Estimating the DOE Office of Fossil Energy's R&D Program Benefits

FY2003 Summary Report

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The DOE/NETL is responsible for providing the FE technology performance assumptions to NEMS, for performing the series of sensitivity runs using the NEMS model, and for calculating the benefits based on the NEMS results. The conclusions in this report are the result of a DOE/FE/NETL effort and do not necessarily reflect the view of EIA.

Table of Contents

Executive Summary

Background

The Department of Energy's (DOE) Office of Fossil Energy (FE) conducts research and development (R&D) in coal and other power systems, carbon sequestration, hydrogen and clean fuels, and oil and natural gas supply and delivery. Federally funded R&D efforts are justified on the basis that they provide public benefits in excess of the costs of the R&D, and that there is a legitimate government role. In the past, each FE R&D program developed benefit estimates independently, using their own method. This made it difficult to evaluate and compare benefit estimates for different programs, or ensure that the benefits estimates were developed on a common basis. In recent years, Administration and Congressional initiatives have placed special emphasis on justifying R&D programs using uniform, transparent, and rigorous models to forecast program benefits.

This report describes the first annual FE effort to estimate its R&D program benefits using consistent, credible modeling approaches for all FE R&D programs. This task was a joint effort between FE's National Energy Technology Laboratory (NETL) and FE Headquarters. DOE's Energy Information Administration's (EIA) National Energy Modeling System (NEMS) was the primary tool used to estimate FE R&D impacts and benefits. NEMS is the modeling framework used to produce EIA's Annual Energy Outlook (AEO) as well as studies commissioned by the U.S. Congress. FE was responsible for supplying the input parameters for the NEMS runs used in this analysis. These parameters are based on current program goals or are determined with the use of in-house models. Although the EIA configured NEMS to reflect the scenarios selected for this analysis, the results and conclusions of this study are solely those of the DOE's Office of Fossil Energy.

Study Approach

This study analyzed three scenarios:

1. The Clear Skies Initiative as represented in the U.S. Senate's Clear Skies Act of 2003, Senate Bill 485 (Scenario 1)

2. The Clear Skies Initiative with higher oil prices and constrained natural gas supplies, resulting in higher natural gas prices (Scenario 2)

3. The Clear Skies Initiative with the Administration's Climate Change Technology Initiative goal of an 18 percent reduction in greenhouse gas (GHG) intensity by 2012. (Scenario 3)

For each NEMS scenario, this assessment considered two cases. Under the first, DOE R&D support is assumed to be terminated after FY2003. For the other, DOE R&D is assumed to continue and all current R&D performance goals and technology deployment schedules are met. The benefits from DOE R&D are represented by the differences between these two cases:

1. “A” Cases (No FE R&D)
   Assumes FE R&D funding stops after FY2003 resulting in a delay in commercialization of a technology, or a decline in the pace of improvement in technology performance.

2. “B” Cases (with FE R&D)
   Assumes R&D funding levels remain at sufficient levels such that FE Program cost and performance goals are achieved on schedule, resulting in earlier market entry of advanced technologies, and/or a more rapid pace of improved technology performance, than that which would have occurred with industry support alone.

NEMS forecasts the changes in oil and gas production, oil imports, technology market penetration, carbon intensity, fuel prices, etc. that result between Cases “A” and “B.” The changes between these two cases are the basis for estimating benefits from FE’s R&D programs.

Environmental benefits of FE’s advanced energy technologies are realized in terms of lower energy costs for U.S. consumers. This is because the scenarios examined in this study use market-based, cap-and-trade approaches to set limits on national emissions of SO_2, NOx, mercury (Hg), and CO_2. These caps are applied to all scenarios and cases, requiring that they achieve the same emission limits. NEMS forecasts the reduction in energy prices resulting from the implementation of FE R&D clean energy technologies. Using these reductions in fuel and electricity costs, economic benefits for FE’s R&D programs can be calculated.

Fossil Energy Program Elements

Both FE’s Oil and Gas Delivery and Supply Research (O&G) and the Coal and Other Power Systems (CPS) Programs were evaluated in this analysis.

Oil and Gas Delivery and Supply R&D Program

In the case of FE O&G R&D, this benefit exercise focused primarily on program activities targeting oil and gas exploration and production (E&P) technologies. For conventional oil and gas resources, O&G program performance was modeled in NEMS by modifying a variety of parameters, including E&P capital and operating costs, well deliverability rates, the pace of adding oil and gas reserves in discovered fields, new well finding rates, and drilling success rates. These input assumptions in NEMS were adjusted to be consistent with those used in comparable runs of FE’s existing oil and gas modeling tools (TORIS and GSAM)[1]. Both existing technology and technological advances were represented by these parameters in NEMS. For unconventional natural gas, similar technology progress levers in NEMS were adjusted to represent the difference between the AEO Reference Case and the No FE R&D Case (Case A).

The O&G benefit estimates are based only on existing program areas as of the FY2002 budget. As such, a number of R&D areas that pertain to expanded or new activities in budgets proposed for FY2003, FY2004, and/or FY2005 were not addressed in this study. Analyses were performed based on two budget levels for the O&G program and the time of the analysis – the proposed FY2004 budget and FY2005 budget levels. Since the originally proposed oil and gas

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[1] TORIS = Total Oil Recovery Information System
GSAM= Gas Systems Analysis Model

E&P program FY2005 budget at the time of the analysis was approximately the same as that for comparable areas in the FY2002 program, it was assumed that the parameter adjustments in NEMS determined for a previous FY2002 case would be applicable for determining program benefits for a proposed FY2005 budget scenario.

Coal and Other Power Systems R&D Program

In the case of the CPS program, the advanced coal plants technology areas modeled include: gasification, sequestration, fuel cells, turbines, and innovations for existing plants. Alternate budget scenarios were not assessed in the analysis. Instead, CPS FY2003 budget levels are assumed to continue at sufficient levels such that all R&D performance goals and technology deployment schedules are met.

CPS program cost and performance values are a modification of the AEO2003 Reference Case. For the with FE R&D case (Case B), the more aggressive performance goals of the CPS program (targets for timing, efficiency, and environmental performance) were overlaid on the AEO2003 Reference Case. The performance values for the No FE R&D (Case A) were determined by delaying by some number of years the cost and performance values of the with FE R&D case (Case B). This assumes that the FE cost and performance goals are eventually met by industry; however, without support from the FE R&D program, it takes longer to achieve the same goals. The number of years to delay a technology's cost and performance was selected on a case-by-case basis, and ranges from five to fifteen years.

FE R&D Benefits

FE R&D benefits are estimated by evaluating the changes between "A" and "B" cases in the NEMS forecasts for each scenario. The difference between these cases is a direct result of FE's R&D Program. Table E.1 lists the impact in 2012 and 2025 of the R&D program on electricity and natural gas prices, oil imports, power generation from coal and natural gas, energy expenditures, and carbon emissions. Table E.2 contains a summary of the monetary benefits that result from these impacts.

Economic Benefits

As illustrated in Figure E.1, the FE R&D program results in significant monetary public benefits. Cumulative economic benefits by 2025 range from $450 to $640 billion (2002 dollars), depending on the scenario. These savings are the result of reduced electricity and natural gas prices. Note that these benefits are based on the DOE's FY2005 budget proposal at the time of the analysis.

it is clear that FE R&D results in energy expenditure savings in all scenarios. The high efficiency of advanced power generating technologies and the resulting increased gas and oil production reduce both cost of electricity and natural gas. Increased production of natural gas contributes to lower gas prices, and increased production of oil reduces U.S. expenditures for crude oil imports by at least $9 billion annually (Figure E.2).

TABLE E.1 SUMMARY OF FE R&D PROGRAM IMPACTS

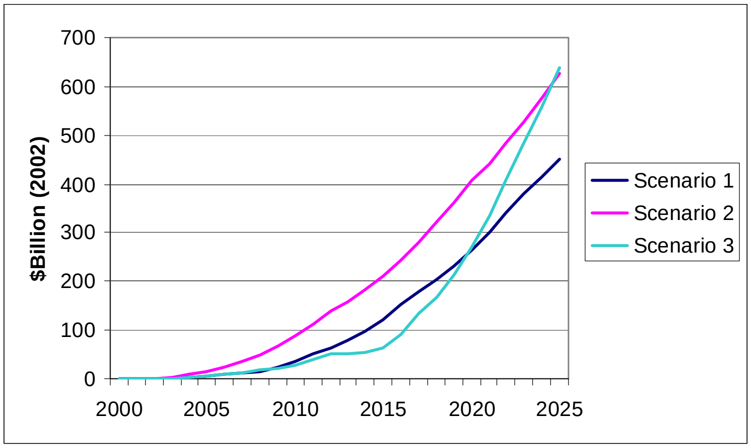
Performance Indicator	Units	Year 2002	Estimated Benefits Due to FE R&D Programs — Case 1: Clear Skies 2012	Case 1: Clear Skies 2025	Case 2: Clear Skies with Low Alternative Gas Supplies 2012	Case 2: 2025	Case 3: Clear Skies with Carbon Constraint 2012	Case 3: 2025
Average Natural Gas Prices	($/MMBtu)							
Wellhead		2.76	0.33	0.56	0.43	0.92	-0.01	0.13
To All Users		4.62	0.38	0.66	0.48	1.00	0.47	0.23
Average Electricity Prices	($/kwhr)	6.9	0.17	0.47	0.38	0.55	-0.08	0.91
Coal Based Power Generation	(Bkwhr)	1868	-37	-167	8	-141	-30	532
Natural Gas Based Power Generation	(Bkwhr)	399	-5	75	22	179	-25	-176
Incremental Natural Gas Production								
Annual	(Tcf/year)	19.38	1.11	2.12	1.27	2.97	1.61	1.69
Cumulative	(Tcf)	---	6.5	28.8	5.3	31.4	7.4	29.6
Incremental Oil Production								
Annual	(MMB/day)	7.77	0.31	0.41	0.32	0.41	0.32	0.44
Cumulative	(Billion Bbls)	---	0.66	1.42	0.66	1.36	0.65	1.62
Reduction in Oil Import Bill	(Billion $)	87.4	3.14	5.08	4.87	10.7	n.e.	n.e.
Cum. Reduction in Energy Expenditures	(Billion $)							
Nat. Gas: Discounted		---						
" " No Discount		---	41	151	56	731	19	151
Electricity: Discounted		---	4.5	127.9	61.1	419.0	-13.2	154.3
" " No Discount		---	14.2	290.8	85.9	203.9	-19.8	394.3
Carbon Emissions	(Million Tonnes Carbon Equivalent)	1536	-18.96	27	0	52.3	n/a	n/a
Carbon Intensity*	(MTCe/ MM$ GDP)	199.8	1.01	0.99	0	0.98	n/a	n/a

*** No FE R&D/With FE R&D**
n.e. = not estimated
n/a = not applicable

Table E.2 FE R&D Program Monetary Benefits Summary (FY05 Budget Level, NEMS-Based)

Program	Energy Expenditure Savings ($billion, 2002 dollars)		
	Electricity	Natural Gas	Oil Imports
Total FE Benefits by 2025			
Scenario 1	291	162	72
Scenario 2	419	215	81
Scenario 3	498	172	ne
CPS Benefits by 2025			
Advanced Power			
Scenario 1	85	61	ne
Scenario 2	278	126	ne
Sequestration			
Scenario 3	127	97	ne
Distributed Generation			
Scenario 1	-	-	ne
Scenario 2	107	-	ne
Scenario 3	41	-	ne
Existing Plants **Scenario 1**	Improvements to Existing Plants reduce mercury emissions by 167 tons by 2025 and result in cost of electricity savings totaling $26 billion.		
O&G Benefits by 2025			
Scenario 1	55	59	69
Scenario 2	91	23	69
Scenario 3	ne	ne	ne

ne = not estimated



Note: The cumulative cost savings in this figure do not equal the sum of electricity and natural gas cost savings in Table E.2. Table E.2 contains the natural gas cost savings to all consumers. Because natural gas price factors into cost of electricity, natural gas cost savings to the utility sector were excluded in this figure to avoid double counting

Figure E.1 Cumulative Economic Benefits of FE R&D from Reduced Electricity and Gas Prices (in billions of dollars)

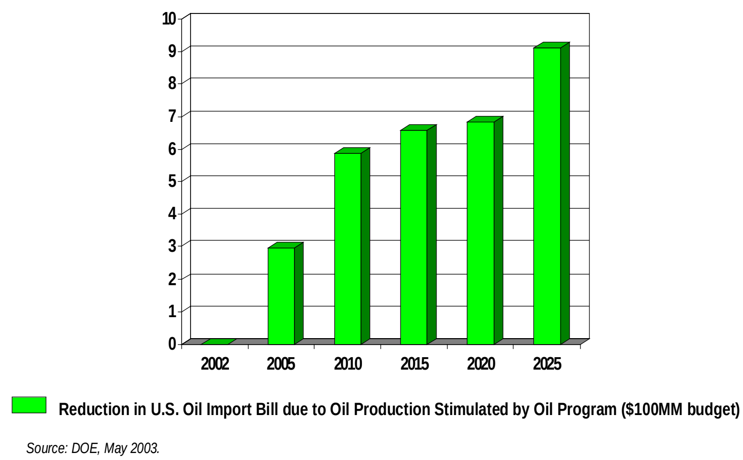


Figure E.2 Reduction in Growth in U.S. Oil Import Bill, Scenario 1: Clear Skies (Billions, $2001)

Environmental Benefits

Figure E.3 illustrates how the greatly enhanced efficiency of FE's advanced power generation technologies enable coal use to grow while at the same time reducing GHG intensity. (The GHG intensity is an economy-wide measure of GHG emissions, defined as million tons of carbon equivalent per million dollars of GDP output.) When advanced coal plants include sequestration, the reduction in GHG intensity is even more dramatic.

