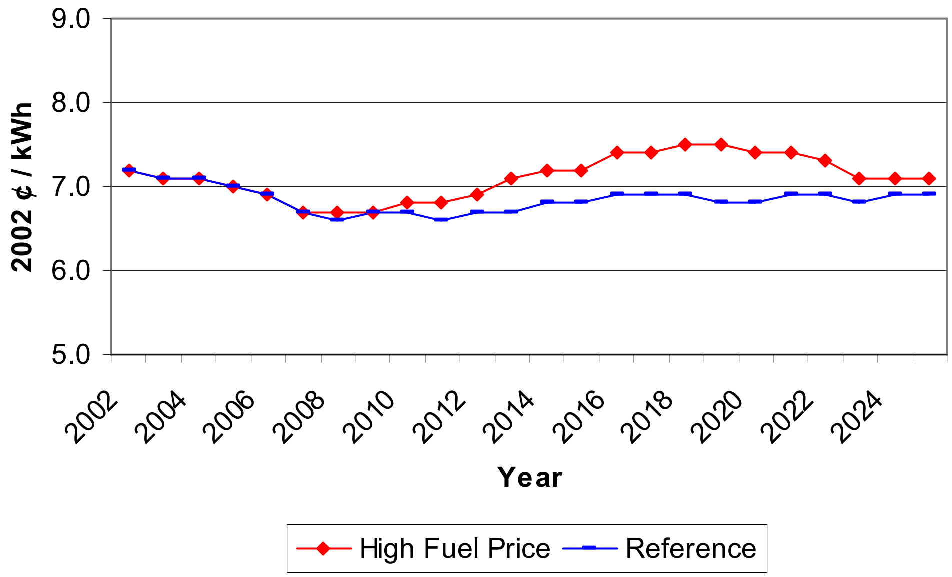

Figure 8 Average U.S. Electricity Prices

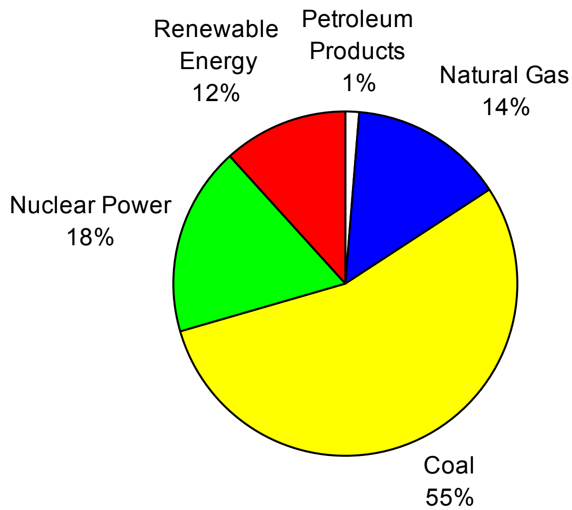

Figure 9   High Fuel Price 2019 Electricity Generating Fuel Mix

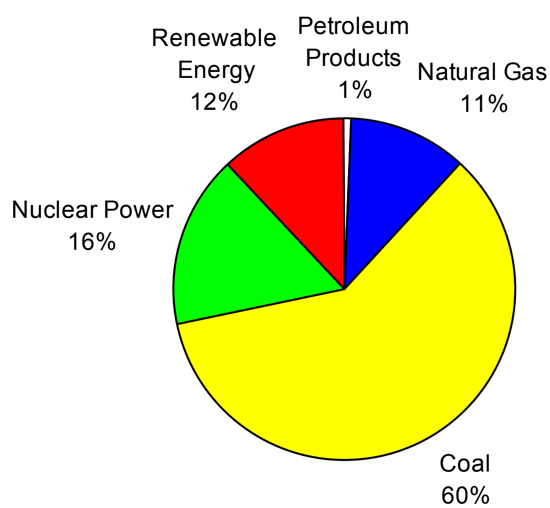

Figure 10 High Fuel Price 2025 Electricity Generating Fuel Mix

5. Carbon Cap Scenario

The Working Group wanted to implement a fairly severe carbon cap. U.S. carbon emissions are reduced to approximately 1580 million metric tons of carbon by the year 2016. After 2016, this cap is held constant through 2050, which is equivalent to stabilizing U.S. carbon emissions at roughly 2003 levels.[11] The carbon cap is implemented through a simple cap-and-trade regime and covers all energy sectors.[12]

In order to simplify potential modeling problems, the Working Group decided to institute a gradual carbon emission reduction leading to the "severe" cap; in other words, this is not intended as a surprise scenario. In this scenario, the carbon emission cap is reduced gradually between 2011 and 2016, see Figure 11.

New nuclear plants were restricted to the same contribution as in the Reference Scenario. Sequestration technology plants were available to help meet the cap. Sequestration technology available in NEMS comes in two types, either an "Advanced Coal" or "Combined Cycle" plant with sequestration. The characteristic differences of sequestration plants are that they are more expensive to build and operate, cannot be built until 2010, and remove 90% of carbon emissions. The proliferation of new sequestration capacity in this scenario does not begin until well after implementation of the cap, around 2022, see Figure 12.

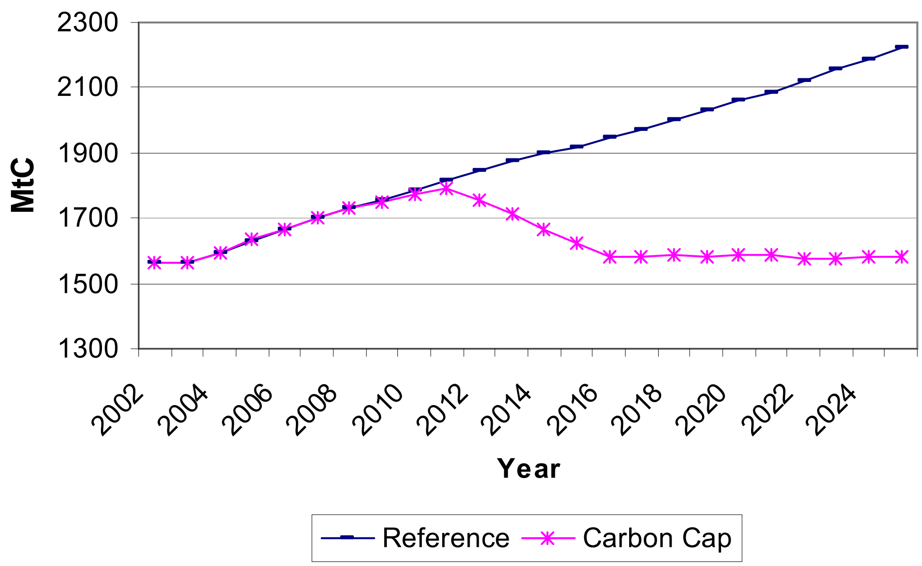

Figure 11. Carbon Emissions for Carbon Cap and Reference Scenarios

[11] Total carbon dioxide emissions in 2003 are estimated at 1578 MtC, EIA, 2005.
[12] No international offsets are employed. Market rules, such as grandfathering and lower plant-size limits, have not been implemented.

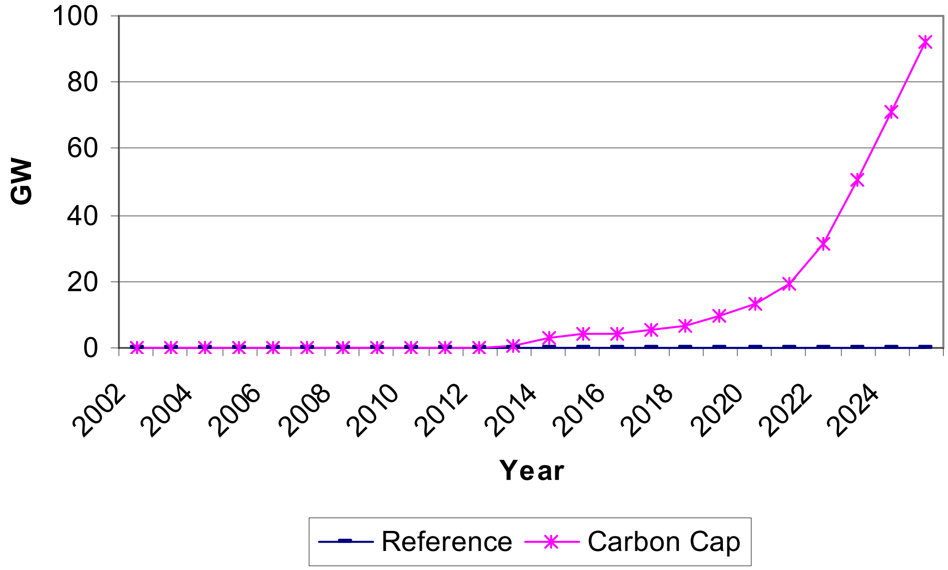

Figure 12. Cumulative Sequestration Plant Capacity Built, Coal and Combined Cycle

5.1 Carbon Allowance Price

The carbon cap leads to a non-zero market clearing price for carbon allowances, which does not exist in the Reference Scenario. Allowance prices peak at $191 per ton[13] in 2016 and then gradually moderate (Figure 13). These prices are within the range that Wiser & Bolinger (2004) identified while evaluating other carbon restricted forecasts for allowance prices.