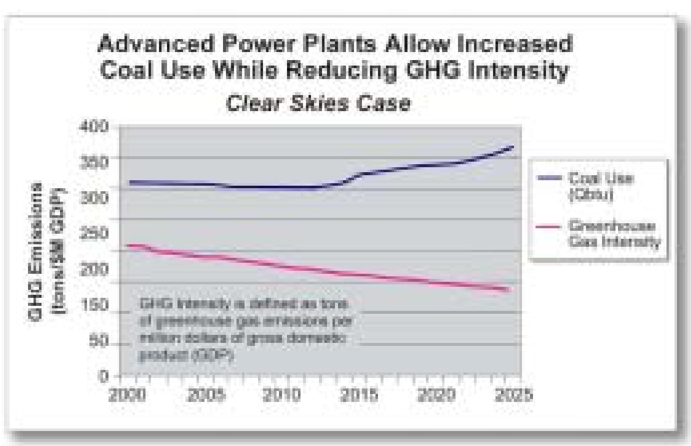


Figure E.3 Coal Use and Greenhouse Gas Intensity Scenario 1: Clear Skies

CPS R&D results in reduced emissions of mercury (Hg) as well. The reduced cost of Hg control provided by FE's technologies makes it possible to meet the 15 ton/year goal of the CSI without exceeding the $35,000 per pound trading price. Without FE R&D, the NEMS model forecasts that the United States will not be able to meet the actual 26 ton and 15 ton Hg caps of the Clear Skies Initiative. Figure E.4 shows the forecast of Hg emissions using FE's advanced technologies. Environmental benefits in terms of additional Hg emissions avoided are 167 tons of Hg emissions avoided between 2010 and 2025, represented by the area between the blue line with solid circle symbols and the green line with diamond symbols.

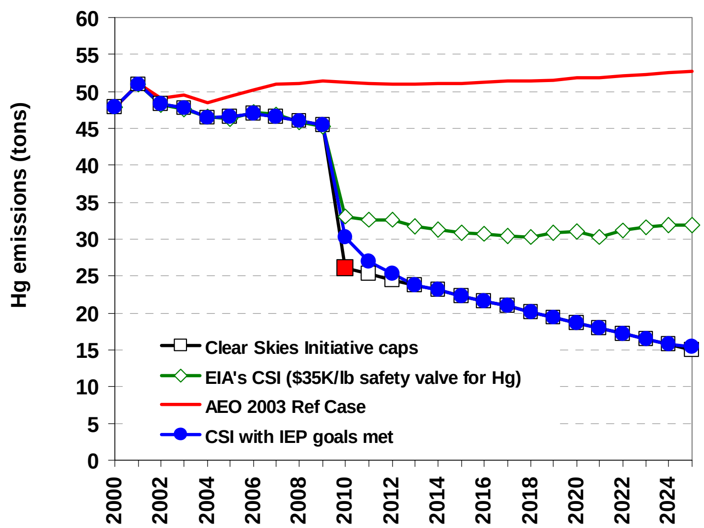


Figure E.4 Environmental Benefit of Avoided Hg Emissions

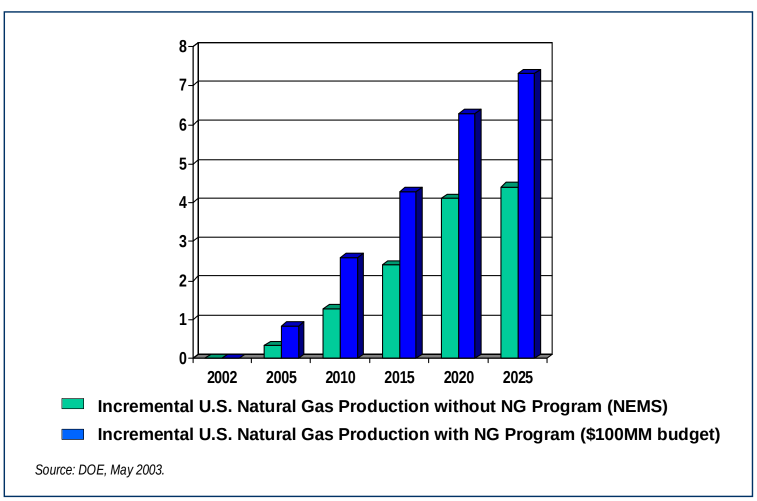


Figure E.5 Incremental U.S. Natural Gas Production
Scenario 1: Clear Skies (Bcf/Year)

Energy Security Benefits

With FE R&D, coal remains the primary fuel for power generation even when limits are placed on sulfur, nitrogen and particulate emissions as well as the scenario in which a carbon constraint is also imposed. This is the direct result of the high efficiencies, clean operation, and capability to capture and sequester carbon dioxide in advanced coal plants. Keeping coal in the power generation fuel mix provides fuel diversity, which reduces demand for natural gas resulting in downward pressure on natural gas prices. Additionally, the technologies developed as a result of FE's O&G program also provide significant increases in incremental oil and natural gas production (see Figures E.5 and E.6). By keeping the fuel mix diverse and making additional fossil fuels available and affordable, FE's R&D Program improves the Nation's energy security.

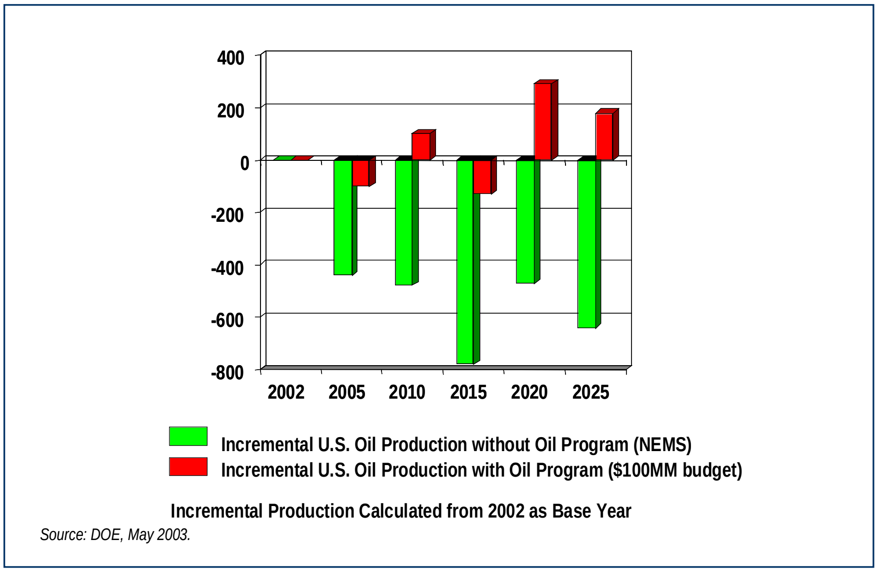


Figure E.6 Incremental U.S. Oil Production
Scenario 1: Clear Skies (Thousand Barrels/Day)

Benefits by Technology

Oil Benefits

The possible range in oil-related program benefits resulting from DOE R&D is primarily dependent on future crude oil prices and R&D program budget levels. Under Scenario 1 (Clear Skies), these benefits include:

- Incremental domestic oil production (crude oil, lease condensate, and natural gas liquids (NGLs)) increases by over 300,000 barrels per day in 2010, growing to over 440,000 barrels per day by 2025 assuming the proposed FY2004 budget at the time of the analysis. Under the proposed FY2005 target budget (at the time of the analysis), incremental domestic production grows to over 830,000 barrels per day by 2025.

- Incremental cumulative oil production over the 2003 to 2025 time period amounts to 1.4 billion barrels under the FY2004 budget, and grows to over 3.3 billion barrels under the proposed FY2005 budget conditions.
- Without DOE R&D, domestic oil production will decline over time, declining by 400,000 to 800,000 barrels per day over the 2015 to 2025 time period compared to 2002. However, with DOE's Oil and Gas Programs at FY2005 proposed budget levels, domestic production will be maintained or could increase by as much as 200,000 barrels per day by 2020, compared to production in 2002.
- Crude oil and petroleum products imports decline by as much as 540,000 barrels per day by 2025 assuming FY2004 budget conditions, and by as much as 940,000 barrels per day by 2025 under FY2005 target budget assumptions.
- Savings in U.S. expenditures for oil imports could be as much as $9 billion annually.

Gas Benefits

Assuming proposed FY2005 budget levels at the time of the analysis, program benefits under Scenario 1 (Clear Skies) include:

- Average wellhead natural gas prices will be reduced by as much as $0.50 per million cubic feet (Mcf) by 2010, and by as much as $0.67 per Mcf by 2025 due to Oil and Gas Program activities, and as much as $0.78 per Mcf with all FE programs contributing. Comparable reductions will also be realized in the price paid for natural gas.
- Lower prices result in reduced expenditures for natural gas in the U.S. by $5 to $9 billion per year due to Oil and Gas Program activities, and up to over $15 billion annually when the benefits of all FE programs are realized.
- Cumulatively, this implies that U.S. consumers will spend $40 billion less on natural gas by 2015 and over $160 billion less on natural gas over the 2002 to 2025 period because of DOE Oil and Gas R&D programs. Annual domestic natural gas production will increase by 1.3 to 1.4 trillion cubic feet (Tcf)/year by 2010 and by nearly 3.4 Tcf/year by 2025. Over the 2003 to 2025 period, assuming target FY2005 budgets, the U.S. will produce over 46 Tcf more domestic natural gas in the Lower 48, 12 Tcf more than under the proposed FY2004 budget.
- Relative to 2002 levels, without DOE's Oil and Gas Program, domestic natural gas production will increase modestly, growing by 2 Tcf annually by 2015, and by 4 Tcf/year by 2005. In contrast, with DOE's Oil and Gas Programs, domestic natural gas production increases by as much as 4 Tcf annually by 2015, and by over 7 Tcf/year by 2025, compared to production in 2002

CPS R&D Program Benefits

Advanced Coal Plants (IGCC, Advanced Turbines, Hybrid Plants)

- With FE's R&D for advanced coal plants, electricity costs are reduced resulting in cumulative savings of $85 billion dollars for Scenario 1 (Clear Skies) to $278 billion dollars in Scenario 2 (higher gas prices) in 2025.

- Without FE's advanced coal plant R&D, natural gas prices rise. With FE's R&D, reduced natural gas prices to all sectors results in savings of $61 billion in Scenario 1 to $126 billion in Scenario 2.
- Without FE's R&D, new advanced coal plant builds are about 35 GW by 2025. The high efficiency and clean, affordable performance of advanced coal plants resulting from successful R&D increases the use of coal for power generation. Nearly 70 GW of new advanced coal plants are built by 2025 in Scenario 1 and about one-third of all new electric generating plants built in Scenario 2 are advanced coal plants (125 GW by 2025).