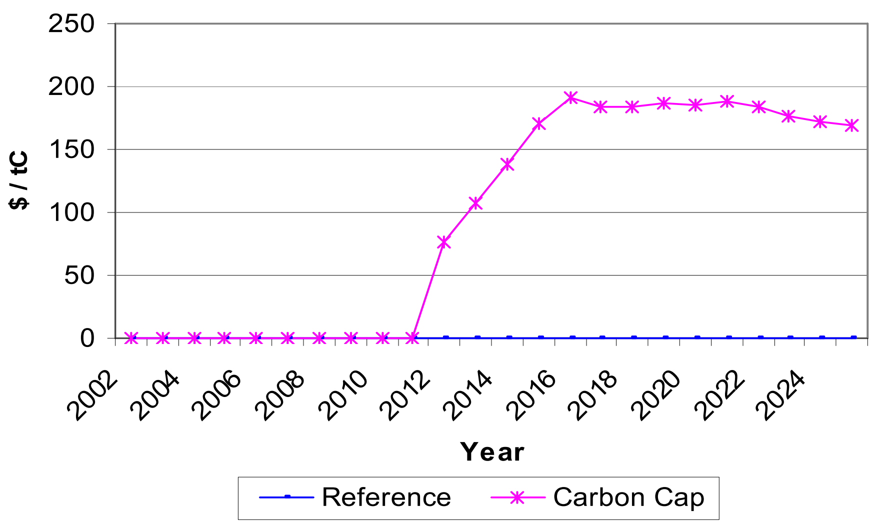

Figure 13. Carbon Emissions Allowance Price

[13] Dollars are 2002 $.

5.2 Electricity Prices

One direct effect of carbon allowance price is that average electricity prices jump about 40% as the cap is phased in. After five years electricity prices flatten out and parallel those of the Reference Scenario. Figure 14 shows the increase in electricity prices due to the 1580 MtC cap. Prices approach ten cents per kWh starting in 2016 compared to about seven cents in the Reference Scenario.

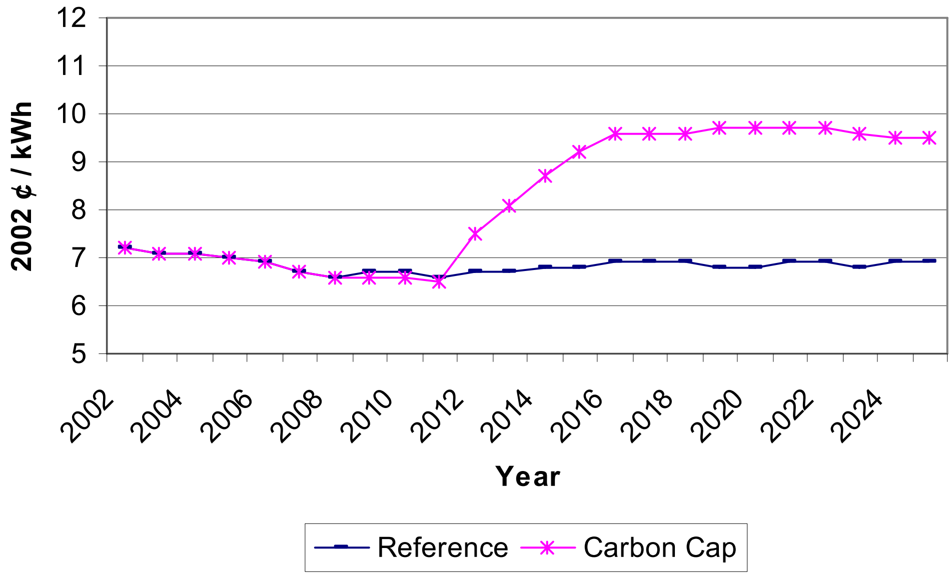

Figure 14. Average U.S. Electricity Price

5.3 Transportation Sector

Some of the most direct impacts of the carbon cap are seen in the transportation sector. Light duty vehicle gasoline consumption is reduced by 17% in 2025 in the Carbon Cap Scenario compared to the Reference Scenario. Interestingly, most of this comes from reduced driving, not from improved fuel economy. Figure 15 shows light duty miles are reduced by 15%, while Figure 16 shows that light duty fuel economy improves merely by 5% in 2025.

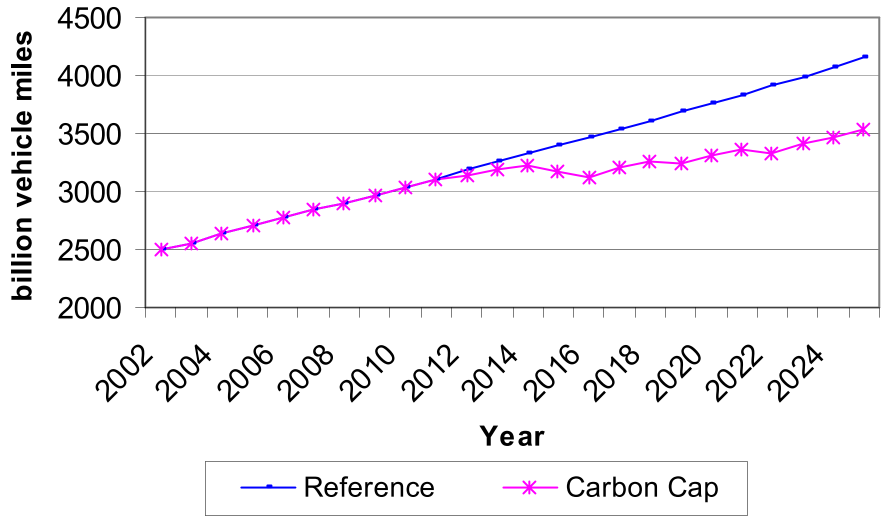

Figure 15. Total Light Duty Vehicle Miles Traveled

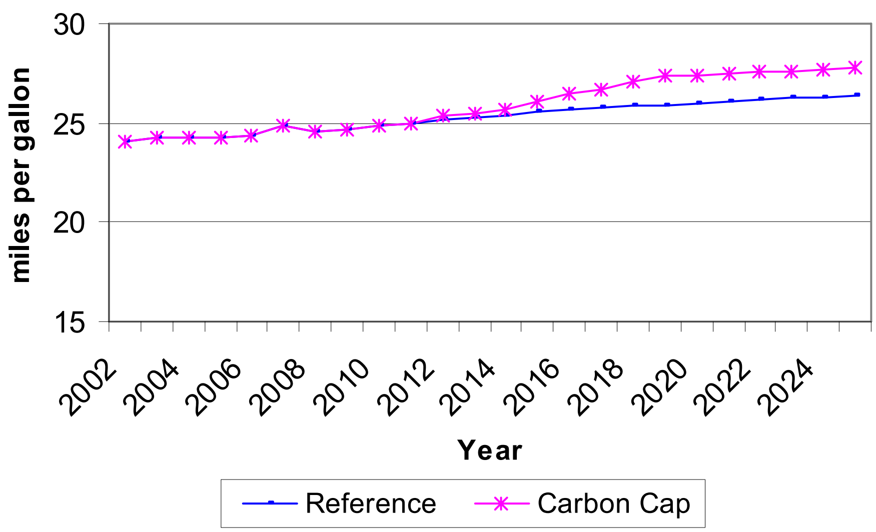

Figure 16. New Light Duty Fuel Economy

5.4 Other Results of Carbon Cap

Capping carbon emissions leads to higher national energy expenditures, (Figure 17). This is due to more expensive generating technologies (instead of coal, there are sequestration and renewable plants), and the cost of emissions allowances. Allowance prices account for between 33% and 50% of difference seen in Figure 17.

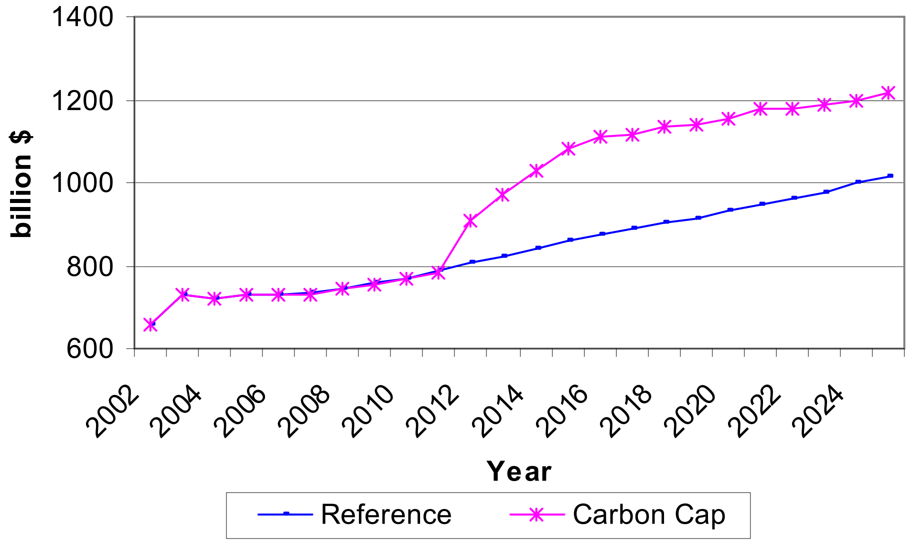

Figure 17 Total Non-Renewable Energy Expenses

With the carbon restriction, U.S. renewable capacity is almost triple the Reference Case forecast by 2025, as seen in Figure 18. Wind and biomass capacity account for over 90% of the additional capacity. The Carbon Cap Scenario forecasts slower growth in overall energy consumption, Figure 19. While natural gas and petroleum use is more or less the same, coal use is severely reduced and the large renewable growth only offsets a fraction of the coal reduction.