Sequestration

- FE's sequestration R&D results in the most economic and efficient approach for sequestration from coal-fired power plants. The first plants come online in 2013 and by 2025, 78 GW of advanced coal plants with sequestration are deployed, representing 20 percent of new electric generating capacity (Scenario 3, Carbon Cap)
- Without FE's sequestration R&D, natural gas prices escalate after 2013 because the electricity sector uses more natural gas to comply with the carbon emission limits.
- The monetary benefits resulting from FE's sequestration research program are $127 billion in reduced cost of electricity and $97 billion in reduced cost of natural gas to consumers.

Distributed Generation (SECA Fuel Cells)

- Without FE R&D, fuel cells have very low market penetration (less than 10 GW by 2025). With FE R&D, fuel cells start to penetrate the market around 2007 as the Solid State Energy Conversion Alliance (SECA) cost reductions begin to make them more cost competitive. This results in about 50 GW of fuel cells in operation by 2025 in all three scenarios.
- Fuel cells mainly replace pulverized coal plants, which increases the demand, and therefore price, of natural gas. Because gas prices increase to all consumers, no monetary benefits are realized in terms of reduced natural gas expenditures.
- Fuel cell R&D significantly reduces electricity costs by saving consumers $41 billion in Scenario 3 (Carbon Cap) to $107 billion in Scenario 2 (High Gas Price). No reduction in electricity expenditures is realized in the Clear Skies Case.

Innovations for Existing Plants (IEP)

- The cost reduction goals of the mercury control R&D program result in a total cumulative benefit by 2025 of about $25 billion.
- Without FE's R&D, the U.S. will not be able to meet the caps of the Clear Skies Initiative (CSI). With IEP R&D, it is possible to meet the 15 ton/year goal of CSI without exceeding the $35,000 per pound trading price. The result is an environmental benefit of 167 tons of Hg emissions avoided between 2010 and 2025.
- IEP R&D results in cost reduction for NO_x control that provides a cumulative benefit of nearly $6 billion from 2010 to 2025.

Non-NEMS Benefits

It was not always possible to use NEMS forecasts to estimate the benefits of each FE program. The following FE technologies were not included in the NEMS-based analysis: hydrogen production from coal, sequestration technologies for high-purity vents and non-CO_2 greenhouse gases, carbon management, natural gas hydrates, LNG imports and storage, deep gas, "Operation Oil Freedom," delivery reliability, oil and gas environmental impacts, and oil shale/sands. Independent analyses (that do not rely on NEMS forecasts) were performed to estimate benefits for some of these programs. For clarity, the non-NEMS-based benefit estimates are listed separately.

Hydrogen

- Comparing a central coal-based hydrogen production plant, pipeline delivery of hydrogen to refueling stations, and use in efficient fuel cell vehicles, with an oil refinery, delivery of gasoline, and use in internal combustion vehicles, FE's Hydrogen R&D program is estimated to save the nation $61 billion dollars in cumulative energy savings by 2025 and $3,125 billion over the lifetime (through 2055).

Non-Energy Sequestration

- In an analysis performed by ARI for NETL, economic benefits were determined for the United States from an investment in carbon sequestration technology development over the next 50 years - a time frame long enough to capture the effects of sustained economic growth and stabilized or reduced GHG emissions. A need for GHG emissions reduction were estimated as a delta between a reference case emissions scenario consistent with the reference case forecast in the AEO 2002 and a reduced GHG emissions scenario consistent with the President's Global Climate Change Initiative (GCCI). Both projections were extrapolated beyond 2020 and 2012 respectively.

  Contributions from a wide range of GHG mitigation options, including carbon sequestration, were considered in projecting how the future emissions reduction need will be met. The premise of the analysis was that the sequestration options would not be available without an aggressive R&D effort, and that sequestration will be a less expensive means of reducing GHG emissions than what would be employed if it were not available. Thus, the economic benefits derive from a reduced cost of GHG emissions mitigation.

  Under a reference case scenario in which GHG emissions are unconstrained through 2050, emissions in the U.S. roughly double, increasing from 1.9 billion metric tons of carbon equivalent per year (BtC/yr) in 2000 to 4.0 BtC/yr in 2050. Under the reduced emissions scenario, the carbon intensity of U.S. GDP is reduced 18% over the next ten years consistent with GCCI. Between 2013 and 2020 emissions grow at half the rate predicted in the AEO reference case. Emissions are stabilized after 2020. Under this scenario a very large need for GHG emission reduction arises, roughly 1.7 BtC/yr by 2050. Table E.3 shows the estimated contribution that various options will make toward meeting the future GHG emissions reduction need. This analysis estimates that cumulative savings of having a sequestration option equal $13 billion in 2020 and $550 billion in 2050.

Table E.3 Reference Case and Reduced Emissions Scenarios for U.S. GHG Emissions (Million Metric Tons of Carbon Equivalent - MMTCE)

		2005	2012	2020	2050
Estimated U.S. GHG Emissions Reduction Need		*32*	*108*	*241*	*1,735*
Contribution from GHG mitigation options	Increased Energy Efficiency and use of Renewables	10	33	69	530
	USDA soil carbon	10	15	30	60
	High technology soil carbon		3	6	30
	EPA reduction in non-CO_2 GHG	7	20	35	70
	High technology reduction in non-CO_2 GHG		6	10	20
	Early value-added geologic sequestration	**3**	**12**	**50**	**100**
	Sub total	30	89	200	810
	Residual emissions reduction need to be addressed by advanced carbon sequestration technology	**2**	**19**	**41**	**925**

Natural Gas Hydrates

- In March 2003, DOE's Oil and Natural Gas Program developed several alternative future production profiles for gas produced from hydrates as part of its program metrics exercise for 2003.[2]
- These alternatives were based on the following scenarios: 1) the proposed program for FY2003, with hydrates R&D funded at about $10 million annually; 2) an expanded program, with hydrates R&D funded at about $15 million annually; 3) a reduced program with hydrates R&D funded at about $5 million annually; and 4) no program. These forecasts were based on early estimates of production by the National Petroleum Council (NPC).
- In the expanded program, the NPC prediction is accelerated by two years. In addition, the curve is slightly steepened to reflect the improved recoverability of the resource. In the reduced program, the prediction is delayed five years and the curve is somewhat flattened to reflect the decreased recoverability of the resource. In the No-Program case, the prediction is delayed 10 years and flattened further to beyond 2025.
- The production impacts of these various schedules are summarized in Table E.4.

Table E.4 Production and Recoverability Impacts of Alternative Gas Hydrate Program Cases (Tcf, absolute and change)

Budget Scenario	Production			
	2015	2020	2025	2013-2025
Base Program	0 Tcf/y	0.35 Tcf/y	1.0 Tcf/y	4.3 Tcf
Reduced	0 (-0)	0 (-0.35)	0.30 (-0.70)	0.8 (-3.5)
No Program	0 (-0)	0 (-0.35)	0 (-1.0)	0 (-4.3)
Enhanced	0.10 (+0.10)	0.85 (+0.55)	1.4 (+0.40)	6.2 (+3.1)

[2] U.S. Department of Energy, National Energy Technology Laboratory, *Gas Exploration, Production and Storage Program: Natural Gas R&D Program Impacts Estimates, Gas Metrics 2003*, April 2003

<u>Oil and Gas Environmental Impacts</u>

- By 2025, FE's Oil and Natural Gas Programs will provide the following environmental benefits:
  - Reduced oil spills -- 37,000 to 100,000 barrels
  - Reduced drilling waste volumes – from 240 to 370 million barrels
  - Fewer impacts to surface acres – 110,000 to 210,000 acres
  - Reduced air emissions:
    - Reduced emissions of CO, NO_x, SO_x, and hydrocarbons – 11,000 to 32,000 tons
    - Reduced CO_2 emissions from E&P operations – 2 to 6 million tons
    - Reduced CO_2 emissions from greater use of natural gas in power generation -- up to 190 million tons.

Chapter 1. Introduction

1.1 Background

In recent years, Administration and Congressional initiatives, such as the President's Management Agenda [Bush, 2002] and the Government Performance and Results Act [GPRA, 1993], have placed special importance on using the same benefit forecasting approaches and models for all programs so that results can be compared. The approaches are to be transparent, credible, rigorous, and measurable.

The National Research Council (NRC) study of retrospective (past) benefits of U.S. Department of Energy Office of Fossil Energy research and development (DOE FE R&D) [NRC, 2001] offered a number of useful methodological guidelines for estimating benefits. For example:

$ While there is a strong tendency to focus on economic benefits, other categories of benefits should be considered, such as those related to environment, security, and knowledge.
$ Environmental benefits of energy technologies are measured in terms of lower-cost compliance resulting in lower electric costs to U.S. consumers when emission reductions are driven by environmental regulation.
$ The impact of DOE-sponsored R&D is to make advanced technologies available much earlier than would happen without DOE R&D, and/or at improved levels of performance.

In addition to these guidelines, discussions at the DOE-sponsored conference on "Estimating the Benefits of Government-Sponsored Energy R&D," held March 4-5, 2002 [Lee, et al, 2003] provided the following considerations for this study:

$ Since many technologies in DOE's energy R&D portfolio compete in the same markets, any approach for estimating benefits should model this competition.
$ The U.S. Energy Information Administration (EIA) National Energy Modeling System (NEMS), which would be a useful approach for projecting the market penetration of new technologies, has a high level of recognition and credibility.
$ The absence of FE R&D delays technology development some number of years (or slows its pace of development) based on the technology's level of maturity and commercial backing.
$ It is important to consider multiple scenarios that reflect the uncertainties associated with future regulations, resource characteristics, technology development, geopolitical changes, and market forces..

On April 17, 2002, Carl Michael Smith, Assistant Secretary for Fossil Energy, and David Garman, Assistant Secretary for Energy Efficiency and Renewable Energy, provided testimony to the U.S. House of Representatives in which they stressed a commitment to improving DOE's methodologies for estimating benefits and developing better performance-based program strategies.

Based on the considerations above, FE initiated a process of progressive methodological enhancements to improve the quality and credibility of its R&D benefits forecasts. This report describes the first phase of this process, which focused on:

- The use of EIA's NEMS model to forecast market penetration, impacts, and benefits of FE technologies as they compete against all other similar technologies,

- The development of future scenarios to represent the most important and likely domestic futures, and

- Explicit modeling by technology to estimate the impact of R&D funding on cost and performance goals.

1.2 The Need for Benefit Analysis

The economic health and future of this nation depends on clean, abundant, inexpensive, and reliable energy. Federally funded energy R&D plays a vital role in achieving these goals. To ensure that government-sponsored R&D provides the most benefit for the American taxpayer, it must be shown that the research results in significant economic, environmental, and energy security benefits; is performed in the most cost effective manner; and would not have been achieved without the government's help.

The results of this analysis are necessary to provide credible estimates of FE's program benefits. These quantitative benefits are valuable input to the following Departmental documents that track the value of FE's programs:

- **The *Joule* system**
  Joule is a comprehensive tool driven by GPRA that provides the means of tracking on-going processes for existing efforts and to score them for management review.

- **The DOE Strategic Plan**
  Developed by the Department, this plan links program goals to DOE's overall mission, goals, and objectives.

- **Program Assessment Rating Tool (PART)**
  DOE is implementing the Office of Management and Budget (OMB) PART program, an R&D criteria system designed to "score" the DOE portfolio. PART is based on over a dozen factors, including potential benefits and past performance.

1.3 Office of Fossil Energy Programs

DOE's FE R&D efforts consist of two major programs:

- Coal & Other Power Systems Research Program
- Oil & Gas Supply & Delivery Research Program

Each of these programs is comprised of a number of research areas which consist of a suite of technologies supported by a variety of projects, all aimed at the ultimate goal of ensuring that our fossil energy resources sustain a clean, reliable, secure, and affordable energy supply.

The following charts (Figures 1.1 and 1.2) describe the Coal & Other Power Systems Research Program and its goals.