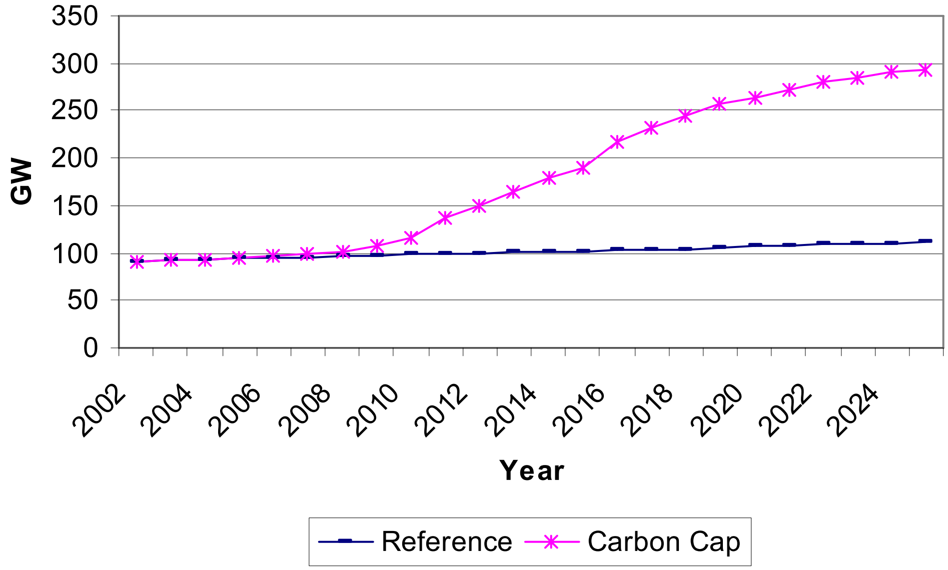

Figure 18 U.S. Renewable Capacity Forecast

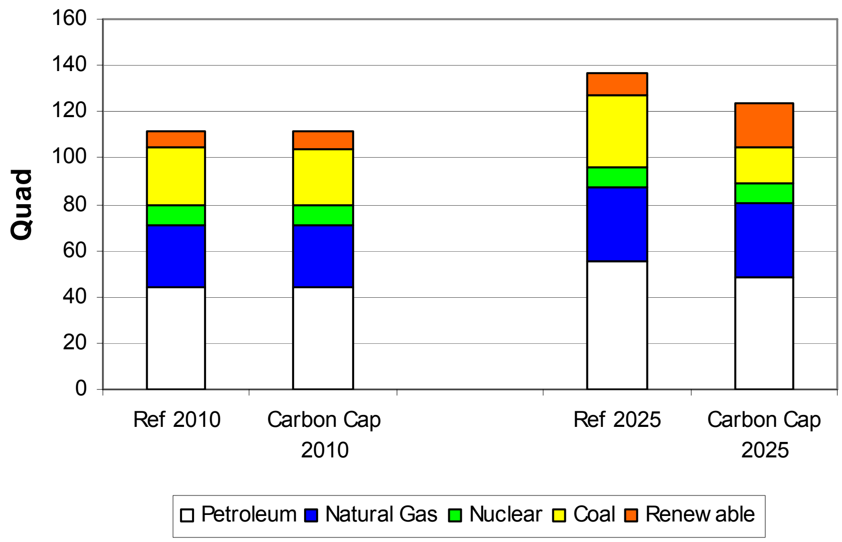

Figure 19 Total U.S. Energy Consumption

6. FE Scenarios as Developed by EIA

EIA, based on a request from FE-NETL, developed six AEO 2005 based Scenarios for FE's benefits analysis that were released in February 2005. The EIA-FE Scenarios are as follows:

Scenario 0: *FE Reference* – Updated version from AEO 2005 Reference Scenario.
Scenario 1: *Clear Skies* – Emissions targets for SO_2, NO_X, and Mercury.
Scenario 2: *Climate Change Initiative* – Electric sector carbon intensity reduction of 18%.
Scenario 3: *Severe Carbon Cap* – Carbon emissions limited to same level as NEMS-LBNL Carbon Cap and Trade Scenario.
Scenario 4: *FE High Price* – Oil and natural gas prices reach same levels as NEMS-LBNL High Fuel Price Scenario.
Scenario 5: *Very High Oil Price* – Similar to Scenario 4 except for oil prices which are increased by approximately another 20%.

The next two sections will briefly summarize the results from the two distinct groups of scenarios, the emission scenarios and the fuel price scenarios. The EIA-FE scenarios will be referred to by their number henceforth.

6.1 EIA-FE Emissions Scenarios

6.1.1 Description of Emissions Scenarios

Scenario 1 is a multiple pollutant scenario. It tries to limit sulfur dioxide emissions to 4.5 million short tons by 2010 and 3.0 million short tons by 2018. NO_X has a 33 state limit of 1.6 million short tons by 2010 and 1.3 million short tons by 2018. The mercury emission targets are 45 short tons by 2010 and 30 short tons by 2018.

Table 3 Emissions Reductions Achieved by Scenario 1 Relative to Scenario 0

	2005	2010	2015	2020	2025
SO2	24%	40%	48%	55%	59%
NO_X	25%	47%	49%	59%	60%
Mercury	8%	44%	46%	47%	46%

.
Scenario 2 has carbon emissions in the electric sector limited starting in 2009. This cap affects only the 40% of the total carbon emissions since 60% of carbon emissions come from buildings, industrial, or transportation. Table 4 shows how electric sector carbon emissions deviate in Scenario 2 from Scenario 0.

Table 4 Climate Change Initiative Electric Sector Emissions Reductions

(in MtC)	2005	2010	2015	2025	2025
Scenario 0	644	715	762	821	902
Scenario 2	645	663	637	636	635
% reduction	0%	7%	16%	23%	30%

Scenario 3, unlike Scenario 2 is carbon limited across all sectors. It is capped at 1580 Mtc starting in 2017. This scenario is almost identical to the Carbon Cap Scenario.

6.1.2 Results of Emissions Scenarios

The next four figures compare emissions of the three emission scenarios with those from Scenario 0. Figure 20 shows the relative carbon reductions for Scenarios 2 and 3. It is interesting that the multi-pollutant limits in Scenario 1 do not have any noticeable secondary effect on carbon.

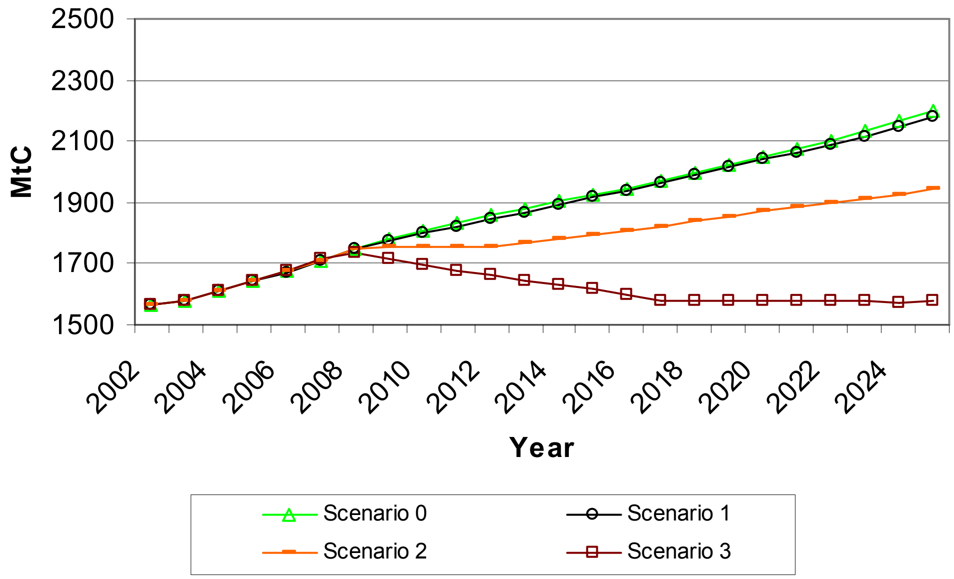

Figure 20 Carbon Emissions

Nonetheless, the carbon limits can affect the emissions of other pollutants. While Scenario 2 has identical SO_2 emissions as Scenario 0, in Figure 21, one can see that the larger carbon reductions in Scenario 3 lead to lower SO_2 emissions. This is due to the fact that coal consumption is cut in half by 2025 in Scenario 3.

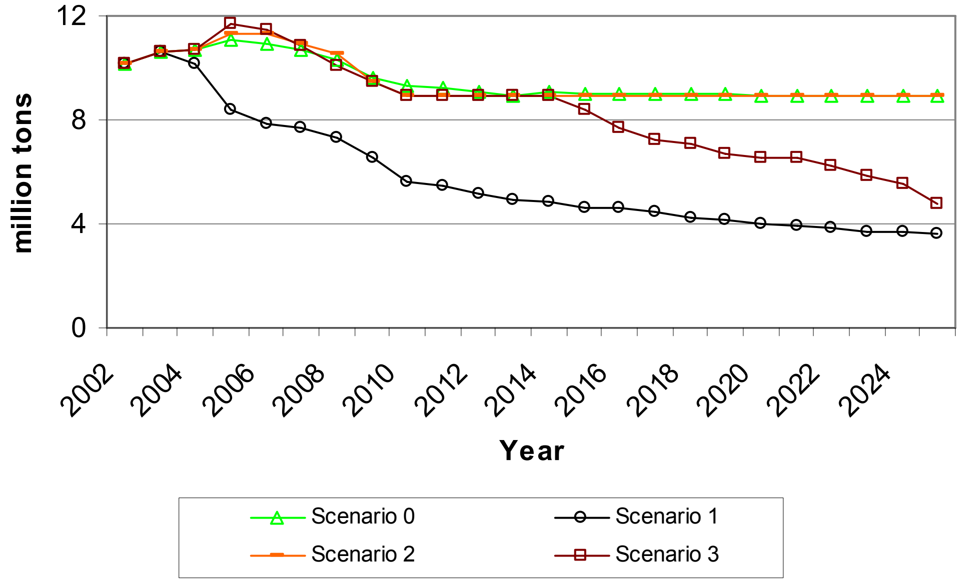

Figure 21 Sulfur Dioxide Emissions

All three emission scenarios lead to reduced NO_X emissions, as shown in Figure 22. Again Scenario 1 has the lowest NO_X emissions, followed by Scenario 3 and then Scenario 2. By the end of the forecast the NO_X, emissions are about the same in Scenario 1 and 3.

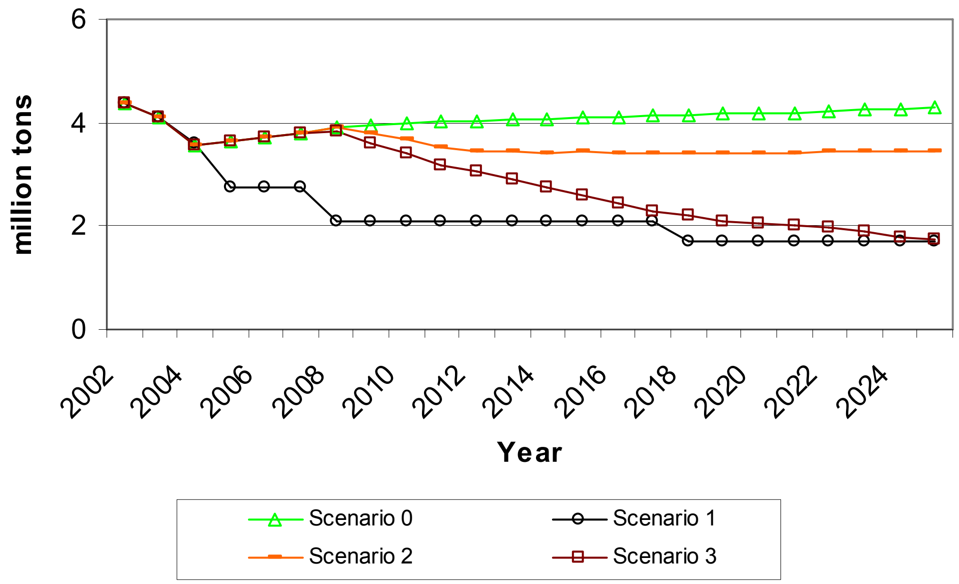

Figure 22 NO_X Emissions

The mercury emissions shown in Figure 23, below, look almost identical to the NO_x emission pattern, except that Scenario 3 surpasses Scenario 1's mercury emission target.

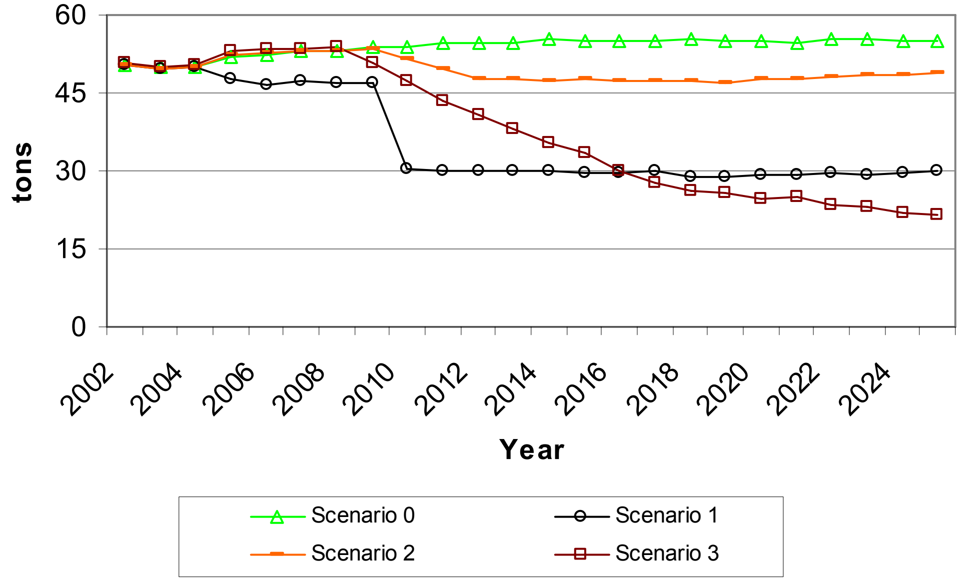

Figure 23 Mercury Emissions

Average electricity prices seem to be most influenced by carbon limits. The SO_2, NO_X, and mercury limits used in Scenario 1, while dramatic as explained above, do not lead to higher electricity prices in Figure 24. These limits lead to a lot of extra NO_X control technology and scrubbers – about 120 GW of each – but those do not in turn lead to other significant changes in the forecast.

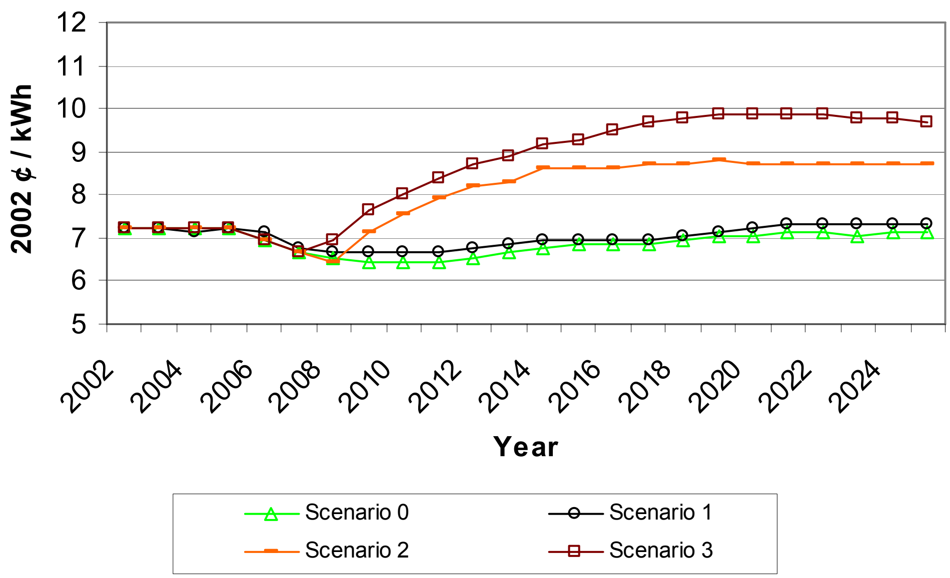

Figure 24 Average U.S. Electricity Price

Likewise Scenario 1 has no noticeable reduction in total energy consumption, shown in Figure 25. While Scenario 3's carbon reductions have a noticeable effect, Scenario 2's carbon reductions have a proportionately smaller effect on overall energy consumption.

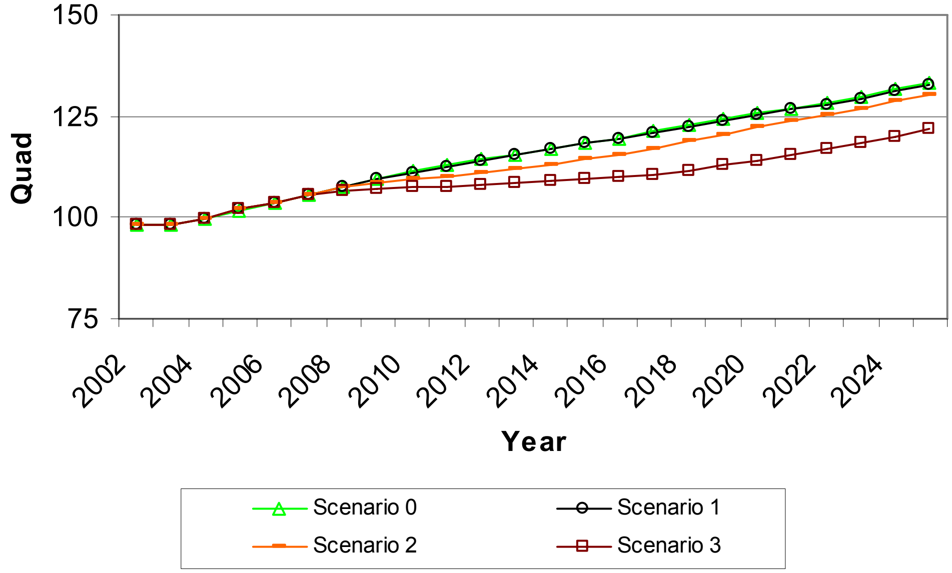

Figure 25 U.S. Total Energy Consumption

Renewable capacity growth, shown in Figure 26, follows the same pattern as most of the other results from these emission scenarios. Only a carbon cap leads to more renewable capacity and the more extreme the case the more growth.