Figure 1.1 Coal & Other Power Systems Key R&D Programs

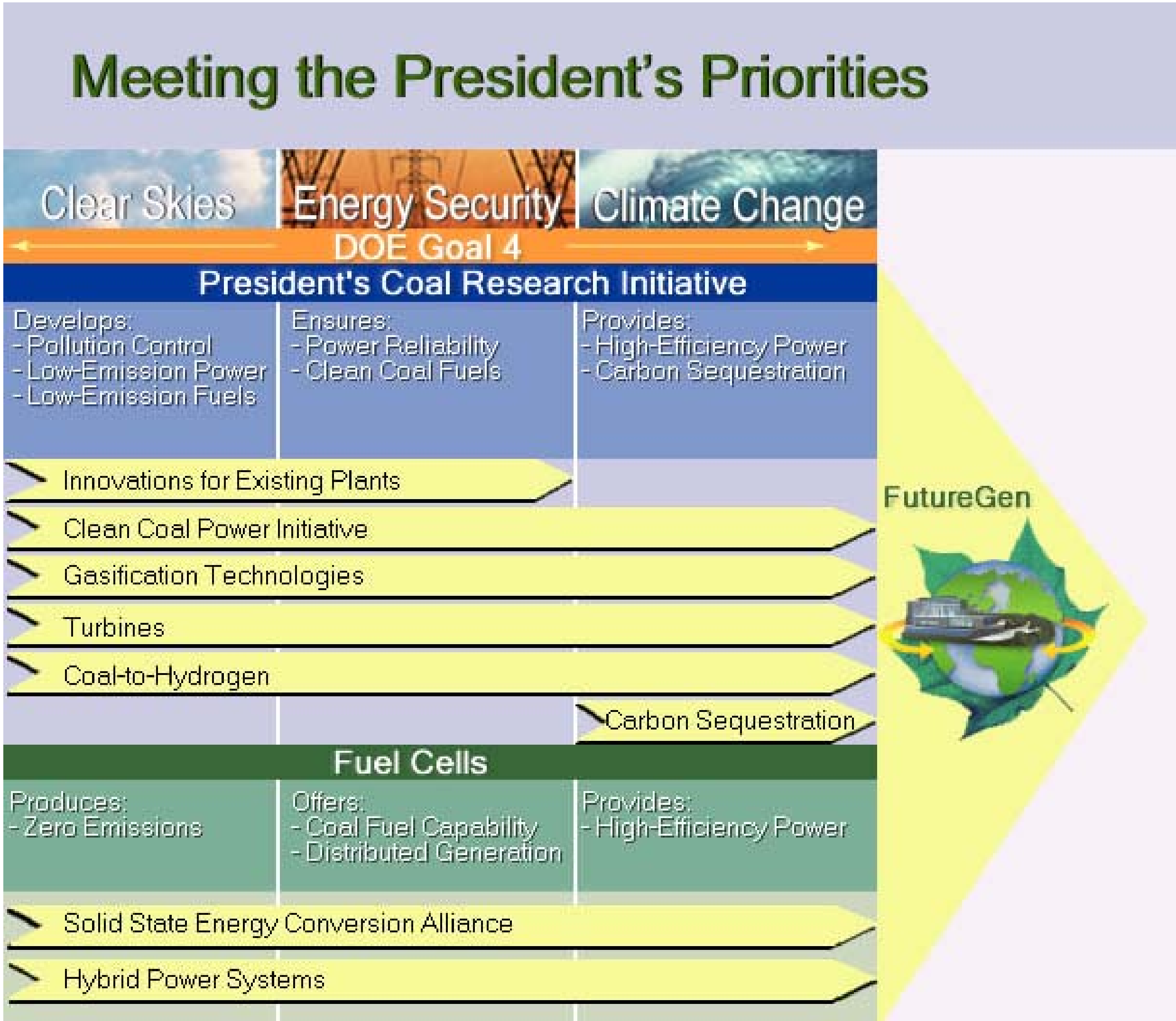


Figure 1.2 Program Goals for the Coal & Other Power Systems Research Program

Figure 1.2 illustrates how FE's Power Systems Program links a variety of technologies that together are capable of achieving the ultimate goal: a fossil-fueled power plant that could push electric generating efficiencies to 60 percent or more – nearly double the efficiencies of today's conventional coal-burning plants.

All Coal and Other Power Systems Programs support the President's priorities in the Coal Research Initiative:

- Clear Skies -- Reducing pollution from power plants to meet the Clear Skies limits for NO_x, SO_2 and mercury
- Energy Security -- Developing clean fuels and ensuring energy reliability
- Climate Change -- Providing high efficiency power generation and sequestration of CO_2.

Technologies are being developed throughout the key R&D programs shown in Figure 1.1 to lower the cost of mercury and NOx control, increase efficiency, increase sequestration friendliness, and decrease cost. Two demonstration initiatives, The Clean Coal Power Initiative and FutureGen, provide the opportunity to prove the design and operation of plants based on these advanced technologies.

These demonstration-type programs provide significant benefits. They serve as large-scale labs for testing new clean power, carbon capture, and coal-to-hydrogen technologies. They also provide a stepping stone toward a future coal-fired power plant that not only would be emission-free but would operate at unprecedented fuel efficiencies. Therefore, the benefits could be viewed as the sum of all of the individual technologies that make-up the future coal-fired plant.

The benefits for the following key program areas were estimated using NEMS:

- Innovations for Existing Plants
- Advanced Coal Plants
    - Gasification Technologies (Integrated Gasification Combined Cycle – IGCC)
    - Turbines of Tomorrow
    - Hybrids (IGCCs with Fuel Cells and Turbines)
- Future Fuel Cells (Solid State Energy Conversion Alliance – SECA)
- Carbon Sequestration

Sometimes NEMS does not provide sufficient detail to extract benefits for a given program element. Further, some technologies are simply not modeled in the current version of NEMS (hydrogen from coal, for example). Therefore, for the following Power Systems Programs, other methods were used to estimate R&D program benefits, which are described in Chapter 6 of this report:

- Coal-to-Hydrogen
- Non-Energy Sequestration
- Demonstration projects and programs such as FutureGen and the Clean Coal Power Initiative.

Figure 1.3 illustrates that the Oil and Gas Supply and Delivery Program consists of a variety of technologies aimed at ensuring energy security, grouped into three major areas:

- Future Oil and Natural Gas Resource Development
- Domestic Oil and Natural Gas Resource Conservation
- Oil and Natural Gas Security and Global Supply

For the Oil & Gas Research Program, this exercise focused primarily on R&D activities targeting oil and natural gas exploration and production technologies. Moreover, it considered only existing program areas in the FY2002 budget. As such, proposed R&D activities associated with expanded or new activities in FY2003, FY2004, and/or FY2005 were not addressed. Roughly 75 percent of the proposed FY2004 program at the time of the analysis is represented here, while roughly 50 percent of the proposed FY2005 target program at the time is represented in these benefits estimates.

R&D benefits were estimated for all of FE, as well as at the program and technology level when possible. A few programs could not be modeled in NEMS; therefore, benefit estimates were calculated using other methods, and results are listed in Section 6.3.

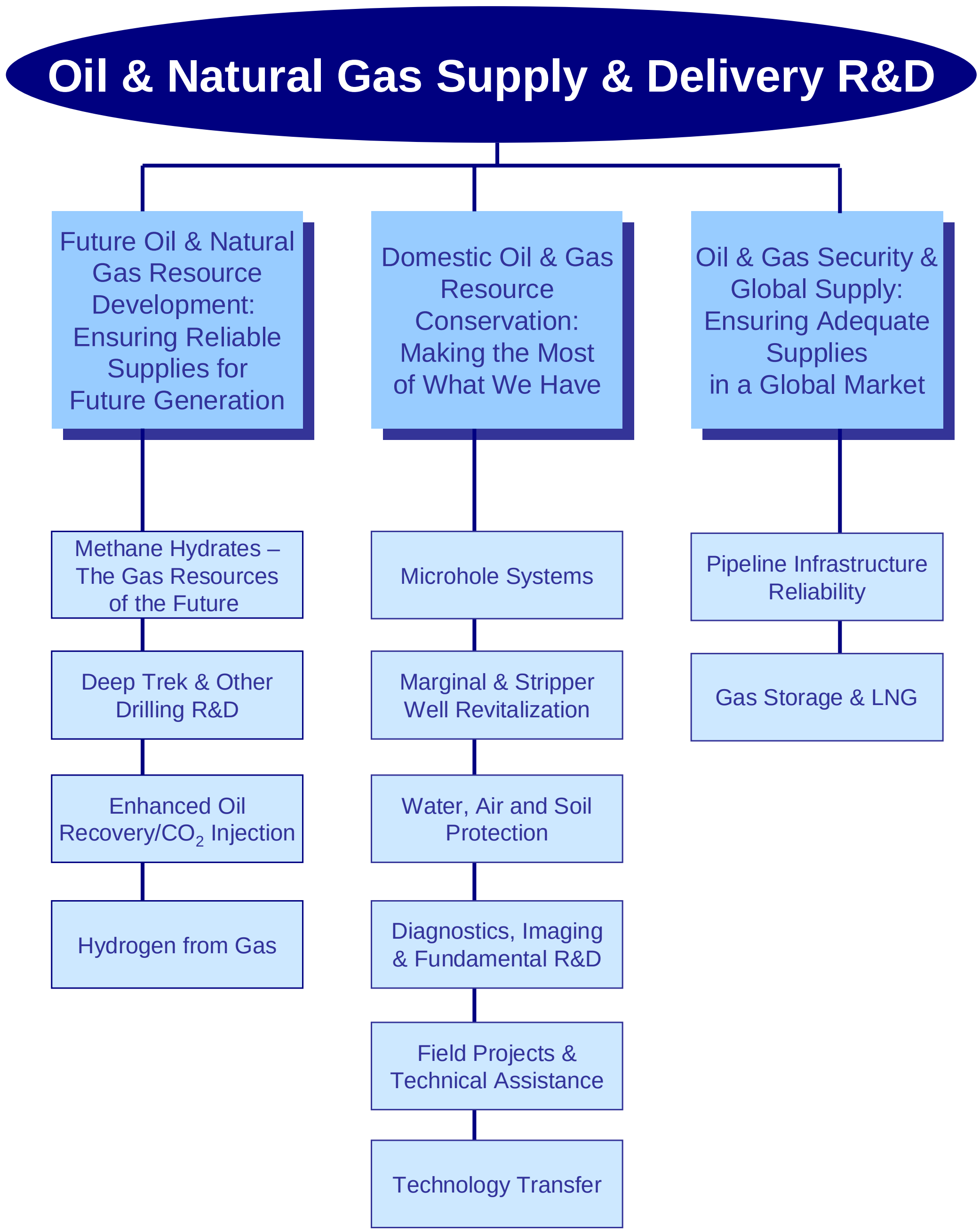


Figure 1.3 Oil & Natural Gas Supply & Delivery Key R&D Programs

1.4 The National Energy Modeling System (NEMS)

Forecasting the impacts and benefits of R&D programs for energy technologies requires a model that simulates the energy sectors of the U.S. economy far into the future. It must meet the following general requirements:

- The model must forecast the production, imports, conversion, consumption, and prices of energy in all sectors of the U.S. economy subject to a variety of assumptions.
- The model must simulate the market competition of electricity and other energy technologies, both in regulated and deregulated markets.
- The model must simulate environmental regulations, including the various forms of market based cap-and-trade systems being proposed by the Administration, U.S. Congress and the U.S. Environmental Protection Agency (EPA).
- The model must forecast the market penetration of advanced energy technologies and the consequent changes in fuel use, energy prices, and emissions.
- The model must be transparent -- the assumptions and solution techniques must be documented and the computer code available for examination and use by others.
- To be of use to FE, the model must include detailed simulations of fossil-fuel supply, distribution, and conversion technologies.
- To be of use to the entire DOE, the model must simulate all energy sectors and technologies under development by DOE.

NEMS is one of the only models that meets most of these criteria. DOE has chosen to use NEMS to forecast the benefits of its programs. These NEMS-derived benefits were used to justify FE's FY2005 R&D budgets at the request of DOE Deputy Secretary Robert Card.

As shown in Figure 1.4, NEMS consists of twelve distinct and independent models (called modules) of U.S. energy sectors. There are four energy supply modules, four energy demand modules, and two energy conversion modules. Each module can be run independently. The Macroeconomic Activity Module simulates energy/economy interactions; the International Energy Activity module simulates the interaction between energy sectors and the entire economy; and the Integrating Module provides the mechanism to achieve a general market equilibrium (convergence) among all the modules.

This study heavily relied upon two NEMS modules: the Oil & Gas Supply Module (OGSM), and the Electricity Market Module (EMM). For more information, documentation is available online at http://www.eia.doe.gov/bookshelf/docs.html [EIA NEMS, 2003].

OGSM forecasts U.S. production of crude oil and natural gas based on endogenously generated supply functions covering both conventional and non-conventional recovery techniques. At the request of FE, EIA modified the code of the OGSM to include the effects of FE R&D on the price and supply of natural gas [EIA P1, 2003]. FE R&D benefits for oil supply technologies were examined in a parallel study [Godec, 2003].