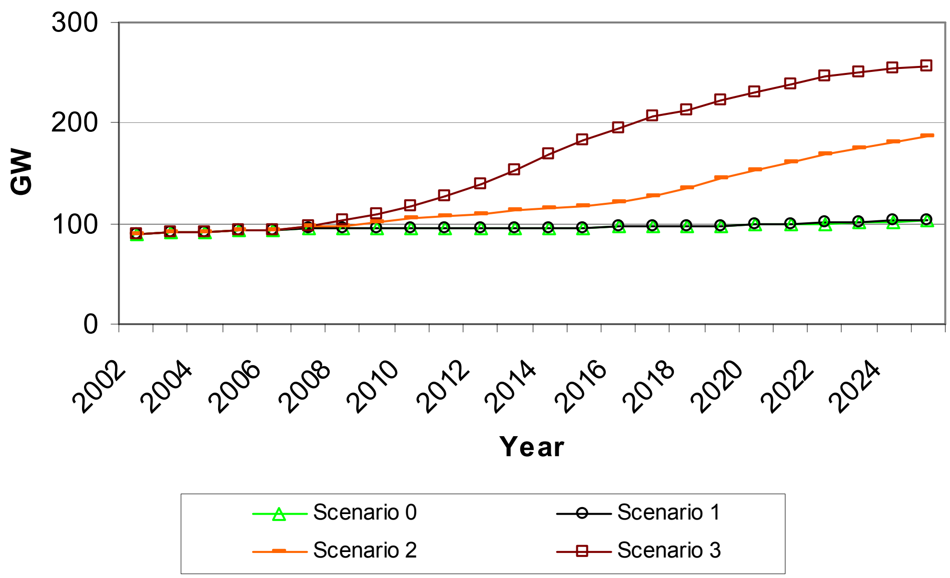

Figure 26 U.S. Renewable Capacity Forecast

6.2 EIA-FE Fuel Price Scenarios

6.2.1 Description of Fuel Price Scenarios

Scenario 4 uses the same price targets as the High Fuel Price Scenario. Those targets were described in section 4, though the implementation is different. Scenario 5 uses a world oil price target that hits about eight dollars higher than Scenario 4 does, as seen below in Figure 27.

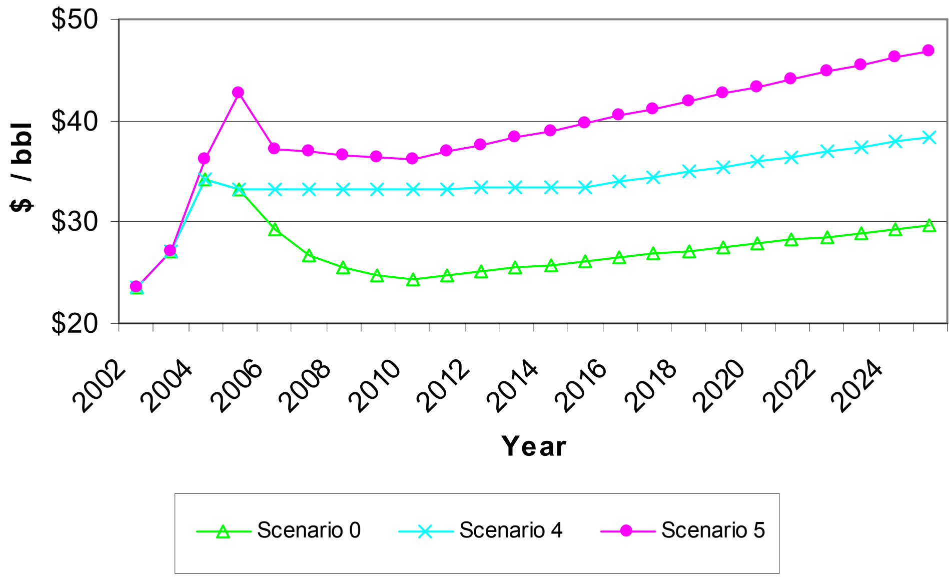

Figure 27 World Oil Price in Scenarios 0, 4 and 5

The natural gas wellhead price in Scenario 4 and 5 are virtually identical, shown below in Figure 28. There does not seem to be any secondary effects in NEMS that has the higher world oil prices disturbing the wellhead price solution.

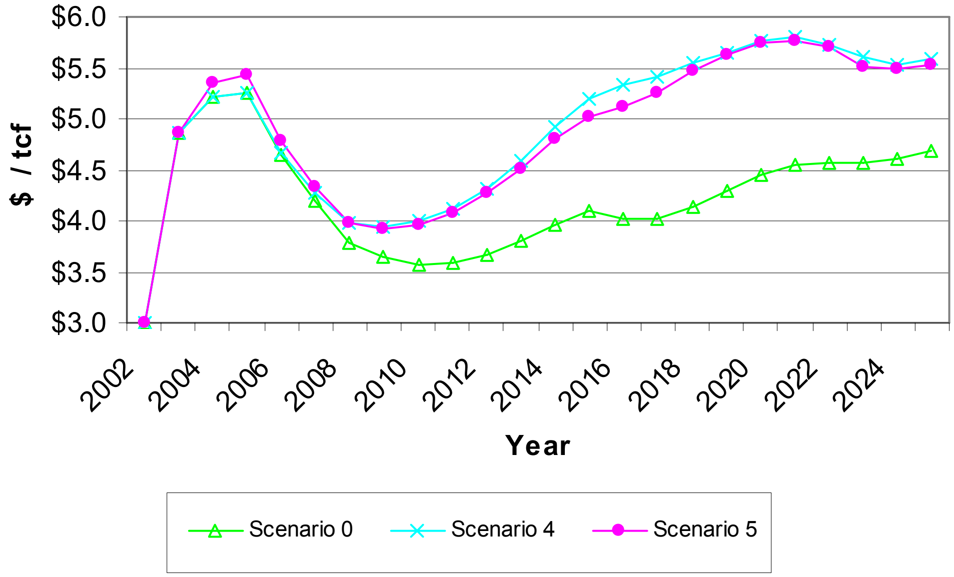

Figure 28 Natural Gas Wellhead Price in Scenarios 0, 4, and 5

6.2.2 Results Fuel Price Scenarios

The fuel price scenarios have almost no effect on total capacity and renewable capacity forecasts. Even the reduction in annual consumption, shown below in Figure 29, is slight, even less than seen in Figure 6 earlier. Electricity prices increase similarly in both Scenario 4 and 5, which is seen in Figure 30.

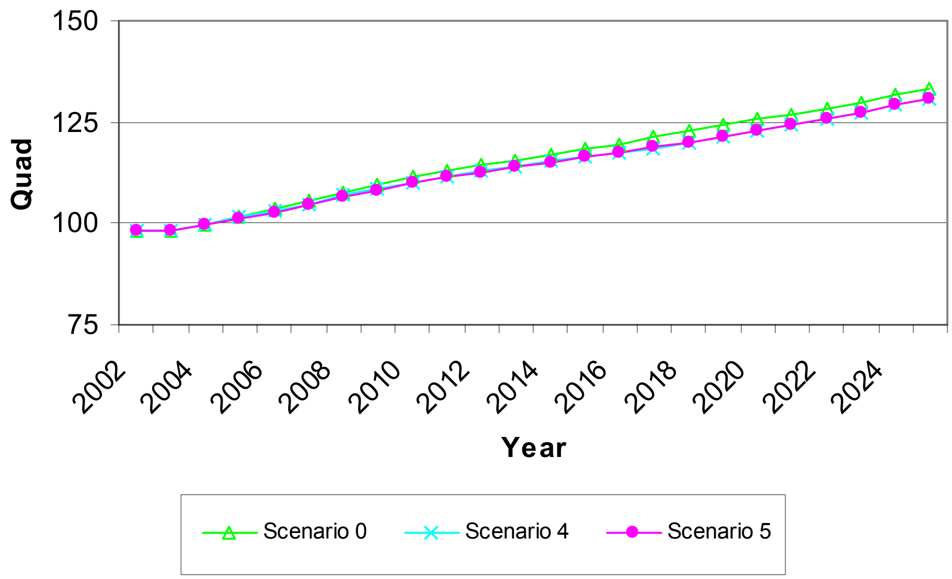

Figure 29 Total Energy Consumption in Scenarios 0, 4 and 5

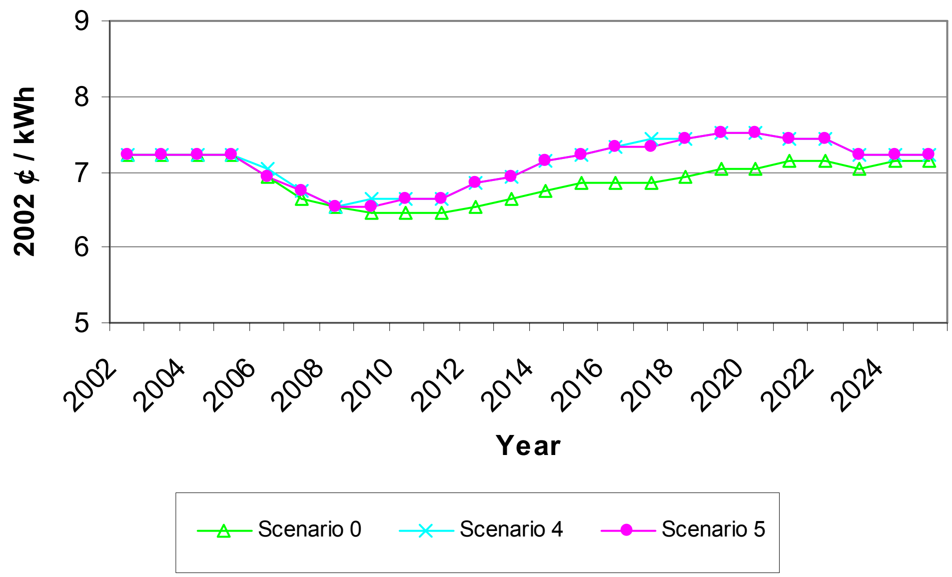

Figure 30 Average U.S. Electricity Price in Scenarios 0, 4, and 5

As was the case with the High Fuel Price Scenario (Figure 7), non-renewable energy expenditures increase in Scenarios 4 and 5, which is seen in Figure 31.

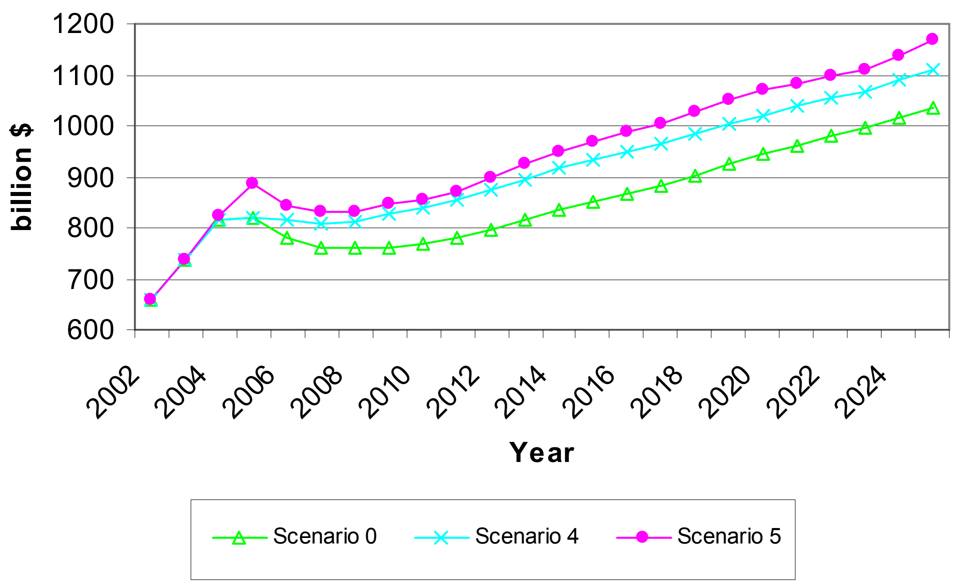

Figure 31 Total Non-Renewable Energy Expenses in Scenarios 0, 4, and 5

7. Comparing EIA-FE Scenarios and Berkeley Lab Scenarios

The EIA-FE scenarios all have many differences from the Berkeley Lab scenarios, because they were based on files about 9 months more recent. A short comparison of AEO 2005 and AEO 2004 will precede comparisons of Berkeley Lab and EIA-FE's scenarios.

7.1 Comparing AEO 2005 and AEO 2004 Reference Scenarios

Scenario 0 is very similar to AEO 2005 Reference Scenario and Section 3.1 explained how similar the Berkeley Lab Reference Scenario and AEO 2004 are. Therefore the major fundamental differences between Scenario 0 and Berkeley Lab's Reference Scenario mirror the differences between AEO 2005 and AEO 2004 Reference Scenarios.

The major demand-side differences in AEO 2005 when compared to AEO 2004 are laid out in Table 5:

Table 5 Key Demand-Side Indicators that Have Changed Since AEO 2004

	AEO 2005 Value 2025	**AEO 2004** Value 2025	**AEO 2005** Growth Rate (2003-2025)	**AEO 2004** Growth Rate (2002-2025)
Residential Households (millions)	142.5	137.8	1.1%	1.0%
Commercial Floorspace (billion square feet)	104.8	101.8	1.7%	1.5%
Industrial Shipments (billions $96)	$8469	$9491	2.3%	2.6%
Light-Duty Vehicle Miles (billion miles)	4053	4173	2.0%	2.2%

Note: All values from EIA, 2004b and EIA, 2005

The fuel price forecasts represent the other major differences in AEO 2005 relative to AEO 2004. Table 6 shows that fossil fuel prices start much higher early in the forecast about 40% for oil and natural gas, 5% for coal. By the end of the forecast, AEO 2005 has all of these prices between 5% and 10% higher.

Table 6 Key Price Differences since AEO 2004, at Beginning and End of Forecast

	AEO 2005, 2005	**AEO 2004,** 2005	**AEO 2005,** 2025	**AEO 2004,** 2025
World Oil Price ($ / bbl)	33.23	23.30	29.63	27.00
Natural Gas Wellhead Price ($ / tcf)	5.18	3.54	4.68	4.40
Coal Minemouth Price ($ / ton)	18.19	17.24	17.85	16.57

Note: All dollars are 2002 $

These higher fuels prices in AEO 2005 lead to lower consumption and make the whole forecast slightly different in every regard.

7.2 Scenario 4 Compared to High Fuel Price Scenario

Scenario 4 and the High Fuel Price Scenario hit the same fuel price targets for 2015 and 2025, though Figure 32 shows how different the forecasts are for oil prices. As stated in the previous section, the EIA-FE scenarios have higher prices, particularly in 2004 through 2007. The other major difference is that Scenario 4 has an elevated oil forecast starting in 2006 while the High Fuel Price Scenario does not begin to elevate until 2010.

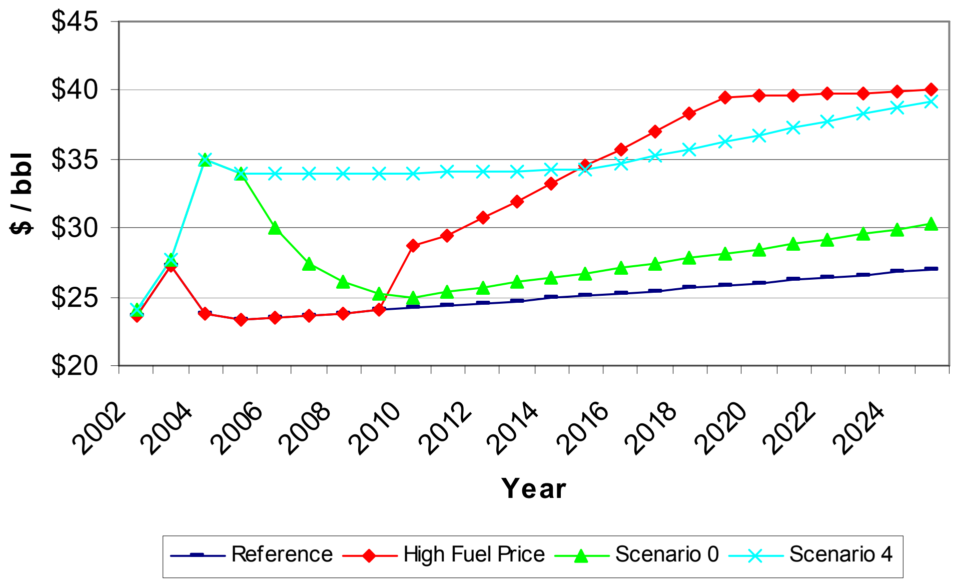

Figure 32 World Oil Price Comparison

Figure 33 shows that both Scenario 4 and the High Fuel Price Scenario project similar natural gas wellhead forecasts beyond 2011. Once again, the discrepancy in the earlier year's forecast is due to the fact that AEO 2005 projects natural gas prices staying higher in the short-term.

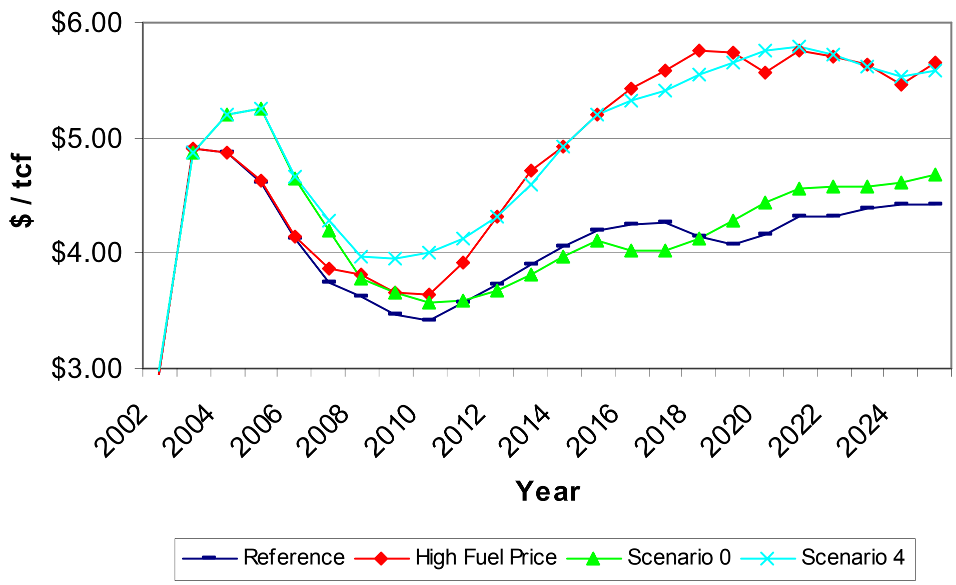

Figure 33 Natural Gas Wellhead Price Comparison

7.2.1 Results Comparison

Most of results of the High Fuel Price Scenario that were shown in Section 4.3 are equivalent for Scenario 4, i.e. total domestic energy consumption and average electricity prices (Figures 6 and 8 above). The most different one is energy expenses, shown in Figure 34. The discrepancy parallels the differences in world oil price between the two forecasts. In the target years, 2015 and 2025, the energy expenses are pretty close to the same, in the interim Scenario 4 is lower, and from 2006 to 2011 expenses are higher. The conclusion drawn is that the different starting point and trajectories taken to hit the world oil price targets are mostly responsible for the energy expenditure differential not other variations in assumptions between the scenarios.