EMM is of particular interest to the DOE-FE because it predicts the types of electricity generators that will be built to meet the United States' increasing electricity demand over the next twenty to twenty-five years. The EMM calculates the least-cost combination of options for the U.S. electricity generating fleet to meet the increasing U.S. demand for electricity, while abiding by existing or proposed environmental regulations.

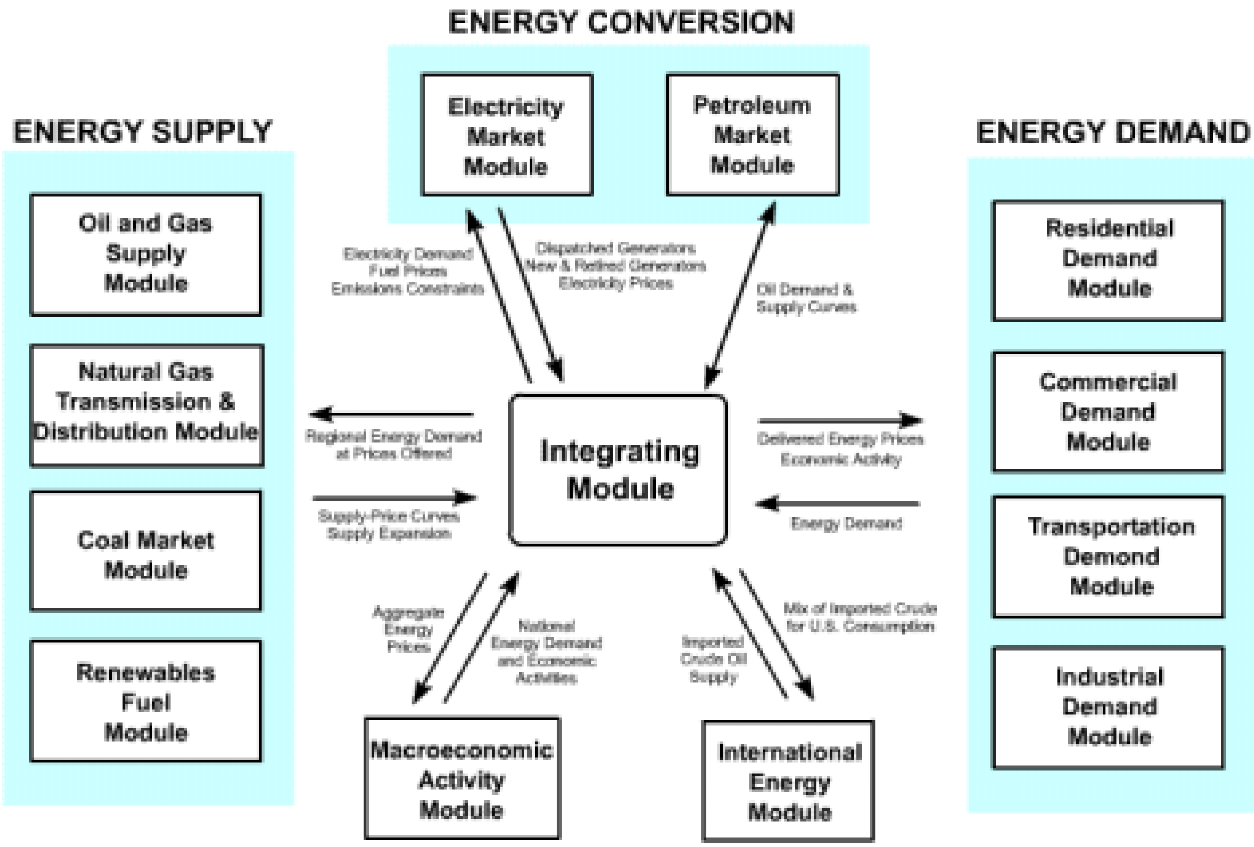


Figure 1.4 Separate energy modules of NEMS and major data exchanged between modules

Electricity Generating Technologies Represented in the EMM

The EMM includes technology descriptions for the existing fleet of electricity generating plants as well as more than 20 types of new plant technologies that compete in an expanding U.S. electricity market. Table 1.1 lists the types of electricity generating technologies that are represented in the EMM.

It should be noted that not all of the advanced coal-fired electricity generating technologies under development by the DOE-FE are represented explicitly in NEMS. Low Emission Boiler Systems (LEBS), Pressurized Fluidized Bed Combustors (PFBC), and Indirect Fired Cycles (IFC) are not represented, although they could be considered to be represented by the generic category for new conventional coal-fired plants. In addition, "Repowering" of existing power plants is not represented in NEMS.

Table 1.1 Electricity Generating Technologies in NEMS

Fossil Fuel Technologies	Nuclear

• Existing coal plants: 32 types with different combinations of pollution control equipment: baghouses, dry scrubbers, wet scrubbers, SCR, cold-side ESP, hot-side ESP, activated carbon injection with fabric filter, activated carbon injection with spray cooling
• Generic PC plant with wet flue gas desulfurization
• Advanced Coal
• Advanced Coal with carbon sequestration
• Gas/Oil Steam Turbine
• Combustion Turbines:
    • Existing
    • Conventional
    • Advanced
• Combined Cycle Turbine Systems:
    • Existing Gas/Oil
    • Conventional Gas/Oil
    • Advanced Gas/Oil
    • Advanced with Sequestration
• Fuel Cells
	• Conventional Nuclear
	• Advanced Nuclear
	
	Renewables
	• Biomass (Wood)
	• Geothermal
	• Municipal Solid Waste
	• Hydroelectric
	• Pumped Storage
	• Wind
	• Solar Thermal
	• Photovoltaic
	
	Distributed Generation
	• Base load: represents heavy-duty micro-turbines, combustion turbines, compression ignition engines, small fuel cells
	• Peak load: represented micro-turbines, frame-type combustion turbines operating on natural gas, and three types of reciprocating engines

NEMS Convergence Tolerance

A NEMS run is considered to be completed (converged) when price and quantity variables change only a small amount between iterations. The small amount of change is called the convergence tolerance. To keep the NEMS run time reasonable, the convergence tolerance for price and quantity variables is set in the range of one percent of the variable's absolute value.

In this study, benefits to U.S. consumers are measured in terms of reductions in energy prices due to the implementation of a FE technology. Because each NEMS case is considered to be converged if energy prices are changing less than one percent between iterations, energy prices can fluctuate within one percent for each NEMS run. Therefore, when energy prices between two NEMS runs are subtracted, an artificial price difference in the range of one percent or less can arise solely from the numerical solution technique. After consultation with the EIA on this matter, a decision was made to ignore price differences of less than one percent in this study [EIA P2, 2003].

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Chapter 2. Methodology for Determining R&D Program Benefits with NEMS

2.1 NEMS Forecast Scenarios with and without FE R&D

The future benefits and impacts of R&D programs are inherently uncertain, as are future economic, geopolitical and regulatory conditions. Thus, it is important to consider a wide range of scenarios that reflect this uncertainty. To represent the most important potential domestic futures that would be addressed by FE technologies, EIA configured NEMS to model the following three scenarios proposed by the Administration:

Scenario 1: The Clear Skies Initiative Base Case
Scenario 1 could be considered somewhat of a "business as usual" scenario under the Clear Skies Initiative. NEMS was configured for FE by EIA to model the regulations proposed in the U.S. Senate's Clear Skies Act of 2003 [Senate Bill 485]. This NEMS configuration differs slightly from the report published by EIA in September 2003 for the Clear Skies Act [EIA S485, 2003].

Scenario 2: The Clear Skies Initiative with Higher Natural Gas Prices
Future natural gas prices are one of the most important factors in energy forecasts today. They significantly affect the choice of technologies, especially of coal and renewables, in the future. Future natural gas prices fundamentally depend on the availability and cost of future natural gas supplies. To test the sensitivity of this factor, Scenario 1 was modified to assume higher crude oil prices and lower natural gas supply potential, resulting in higher natural gas prices. To create this scenario, the following changes were made to NEMS:

- Oil prices corresponding to EIA's Annual Energy Outlook (AEO) 2003 High World Oil Price Case were assumed
- The domestic supply was constrained by restricting sources outside of the lower-48, including Canadian supplies and LNG
- The Alaskan pipeline project was delayed so that would not be available within the forecast period.

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Scenario 3: The Clear Skies Initiative with the Climate Change Technology Initiative
Scenario 3 adds a cap on carbon emissions from the electricity sector to Scenario 1. The carbon cap uses the same market-based, cap-and-trade system as in the Clear Skies Act. The carbon cap is chosen to meet the Administration's Climate Change Technology Initiative (CCTI) goal of reducing greenhouse gas (GHG) intensity by 18 percent in 2012 and to continue efforts beyond 2012 to reduce GHG intensity.

2.2 Design of "Cases" with and without FE R&D

Each of the three NEMS scenarios described in the previous section were run with and without FE R&D goals. This produced six NEMS "cases." Each NEMS case was assigned either the letter "A" or "B" to indicate whether the case is without or with FE R&D goals. The "A" and "B" cases are described below:

<u>"A" Cases</u> ***(The baseline case….No FE R&D)***
"A" cases represent what would happen *without the support* of FE's R&D program. To determine the cost and performance of technologies without FE R&D, an approach similar to that used in the NRC retrospective benefit analysis [NRC, 2001] was adopted. The NRC assumed that FE R&D caused technologies to be introduced into the marketplace five years earlier than without FE R&D. The NRC acknowledged that the extent to which government R&D programs accelerate the introduction of a technology might vary considerably. Therefore, the shift in commercial availability of FE's technologies was selected on a case-by case basis, and for this analysis, ranged from 5 to 15 years depending on a technology's complexity, maturity, and probability that industry would do the necessary R&D without federal support. Without the support of FE R&D funding after FY2003, the "A" cases do not benefit from the acceleration of commercial introduction, and lag behind the performance assumed for the "B" cases.

<u>"B" Cases</u> ***(The case with all FE R&D goals met)***
"B" cases represent the cost and performance of FE technologies *with* FE R&D. In this analysis, FE R&D funding levels are assumed to continue as planned and that all of FE's future cost and performance goals are achieved. Cost and performance data forecasted by the AEO2003 Reference Case was modified to reflect successful achievement of FE R&D goals (cost and/or efficiency). For purposes of this effort, FE's O&G R&D program activities were assumed to be included in the AEO 2003 Reference Case.

Details of the specific assumptions made for FE's technologies are described in Chapters 4 and 5 of this report.

2.3 Comparing Cases A and B to Isolate Benefits of Overall Program

The overall benefits of FE's R&D program can be determined by a comparison of Case A (without continued FE R&D program) and Case B (with continued FE R&D programs that meet goals and targets). The difference between the results of the cases is a direct consequence of the FE R&D program as stated in the following equation:

Case B – Case A = Benefit of FE R&D Program

For any forecasted variable, V, the following expression determines the impact of the entire DOE/FE R&D program on that variable.

$$\textbf{Impact of FE R\&D on } \mathbf{V = V_{Case\ B} - V_{Case\ A}}$$

Examples of variables evaluated in this study include GHG emissions, GHG intensity, fossil fuel use, domestic fossil fuel production and imports, natural gas and oil prices to various sectors, new electricity generating plant capacity, etc.

2.4 Subtractive and Additive Methods to Isolate Benefits by Technology

Determining technology or program-level benefits, that is, the portion of total benefits that can be attributed to an individual technology or program requires additional NEMS cases. Two methods were used to arrive at program-level benefits, one referred to as the "subtractive method," and the other as the "additive method."

In this report, the benefits reported are for the more conservative subtractive method. However, Appendix A presents the results of both methods for comparison.