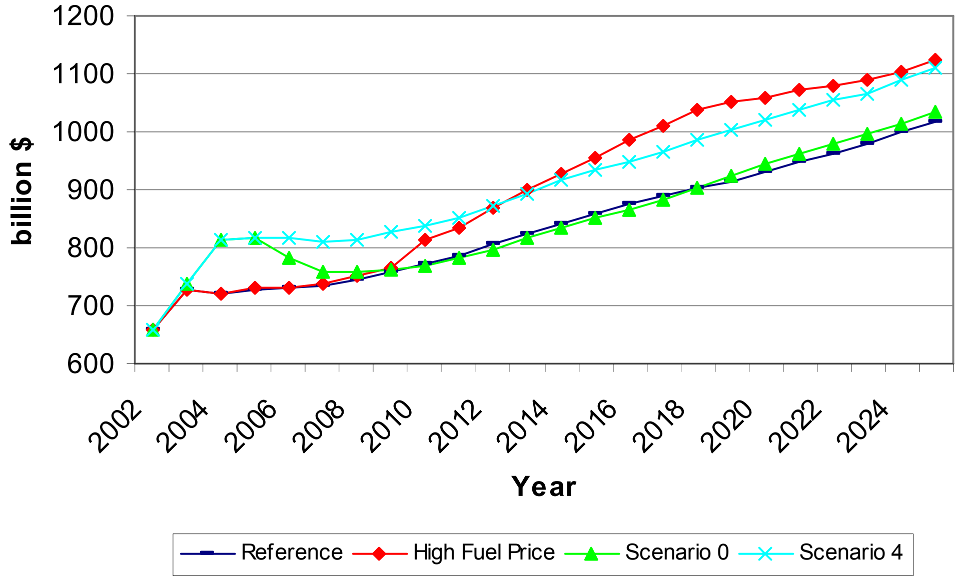

Figure 34 Non-Renewable Energy Expenses Comparison

7.3 Scenario 3 compared to Carbon Cap Scenario

Scenario 3 has the same carbon emissions target as the Carbon Cap Scenario. However, the cap starts to be phased in a few years earlier, as shown in Figure 35. The other noticeable difference between these scenarios is that Scenario 3 allows for nuclear plant builds beyond what Scenario 0 forecasts. Table 7 shows how much higher the nuclear growth is in Scenario 3; four gigawatts (GW) higher in 2015, up to 41 GW higher in 2025.

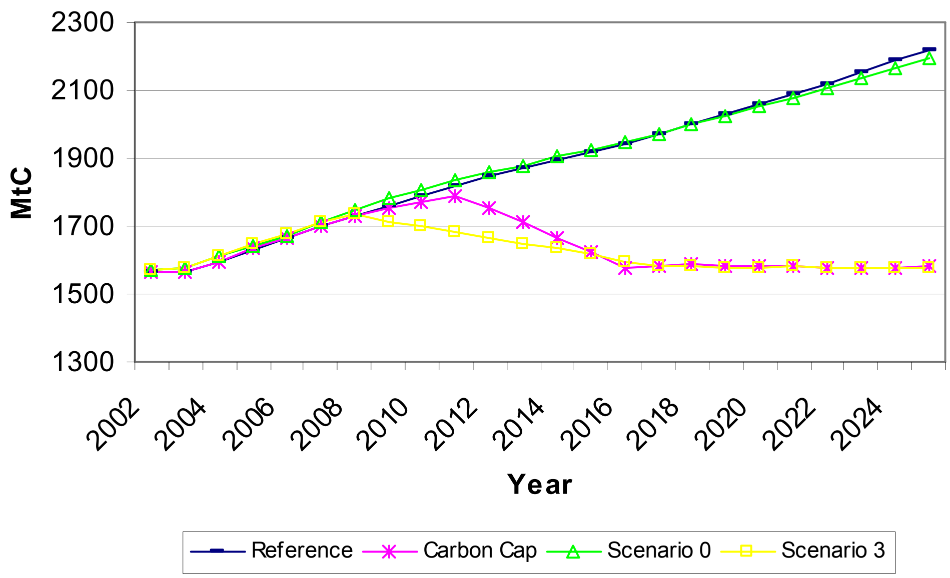

Figure 35 Carbon Emissions Comparison

Table 7 U.S. Nuclear Capacity Growth Comparison, (GW)

	2005	2010	2015	2020	2025
Reference	100	101	102	103	103
Carbon Cap	100	101	102	103	103
Scenario 0	100	101	102	103	103
Scenario 3	100	101	106	118	144

Even with the difference in nuclear capacity growth, Scenario 3 and the Carbon Cap Scenario are very similar. Figure 36 shows the capacity difference by technology group between each set of carbon and reference scenarios for 2025. For example, Scenario 3 has about 50 GW more sequestration capacity in 2025 than Scenario 0, while the Carbon Cap Scenario has 273 GW more renewable and sequestration capacity combined and 282 GW less fossil and other capacity in 2025 than the Reference Scenario. The net capacity change is pretty similar in both sets of scenarios.

The NEMS supply-side technologies that are zero or low carbon emitting technologies are renewables, nuclear, and sequestration. When looking at capacity growth of these three categories together, the nuclear growth in the EIA scenarios is offset by more renewable and sequestration capacity in the Berkeley Lab scenarios.

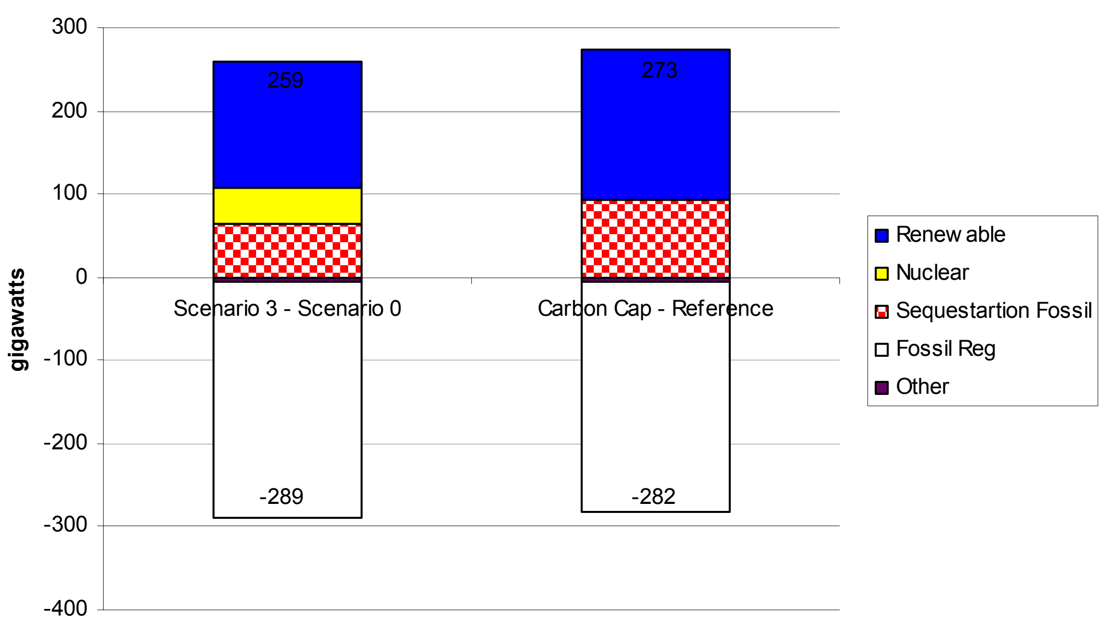

Figure 36 Comparison of Capacity Growth Difference: Forecasts for 2025

Most everything else is barely indistinguishable between Scenario 3 and the Carbon Cap scenario. Figure 37 shows the fuel consumption forecasts. The slopes of these scenarios are strikingly similar to those of the carbon emissions seen in Figure 35. The total non-renewable energy expenses are more different but that is generally during the periods where the cap is phased in differently, note Figure 38.

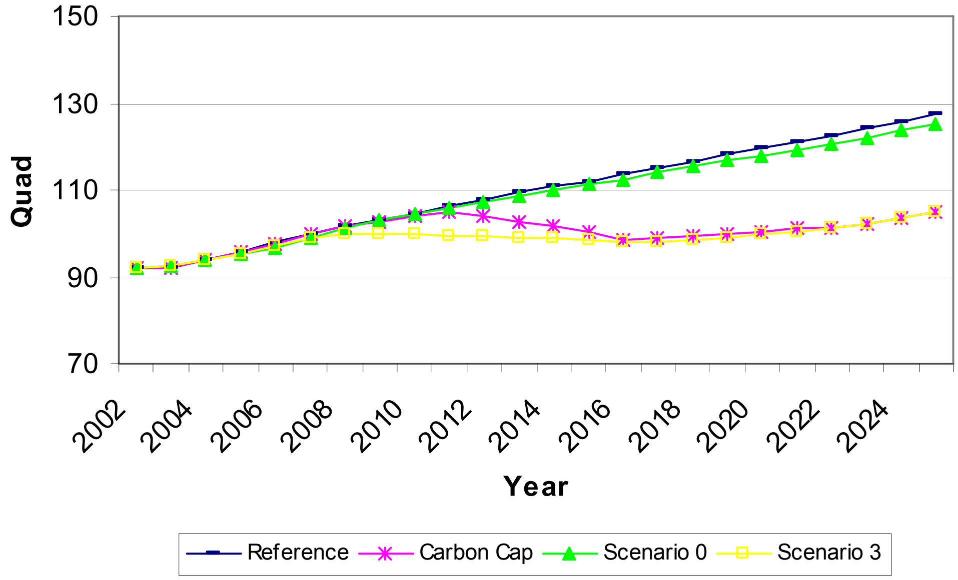

Figure 37 Total Fuel Consumption Comparison

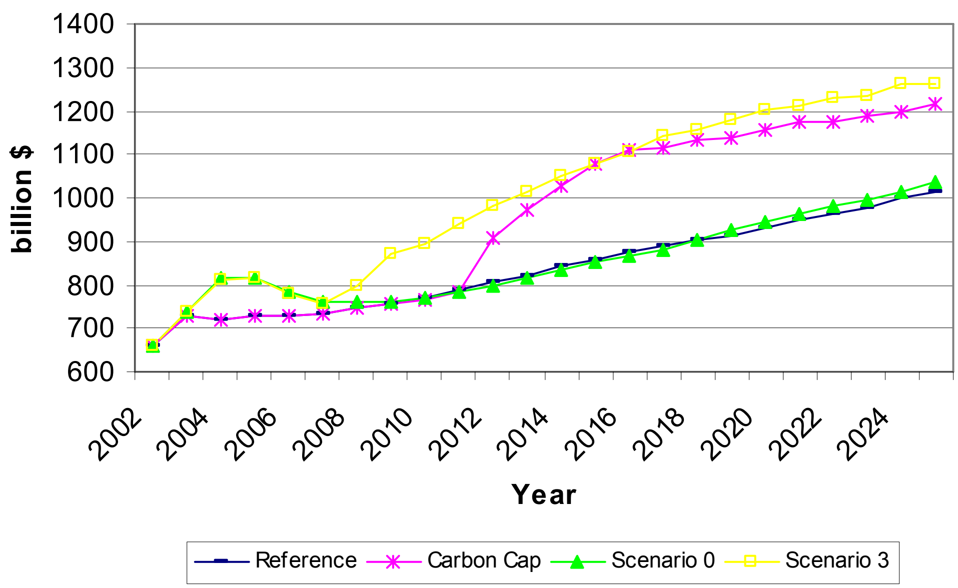

Figure 38 Total Non-Renewable Energy Expenses Comparison

A notable difference that will require further evaluation is that EIA has achieved quicker convergence with the newer version of the model. The source of this improvement is not currently known. Therefore, determining the appropriate convergence criteria for a carbon constrained scenario is a priority for the future use of NEMS-LBNL.

7.4 Summary of Differences between EIA and Berkeley Lab Scenarios

The scenarios designed by EIA for FE are distinct from the Berkeley Lab scenarios. The most fundamental difference is that the EIA-FE scenarios are based on AEO 2005 while Berkeley Lab scenarios are based on AEO 2004. The implementation of both Carbon Scenarios is fairly similar, but the High Fuels Scenarios, which were more difficult to execute, had more differences. Nonetheless, the results of the corresponding EIA-FE scenarios seem reasonably consistent overall with those from the Berkeley Lab scenarios.

These scenarios are just Static Cases. Even though most indicators shown in this report suggest that the results are similar, the GPRA analysis measures the sensitivity of these results not the absolute values. While there is no indication that the sensitivity of any of the metrics reported herein differs between Berkeley Lab and EIA-FE scenarios, such a conclusion has not been substantiated.

8. Conclusions

This work was inspired by an interest in quantifying the uncertainty associated with energy forecasting. Looking at a small sample of alternative futures some conclusions can be drawn that apply within the range that was examined.

- The dramatic price changes in the Higher Fuel Price forecast had limited affects on results. According to NEMS-LBNL price uncertainty leads only to limited changes in consumption. In other words, energy demand is price inelastic, for oil and natural gas prices.
- A future with emissions caps shows a wider range of results.
- The scenarios created by EIA and Berkeley Lab are notably different, however that is mostly because EIA's were based on AEO 2005 and Berkeley Lab's were based on AEO 2004.
- The emissions reductions in Scenario 1 may affect control technology and allowance prices but do not lead to different energy quantity results.
- The EIA and Berkeley Lab implementations of High Fuel Price and Carbon Cap Scenarios have noticeable differences, yet overall results are similar.

9. Next Steps

The immediate follow-up to this work will be several DOE offices reviewing the scenarios and EE picking which if any scenarios to use in their GPRA-07 analysis that is in progress. There are no compelling reasons to avoid using the EIA scenarios, the results seem to be consistent with Berkeley Lab scenario results, and Berkeley Lab scenarios would still need to be added to AEO 2005 for use this year.

Another step that will be taken shortly in the EE GPRA process is the setting up of the Baseline and Program Reference Cases. These cases can show the effects of this sort of uncertainty on the benefits analysis.

Also, a project looking at a wider representation of alternative energy futures will be commencing shortly at Berkeley Lab. This is an attempt to enumerate fundamental structural differences to the Reference Scenario future.

10. References

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Appendix A. Changes to Reference Case-r2

Note: This was sent via email by Andy Kydes, EIA

Updates to the AEO2004 Reference Case
May 5, 2004

The majority of the changes listed below had minor to negligible impacts on the revised AEO2004 reference case.

STEO Benchmarking

The natural gas end-use and wellhead prices, pipeline, lease, and plant fuel, balancing item, and imports were benchmarked to the March 2004 Short-Term Energy Outlook through 2005 rather than the September 2003 version through 2004. Benchmarking of the import levels (primarily Canada) required some minimal parameter adjustment which had some longer-term impact.

The higher STEO-year prices caused the onshore conventional drilling levels to increase above current expectations. The drilling equations were adjusted to provide levels consistent with history.

The 2002 historical values for residential and commercial natural gas consumption and prices were updated.

Liquefied Natural Gas

Instead of setting earliest start years for regasification capacity increments exogenously, they were set endogenously based on when the previous incremental capacity step came online in a given region. In a high demand case, the earliest start years were shortened by a year. Three more 1 Bcf/d potential plants were added to each of the two Gulf regions in the event of a high demand case.

Alaska Consumption

Forecast values for supply/demand discrepancy in Alaska were set to the average over the last 7 historical years rather than just the last year. Industrial consumption in Alaska was set to an historical average rather than use an estimated equation.

Alaska and MacKenzie Pipelines

The weighted-average return on capital was set endogenously rather than exogenously for setting pipeline rates on both the Alaska and MacKenzie Delta pipelines to Alberta. The percent expansion on the Alaska pipeline was lowered from 23 to 22 percent. The initial volumes on the MacKenzie pipeline were lowered from 1.5 bcf/d to 1.2 bcf/d and adjustments were made for pipeline fuel use. The MacKenzie pipeline was allowed to expand by 58 percent rather than 23 percent to match announced estimates. The risk associated with an anticipated price drop due to the introduction of the pipeline was lowered from $0.23 to $0.10 per Mcf in 2001 dollars. The trigger price for a MacKenzie expansion was lowered by $0.02/mcf.

Natural Gas End-Use Margins
The growth factor on the natural gas price margins to electric generators was lowered slightly to reflect slightly lower consumption.

Offshore Deep Eastern Gulf Royalty Rate
There was a typo in the royalty rate used for projects in the deep waters of Eastern Gulf of Mexico. The royalty rate has been corrected. This correction does not impact the results since the deep waters of the Eastern Gulf of Mexico [are] under drilling moratoria -- no wells are drilled in this region. However, the correction was made in case you wanted to run sensitivity cases that might affect drilling in this area.

Royalty Relief of Deep Wells in the Shallow Waters of the GOM
The provisions from the *Oil and Gas and Sulphur Operations in the Outer Continental Shelf - Relief of Reduction in Royalty Rates - Deep Gas Provision* (30 CFR Part 203) were incorporated. Royalty rates were adjusted for wells deeper than 15,000 feet in the shallow waters of the Gulf of Mexico.

Representation of "Access" to Unconventional Gas Resources

There were 2 changes to the "access" representation in the AEO2004 Reference Case which tended to offset each other in the reference case as confirmed by later testing. Although their effect on overall model results was minimal for AEO2004, both of these adjustments were made so that future cases involving access issues could be appropriately addressed.

Update the Plant File
We updated the plant file to reflect Browns Ferry 1 returning to service in 2007, since the AEO2004 reference case inadvertently left it out of service for the entire forecast. A few minor changes were made in the scheduling of nuclear uprates, which were incorrect in the AEO2004 and resulted in slightly lower generation in the uprate year.

Coding Corrections
A few additional minor changes were made: we changed the value of the PTC subsidy from 18.9 cents/kWh to 20.4 cents/kWh (1987$) because incorrect tax rate was used when calculating the after-tax value of the PTC. We also benchmarked the year 2002 SO_2 allowance bank so the model could start with quantities from the latest historical year. A report writer error on accumulating retirements was corrected.

All of the previously listed changed were provided in the version of the model delivered on April 22, 2004, an additional set of changes were provided on May 5, 2004. We corrected and overwrite error in the planning module for the last few years of the planning horizon for mercury and NO_x cases. The correction has at most a minor impact on the results delivered but may be more significant in sensitivity cases you may run.