Subtractive Method

The subtractive method started with Case B, which assumed that all FE research would be successful. Program level benefits were calculated by modifying the Case B run such that all research was successful except for one technology (or suite of technologies). By changing the assumptions for only the technology(s) associated with one program, that program's benefits are isolated. Program costs and performance goals were used as NEMS inputs for all technologies, except for the one whose individual benefits were being calculated. All other inputs and assumptions were identical to Case B. The individual runs resulted in a case representing a future without the isolated technology. A separate run was conducted for each program's technologies. The results of the individual runs were each compared to the results of the Case B run, where all technologies were successful. The difference between the runs is solely attributable to the technology "subtracted" from the individual run. The calculation used to determine program-level benefits can be expressed by

Case B – (Case B without Technology 1) = Benefit of Technology 1

Again, the impact of the entire DOE/FE R&D program on each variable, V, forecasted by NEMS, is calculated as

$$\textbf{Impact of FE R\&D on V} = V_{\text{Case B}} - V_{\text{Case A}}$$

The impact of FE R&D on one particular technology, for example, advanced coal power plants, is estimated as

$$\textbf{Impact of Advanced Coal R\&D on V} = V_{\text{Case B}} - V_{\text{Case B – Advanced Coal}}$$

"Advanced Coal" power is one of the technologies directly modeled in NEMS. The only difference between Case B and "Case B – Advanced Coal" is that the cost and performance inputs for the advanced coal power plant technology were set to match the Case A (without R&D) values. The difference between these NEMS cases, one in which goals for advanced coal power are met and one in which goals for advanced coal power are not met, can be attributed directly to R&D Programs for advanced coal power plants.

The subtractive method is generally a more conservative approach, yielding lower benefits estimates, because the ”B” Cases includes a suite of competitive FE technologies that meet cost and performance goals. These technologies can restore some of the impacts caused by removing the goals of one technology/program. This forces a less advanced technology to compete with other technologies that have benefited from aggressive research efforts.

Additive Method

The “additive” method instead assumes that *no* R&D goals are successfully met, *except for* one technology’s/program’s. Using this approach, the Case A was modified by changing the cost and performance parameters of one technology/program to match the values used in Case B, where FE R&D goals are met. The results of the modified cases were compared to the Case A where R&D goals are not achieved. This calculation can be expressed as:

$$\textbf{Impact of Advanced Coal R\&D on V} = \mathbf{V_{Case\ A\ +\ Advanced\ Coal} - V_{Case\ A}}$$

In the additive method, only one advanced technology is successful and it tends to dominate the marketplace because it is competing against less advanced technologies. The actual benefit of the program most likely is somewhere between these two limits.

The Portfolio Effect

For some benefit parameters, the subtractive method also results in what is referred to as a “portfolio effect.” When the benefits forecasted for each individual program using the subtractive method are added together, the sum of individual benefit is less than the benefit calculated by comparing Case A (without continued R&D) to Case B (with continued R&D and successful completion of all programs). The synergism resulting from the success for all programs gives a benefit that is greater than the sum of the individual program benefits. While this effect does not occur consistently, it indicates that there may be some measurable benefit of having multiple successful research programs. This study does not explore such an effect in depth, but we suggest it be further analyzed in future work.

2.5 Cumulative Benefits

In this analysis, benefits are estimated year-by-year through 2025. This timeframe is consistent with the forecast horizon of NEMS, which presently extends to 2025. The choice of 2025 as an endpoint was driven, in part, by the availability of data (mainly from NEMS) needed for scenario development. This endpoint also provides a reasonable horizon for estimating the expected benefits of technologies that are only now beginning to mature into marketable products. Unfortunately, some of FE’s Programs (e.g., carbon sequestration, methane hydrates, hydrogen infrastructure, etc.) will likely reach commercialization near or after 2025. For those Programs, benefits are significantly underestimated or missed entirely. An approach for accounting for benefits beyond 2025 was not developed during this study, but it is anticipated that future benefit analyses will account for these longer-term benefits.

Because benefits were calculated in the form of an annual time series, the time series of benefits were converted to a single metric in two ways:

1) Calculate a total cumulative benefit between 2003 and 2025 in present day dollars (2002 dollars).

2) Calculate the total present value of the time series using an assumed discount rate of five percent.

Choice of the discount rate is one of the most controversial and important topics within cost-benefit analysis. The available literature was reviewed to provide some insight into the choice of a discount rate to use in this study. OMB recommends a seven percent discount rate for social benefit-cost analysis [OMB, 1992; and 1996]. In an EPA report of guidelines for its economic analyses [EPA, 2000], a three percent discount rate is recommended. However, EPA's recent financial impact analysis of the Clear Skies Act uses a 5.3 percent discount rate [EPA, 2002][3] and their benefit analysis of the Clear Skies Act forecasts benefits using both a three percent and seven percent rate [EPA, 2003]. Therefore, for this study, a discount rate of five percent was selected as a reasonable "mid-point" rate based on the literature reviewed.

This report provides the benefits both discounted and non-discounted, leaving the reader to decide which values are most appropriate for a given audience.

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Chapter 3. Description of NEMS Scenarios

3.1 Scenario 1: The Clear Skies Initiative

The Clear Skies Scenario (Scenario 1) forecasts benefits assuming that Clear Skies legislation will be enacted. The Clear Skies Act of 2003 amends Title IV of the Clean Air Act and is a mandatory cap-and-trade program intended to reduce power plant emissions of NOx, SO_2, and mercury. Power generators are expected to meet the caps primarily by using emissions control equipment. Fuel switching may also be required, but this is a secondary means of achieving the targets. Table 3.1 lists the Clear Skies Legislation emission targets for power plants.

Table 3.1 Clear Skies Legislation Emission Targets for Power Plants

Emission	Clear Skies Targets
Nitrogen Oxides (NOx)	2.1 million tons in 2008 1.7 million tons in 2018*
Sulfur Dioxide (SO_2)	4.5 million tons in 2010 3.0 million tons in 2018
Mercury (Hg)	26 tons in 2010 15 tons in 2018
*Limit on NOx emissions is split between 20 regions - .538 million tons in West and 1.562 million tons in East in 2008, with a further reduction to 1.138 million tons in the East in 2018.	

Although the Clear Skies Act sets emissions caps for the power sector, the legislation also sets a maximum price that power companies can pay for mercury, SO_2, and NO_x allowances. This so-called "safety valve" relaxes the emissions caps if the maximum price is reached. It is not expected that the maximum price will be met for SO_2 and NO_x under the conditions assumed in this analysis. The mercury cap, however, is triggered but this analysis forced the cap to be met in spite of the safety valve.

For the Clear Skies Scenario, NEMS applied these caps to the power generation sector and modeled the mix of technologies that would most optimally meet the targets. Because emissions caps were used, it was not possible to determine emissions reductions from each technology by comparing different runs, because, due to the cap, the sector-wide emissions were always the same. No runs resulted in a situation where emissions were lower than the cap.

3.2 Scenario 2: Restricted Gas Supply/High Natural Gas Prices

The benefits attributable to DOE R&D can depend upon the availability of and U.S. accessibility to alternative, non-Lower 48 sources of natural gas supplies. To provide a better understanding of this dependence, this scenario was considered assuming that sources of supply, other than from the Lower-48, would be constrained. This scenario assumes the same conditions as assumed in Scenario 1, except that higher oil prices are assumed (oil prices corresponding to the AEO 2003 High World Oil Price Case were assumed), and alternative, non-Lower 48 sources of natural gas supply are constrained as follows:

- Construction of an Alaska natural gas pipeline is assumed to be delayed such that it will be 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 Case assumptions.
- Once initially on line, the Mackenzie Delta pipeline in Canada is not allowed to expand again.
- No new LNG facilities are allowed on U.S. shores (under the other scenarios, LNG facilities are allowed on the Atlantic and Gulf Coasts).
- Non-U.S. LNG facilities are not allowed to expand again once built (this results in about 1/2 the capacity as assumed under Reference Case conditions). This applies to planned facilities in the Bahamas and Baja California.
- The existing four U.S. LNG facilities (Cove Point, Elba Island, Lake Charles, and Everett-DistriGas) are only allowed to expand 1/2 as much as allowed under Reference Case conditions.

3.3 Scenario 3: The Clear Skies Initiative with the Climate Change Technology Initiative

FE's carbon sequestration R&D program develops technologies to capture and sequester carbon from electricity generating plants using fossil fuels. The carbon sequestration technologies add significant capital and operating costs to electricity generating plants; therefore, carbon sequestration technologies will be built only if some type of incentive is in place to force the reduction of national carbon emissions.

For this study, a market-based cap-and-trade system, like that used in the Clear Skies Initiative for SO_2, NO_x, and Hg, was applied to <u>reduce carbon emissions from the electricity sector</u>. The carbon cap was set to meet the Administration's "Global Climate Change Initiative" goal of an 18 percent reduction in national GHG intensity (below the 2002 level) by 2012 [Whitehouse]. The GHG intensity is defined as the ratio of total U.S. GHG emissions (in million metric tons of carbon equivalent emissions (mmtce)) to the U.S. GDP.

Starting in 2009, the carbon emission cap for the electricity sector was gradually lowered until the Administration's goal was met in 2012. To meet the Administration's goal, <u>carbon emissions from the electricity sector had to be reduced by 106 mmtce in 2012 to a total emission level of 600 mmtce</u>. After 2012, the carbon emissions were held at the 2012 level of 600 mmtce, thereby stabilizing carbon emissions from the electricity sector. As a comparison, the carbon emission reduction of 106 mmtce required in this analysis represents a six percent reduction in national carbon emissions below that achieved by 2012 in the AEO 2003 Reference Case.

3.4 References

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Chapter 4. Cost and Performance Goals for Fossil Energy Electricity Generating Technologies

4.1 Defining NEMS Input for Coal & Other Power Systems Technologies

The NEMS Electricity Market Module (EMM) contains more than 20 electric generating technologies that compete for the increasing electricity market [EIA EMM, 2002]. Most of the electricity generating technologies under development by FE's CPS Program are explicitly represented in the EMM. Table 4.1 below shows the EMM technologies that were used to represent CPS Program technologies.

To represent FE technologies, the cost and performance specifications for the EMM technologies in column one were set to meet CPS goals for the technologies in column two. The cost and performance goals for CPS technologies were set as exogenous, year-by-year, input. In addition to the EMM, NEMS' Commercial and Residential Modules were used to model SECA fuel cells in non-utility distributed generation (DG) applications.

Table 4.1 EMM Technologies Used to Represent CPS Advanced Technologies

CPS Technology	EMM Technology used to Represent CPS Technology
Hg Controls for Existing Coal Plants	Activated Carbon Injection
NOx Controls for Existing Plants	SCR
Pulverized Coal (Low Emission Boiler Systems, Pressurized Fluidized Bed Combustors, and Indirect Fired Cycles)[1]	Conventional Pulverized Coal
Advanced IGCC Hybrid[2] plants	Advanced Coal
Advanced IGCC Hybrid plants with carbon sequestration	Advanced Coal with Sequestration
Fuel Cells (SECA)[3]	Fuel Cells
Fuel Cells (SECA)	Distributed Baseload

1. Benefits for these technologies were not calculated in this study.
2. IGCC Hybrid plants include the use of advanced turbines and SECA fuel cells.
3. SECA fuel cells were modeled in the EMM and the Commercial and Residential Modules

The EMM technology learning equation was used to forecast the capital cost of all non-FE technologies. The learning equation assumes that the cost of a technology decreases exponentially with market penetration [Kydes, 1999]. The initial capital costs and learning factors set by the EIA in the AEO 2003 Reference Case were unchanged.

An advantage of using the NEMS EMM is that market penetration forecasts take into account the fact that many CPS technologies will compete against each other in the same markets. They will also compete against more than 20 other commercially available technologies, including natural gas turbines, renewables, and nuclear. Further, as the EMM interacts with other NEMS modules, the impacts of new electricity generating technologies on other energy markets, on the entire U.S. economy, and on energy costs to consumers are captured.

The cost and performance of FE technologies were adjusted to generate a case with FE R&D and a baseline case to represent what would occur without the FE CPS Program:

1) **FE R&D Case**

   The cost and performance (efficiency) of FE technologies were set as fixed, year-by-year, exogenous input so as to meet the CPS Program Strategic Performance Goals (PSPG). This case represents what occurs when the FE CPS program is successful.

2) **No FE R&D Case**

   According to guidance from the OMB, the definition of a baseline is “the way the world would look absent the proposed regulation.” [OMB, 1996]. In this study, the baseline is more appropriately defined as “the way the world would look absent the proposed research.” Additionally, following the recommendations from the NRC in their retrospective benefits report [NRC, 2001], the impact of government sponsored R&D programs was assumed to accelerate the introduction of a technology in the marketplace by a given number of years. The baseline assumes that the cost goals would still be achieved by industry; however, without government-sponsored R&D the goals would be met at a later date. In this case, the cost and performance data was set so that the CPS goals are met at a later date.

NEMS was run for both the case with R&D and a baseline case that represents what the world would look like absent this R&D. The difference between these two NEMS cases provides an estimate of the benefits of the R&D program in a given scenario.

For this benefits analysis, only the cost and performance data for FE technologies were modified. EIA initially set up NEMS to simulate the scenarios chosen for this study. Once EIA transferred the NEMS configurations to NETL/DOE, no other changes were made.

The cost and performance of technologies forecasted by the AEO 2003 Reference Case generally fall somewhere between that for the two cases described above. In their AEO Reference Case, EIA attempts to forecast the advancement of technologies assuming that all regulations and R&D programs (both industry and federal) are maintained at their present status.

4.2 The Case with FE R&D: Using CPS Program Goals

The cases with FE R&D (called "B" cases) assume that PSPGs are successfully achieved as planned. The technologies modeled, applicable program objectives (PSPGs), and assumed deployment acceleration due to FE R&D, are summarized in Table 4.2.

Table 4.2 Technologies Explicitly Modeled

CPS Technology	Acceleration due to R&D	PSPG Target	PSPG Date	Commercial Deployment Date
IEP Hg	*10-15 years*	*Cost of Hg removal with Activated Carbon Injection (ACI) reduced by 25% in 2010 and 50% in 2015*	*2010* *2015*	
IEP NO_X		*Cost of NOx removal with SCR reduced by 25% in 2010 and 50% in 2015*	*2010* *2015*	
Advanced IGCC	*10 years*	*50% HHV efficiency, $1000/kW* *60% HHV efficiency, $850/kW*	*2010* *2020*	*2014* *2024*
Advanced IGCC with Sequestration	*15 years*	*10% increase in COE compared to IGCC with no sequestration*	*2012*	*2012*
Advanced Turbines	*10 years*	*No PSPG target for turbines. To meet high efficiency of IGCC systems the following turbine efficiency targets were assumed:* *58% HHV efficiency* *68% HHV efficiency*		*2012* *2017*
Advanced Turbine with Sequestration		*No PSPG target. But advancements from coal sequestration technology are assumed to reduce cost and improve efficiency of turbine*		*2012*
SECA FC -- Utility	*15 years*	*50% HHV efficiency, $400/kW*	*2010*	*2012*
SECA FC -- Residential & Commercial		*50% HHV efficiency, $500/kW (80% overall efficiency in CHP mode)*		

ACI = activated carbon
SCR = selective catalytic reduction
CHP = combined heat and power

4.3 The Case without FE R&D: Shifting the Timing of Technology Development and Commercialization

The impact of FE's CPS R&D program is assumed to cause advanced technologies to be commercialized at an earlier date than would have happened without CPS R&D. Without CPS R&D, industry alone may or may not develop and commercialize the technologies at a later date, and an adjustment to the timing for commercial availability must be made. Based on the maturity of the technology, the following rationale describes the acceleration in commercial availability as the result of FE's R&D program. Without government-sponsored R&D, commercialization of these technologies would therefore be delayed by that period of time.

- **Innovations to Existing Plants (IEP) Program**

  Retrofit emissions controls are currently available, but are expensive and inadequate for some applications such as mercury removal. The IEP Program plans to significantly reduce the cost of these systems for compliance in the near-term (by 2010). Therefore, the IEP Program is assumed to accelerate development by 10-15 years.

- **Advanced Coal (IGCC Hybrid plants)**

  The few IGCC plants operating today do not utilize many of the advanced components being developed in the CPS IGCC Program. These components will significantly improve efficiency and reduce cost, and will provide carbon-sequestration ready concentrated gas streams. Because IGCC using coal is an immature technology (only two plants operating in the U.S.), the successful development and integration of key technology components is expected to take some time. The IGCC program is assumed to accelerate deployment of advanced systems by 15 years.

- **Turbines**

  Turbines for gas-fired combined cycle power generation are a mature technology. However, much work is needed to ensure that they will efficiently operate on coal-derived syngas from IGCC plants or other opportunity fuels. FE's current Turbine Program focuses on the development of a fuel-flexible turbine. This is not something being pursued by private industry, and therefore, the Turbine Program is assumed to accelerate development by 10 years. These turbines are an essential technology for IGCC plants to achieve their extremely high efficiency and excellent environmental performance.

- **Carbon Sequestration**

  Sequestration technology is in the very early stages of development and therefore is one of FE's longer-term efforts. Although there are several applications of sequestration technology that can have an impact in the near term, the deployment of sequestration technology in the power market is not likely to happen soon and could significantly increase the cost of electricity. To develop an advanced process that separates and sequesters greenhouse gases (and perhaps other pollutants at the same time) at competitive costs, the commercialization advancement for the Sequestration Program is assumed to be 15 years. (Other beneficial outcomes of the Sequestration Program not captured by this NEMS model methodology include the incremental oil and/or natural gas supplies that could result from the geologic sequestration of CO_2 in depleted oil and gas fields or unmineable coal seams.)

- **Fuel Cells**

  FE's Program for SECA fuel cells is developing an entirely new solid oxide fuel cell (SOFC) design that is planned to be very inexpensive and reliable. This Program plans to dramatically lower capital costs compared to current SOFC technology. The lowest capital cost forecast for fuel cell technology in the NEMS AEO 2003 Reference Case is about $1,200/kW (in today's dollars) by 2025. SECA fuel cells will achieve $400/kW by capitalizing on a mass customization approach through a unique collaborative effort with industry teams, core technology research organizations, and government agencies. Because SECA fuel cells represent the introduction of much more advanced, novel concepts than available for fuel cells today, cost and performance goals are represented by a step change rather than a gradual, linear change. Without the government's funding and facilitation of dialogue among the variety of organizations participating in this effort, it is assumed that it would take the industry at least 15 years longer to develop this technology, if it would be developed at all.

4.4 Detailed Input Assumptions

A graphical presentation of the capital cost and efficiency used as EMM input for CPS technologies in this analysis is provided in Figures 4.1 and 4.2. Each set of colored curves represents a particular technology both with and without the R&D program (see legend). The difference between the same colored curves reflects the date at which technologies enter the market place with and without the support of the R&D funding. For a year-by-year listing of input data for capital cost and heat rates (efficiency) and additional assumptions made for this study, see Appendix C.

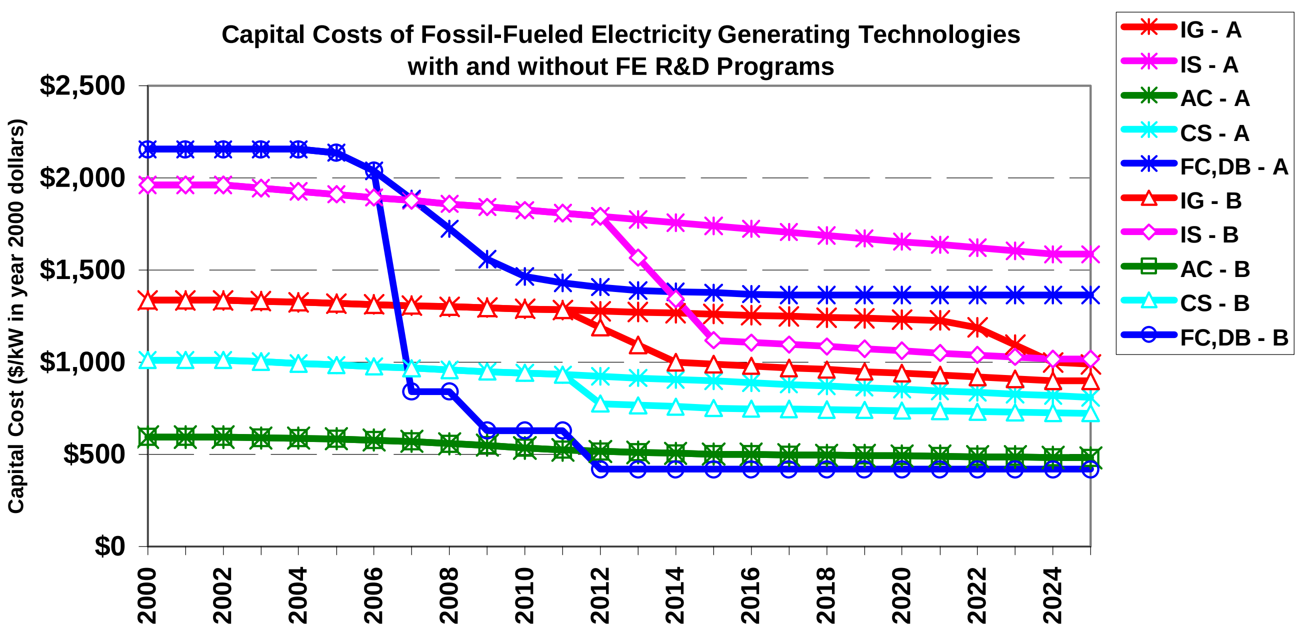

Figure 4.1 Input Assumptions for CPS Capital Costs

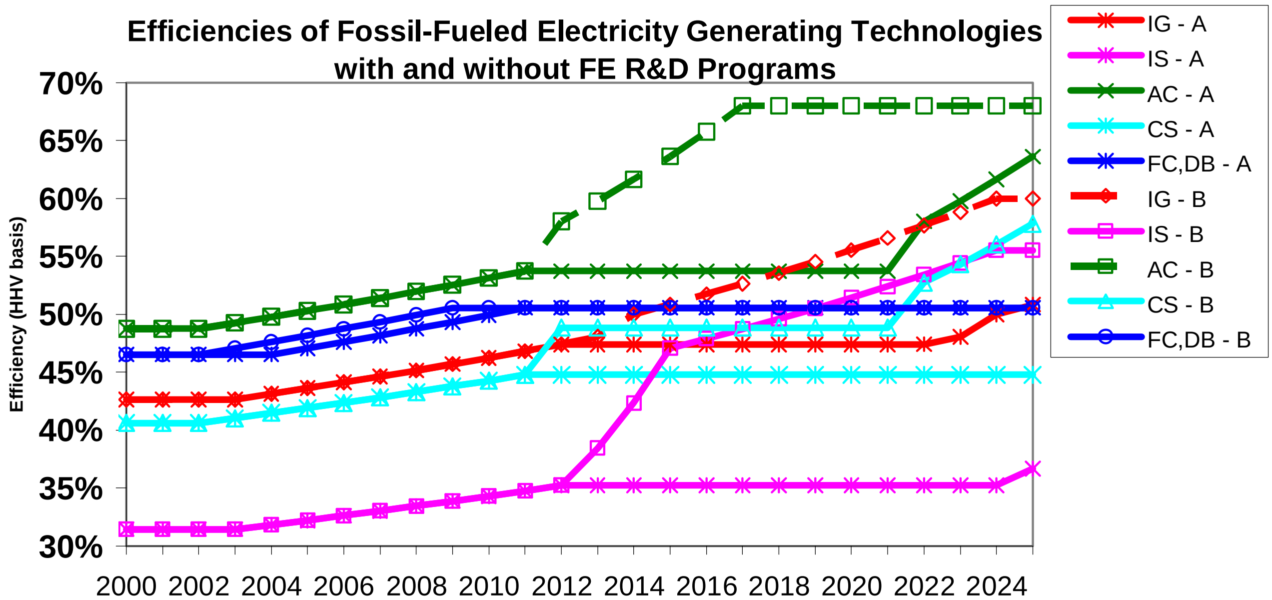

Figure 4.2 Input Assumptions for CPS Efficiencies

KEY:	
– A	No FE R&D (baseline)
– B	FE R&D
IG	IGCC
IS	IGCC with sequestration
AC	Advanced combined cycle
CS	Advanced combined cycle with sequestration
FC, DB	Fuel Cells for grid support and baseload DG

4.5 FE CPS Technologies/Programs Not Modeled in NEMS

Several emerging technologies in existing programs of the FY2002 budget could not be modeled using NEMS. Benefits of these programs were estimated using means other than NEMS forecasts. These program areas are:

- Coal-to-Hydrogen
- High purity vents and non-CO_2 greenhouse gas sequestration
- Terrestrial Sequestration
- CCPI
- FutureGen

Coal-to-Hydrogen

To estimate the benefits of a hydrogen economy, an estimate of hydrogen demand was determined from the DOE Hydrogen Posture Plan Scenario (internal DOE report). The posture plan estimates that the portion of light duty vehicles (LDV) sales that are fuel cell vehicles (FCV) is four percent by 2018, 27 percent by 2020, 78 percent in 2030, and 100 percent by 2038. By comparing the efficiency of FCVs with internal combustion engine vehicles (ICEV), savings in fuel costs, energy, and emissions reductions can be determined. Table 4.3 lists the market penetration and efficiency ratios assumed for FCVs.

Table 4.3 Fuel Cell Vehicle Assumptions

Year	Market Penetration of LDVs that are FCVs (%)	Efficiency Ratio FCV/ICEV
2018	4	2.25
2020	27	
2030	78	2.5
2038	100	
2040	100	2.5
2050	100	3.0

Additional assumptions include:

- New vehicle annual sales increase at 7.3 percent of total LDV fleet
- Annual scrapping is 5.8 percent of the vehicle fleet
- Vehicle life is 15.5 years
- Fuel costs are based on average year 2000 costs as reported by the EIA
- Hydrogen-from-coal plants are nominally 150 million standard cubic feet per day
- Advanced coal-fired IGCC plants are assumed to emit 0.04 lbs SO_2/MMBtu through more severe operation of a Rectisol unit with SO_2 recovery of 99 percent

A system analysis of a coal-fueled central hydrogen plant [Mitretek, 2002] with pipeline delivery of hydrogen to refueling stations and use in efficient FCVs was compared to the most likely alternative, that is, oil refining and delivery of gasoline for use in ICEVs.

Non-Energy Sequestration

Contributions from a wide range of GHG mitigation options, including carbon sequestration, are considered in projecting how the future emissions reduction need will be met. The premise of the analysis is that the sequestration options would not be available without an aggressive R&D effort, and that sequestration will be a less expensive means of reducing GHG emissions than what would employed if it were not available. Thus, the economic benefits derive from a reduced cost of GHG emissions mitigation.

The following describes the approach taken to estimate the emissions reduction need for non-energy CO_2 and non-CO_2 greenhouse gases.

Non-energy CO_2 emissions estimates are taken from the EIA 2001 report, "Emissions of Greenhouse Gases in the United States 2000." [EIA, 2001] The main areas are gas flaring, CO_2 in natural gas, cement production, other industrial, and waste combustion.

Growth in emissions from gas flaring through 2020 is assumed to be directly proportional to expected growth in natural gas use contained in the AEO 2002 reference case forecast. Projected emissions from CO_2 in natural gas grow at a higher rate than natural gas production due to the expected pursuit of deeper and higher CO_2 content natural gas deposits. The study estimates that the average CO_2 content of natural gas will increase by 50 percent between 2000 and 2020. Beyond 2020, gas flaring is assumed to stabilize.

CO_2 emissions from cement production, other industrial, and waste combustion are assumed to grow between 2000 and 2050 at the rate of 2.8 percent per year, equal to the rate of growth of CO_2 emissions from energy use.

Non-CO_2 GHGs included in the benefits analysis are: methane (CH_4), nitrous oxide (N_2O), and halocarbon global warming potentials (HGWPs). Anthropogenic emissions of CH_4 come from three categories of sources: energy production (natural gas systems, coal mining, fuel use, and oil production and transport), landfills, and other (e.g., livestock manure, enteric fermentation). Projections for CH_4 emissions from energy use through 2020 are taken from the AEO 2002 (page 99). The average growth rate in CH_4 emissions from energy systems between 2000 and 2020, 0.9 percent per year, is extrapolated through 2050. The estimates for CH_4 emissions from landfills and other sources are taken from the EPA document, "U.S. Methane Emissions 1990-2020 [EPA, 1999; EPA, 2001]." Emissions from landfills are expected to decrease beyond 2020 due to the deployment of landfill gas recovery and use systems. Methane emissions from other sources are estimated to grow post 2020 at a rate of 0.96 percent per year.

N_2O emissions come primarily from agriculture and mobile combustion, with power plants contributing roughly four percent of 2000 emissions. The Climate Action Report (CAR) estimates N_2O emissions to grow at a rate of 0.78 percent per year between 2000 and 2020[EPA, 2001]. The annual growth rate of 0.78 percent was extrapolated through 2050.

HGWP emissions estimates are taken from the EIA Emissions of GHGs in the United States. Annual emissions of HGWPs have increased by more than 50 percent over the past ten years, and the CAR projects an annual rate of increase of six percent per year between 2000 and 2020. The CAR HGWP growth rate of six percent was applied through 2020, and a three percent growth rate was assumed post 2020.

Not included in $Q_{reference}$ are projected changes in the rate of net GHG uptake from domestic forests, farms, and other terrestrial ecosystems. Most experts agree that the natural carbon uptake will decrease over the next 20 years, primarily due to the aging of second growth forests in the northeast [DOS, 2002]. All else equal, including the change in domestic terrestrial carbon uptake would increase the need for GHG emissions reduction.

$Q_{reduced}$ The reduced emissions scenario assumed in this study are as follows:

- 2002 – 2012: GHG intensity reduced to 152 mtC/$GDP, 18 percent below AEO 2002 reference case.
- 2013 – 2020: Annual emissions growth rate 50 percent below AEO 2002 reference case.
- 2021 – 2050: GHG emissions stabilized at the 2020 emissions level.

Q_{need} The emissions reduction needed equals the difference between the reference case and reduced emissions scenarios.

Quantity of GHG Emissions Reduction Supplied by Carbon Sequestration. Carbon sequestration is one of many technologies used to meet the emissions reduction need. The equation below shows technologies and approaches considered in the analyses.

$$Q_{need} = Q_{eff\&rnew} + Q_{soil} + Q_{HTsoil} + Q_{nonCO2} + Q_{HTnonCO2} + Q_{VAgeoseq} + Q_{ADVseq}$$

Where

Q_{need}	The U.S. emissions reduction need
$Q_{eff\&rnew}$	Reduction achieved with efficiency and renewables
Q_{soil}	Reduction achieved with increased carbon storage in soils
Q_{HTsoil}	Reduction achieved with increased carbon storage in soils using advanced technologies
Q_{nonCO2}	Reduction achieved with non-CO_2 GHG abatement
$Q_{HTnonCO2}$	Reduction achieved with non-CO_2 GHG abatement using advanced technology
$Q_{VAgeoseq}$	Reduction achieved with value-added geologic storage (EOR and ECBM)
Q_{ADVseq}	Residual need for emissions reduction to be met with advanced sequestration technology

References

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<u>CCPI and FutureGen</u>
Two demonstration initiatives, CCPI and FutureGen, provide the opportunity to prove the design and operation of coal-based power plants using advanced technologies developed through FE's R&D program.

These demonstration-type programs provide significant benefits. They serve as large-scale labs for testing new clean power, carbon capture, and coal-to-hydrogen technologies. They also provide a stepping stone toward a future coal-fired power plant that not only would be emission-free but would operate at unprecedented fuel efficiencies. For this analysis, the benefits are viewed as the sum of all of the individual technologies that make-up the future coal-fired plant.

4.6 References

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Chapter 5. Cost and Performance Goals for Oil and Natural Gas Supply Technologies

This chapter describes the approach for using the NEMS Oil and Gas Supply Model (OGSM) to represent the benefits attributable to FE's Oil and Natural Gas (O&G) Programs. The initial approach was to develop NEMS-based program metrics and benefits consistent with the forecasts published in the EIA 2002 AEO. Moreover, the plan was for the technology assumptions relating to the R&D programs to be based on the programmatic assumptions from the most recent O&G program metrics available at the time, developed using the models traditionally used by the programs -- the Gas Systems Analysis Model (GSAM) and the Total Oil Recovery Information System (TORIS). Program budget levels comparable to those in FY2002 were assumed in these metrics runs.

However, several events occurred over the course of the effort that changed these plans:

- EIA released its 2003 AEO, which contained fundamental changes relative to the 2002 AEO.
- The Administration proposed an O&G Program budget for FY2004 that was substantially smaller than the FY2002 budget upon which the existing program benefits and metrics were based. Consequently, adjustments were required to correspond to these reduced budget expectations.

These changes are described below.

5.1 Defining NEMS Input for Oil and Natural Gas Technology

As an initial step, a review of results from previous EIA studies using NEMS was conducted to develop a preliminary understanding of the sensitivity of NEMS/OGSM to assumptions and input parameters used to represent technology change. A comparison was also made between the finding rate and drilling success rate assumptions in the AEO 2002 technology scenarios to the results from previous TORIS and GSAM runs. The rationale for this comparison is that the finding rate and drilling success rates are the traditional technology parameters used for conventional oil and gas resources in OGSM.

Next, a comparison was made between various parameters that could be used to represent technology performance in OGSM and those currently used in GSAM and TORIS. This allowed for a matching of existing parameters used in the program metrics analysis with possible corresponding OGSM technology parameters.

Finally, OGSM technology parameters were mapped to corresponding program areas in the O&G Program budgets for FY2002. This included both existing OGSM technology parameters and other OGSM inputs that could be utilized for the purpose of representing technological advances. This helped identify program areas with no corresponding technology levers in OGSM, and any program areas not currently represented in TORIS/GSAM that may be represented in OGSM.

5.1.1 Conventional Oil and Gas Resources

The impacts of Natural Gas Program activities are captured in GSAM for conventional natural gas resources through 14 technology and cost input parameters. Likewise, comparable technology parameters are used in TORIS for the impacts of Oil Program activities. From mapping these parameters in TORIS and GSAM to the corresponding OGSM technology parameters, recommended values were developed for adjusting OGSM parameters that were consistent with those assumed in the previous O&G Program metrics based on FY2002 budget levels. These parameters were expressed in terms of a rate of improvement per year due to technology change, relative to the values in the AEO 2002 Reference Case. The technology parameters used for conventional oil and gas resources in OGSM included the following:

1. Finding rates
2. Drilling costs
3. Lease equipment costs
4. Operating costs
5. Exploration drilling success rates
6. Development drilling success rates
7. Initial production rates (New proposed technology parameter)
8. Production-to-reserves ratios (New proposed technology parameter)
9. Development pace for inferred reserves (New proposed technology parameter)

The recommended approach for representing the benefits of O&G program activities using these parameters is described below.

Finding rates. The "productivity" and "recovery efficiency" technology parameters used by GSAM were related to the finding rate technology parameter in OGSM. Similarly, the "continuity function," ER, and E_v technology parameters in TORIS were related to the OGSM finding rate parameters. In contrast to the 2002 AEO, the 2003 AEO Reference Case did not assume any change in the rate of improvement in finding rates due to technological change for two of the three categories of finding rates used in OGSM. The "new field wildcat" and "development" drilling finding rates in OGSM are not assumed to change over time due to technology improvement in the AEO 2003 Reference Case. Consequently, a corresponding reduction in the pace of technological change could not be assumed in a No FE R&D Case. For the category "other exploratory" drilling, the rate of improvement due to technology was reduced from 3.00 percent per year in the Reference Case to 2.58 percent per year in the No FE R&D Case for all onshore regions except for Region 2 (Gulf Coast), where a value of 1.90 percent per year was assumed for the No FE R&D Case. Similarly, for the "composite" offshore finding rate assumed in OGSM, the rate of improvement due to technology was reduced from 2.00 percent per year in the Reference Case to 1.58 percent per year in the No FE R&D Case.

Drilling, lease equipment, and operating costs. Assumptions for cost reductions over time for three categories of costs – drilling, lease equipment, and operating -- are assumed in OGSM for the AEO 2003 Reference Case; and cost parameters in TORIS and GSAM directly comparable to these exist. Based on cost reduction assumptions in the O&G Program metrics, the following values for OGSM cost parameters for the No FE R&D Case were assumed:

	Annual Percentage Reduction in Costs	
	Reference Case	**No FE R&D Case**
Drilling Costs		
Onshore	1.87%	0.94%
Offshore	1.50%	1.13%
Alaska	1.00%	0.94%
Lease Equipment Costs		
Onshore	1.20%	1.20%
Offshore	1.50%	0.75%
Alaska	1.00%	1.00%
Operating Costs		
Onshore	0.54%	0.47%
Offshore	1.50%	0.93%
Alaska	1.00%	1.00%

In addition, Oil and Gas Environmental Program activities targeted at reducing the costs of environmental compliance were also considered, and an average percentage change in costs due to program activities was developed, based on the most recent Environmental Program metrics. This increase in costs due to greater environmental requirements required adjusting OGSM drilling and operation costs in the No FE R&D Case:

	Capital Costs ($/well)		**Operating Costs ($/well)**	
	Oil	**Gas**	**Oil**	**Gas**
One time average cost increase - onshore	$13,807	$20,549	$3,158	$1,701
Average costs per onshore well	$444,000	$613,000	$27,040	$22,200
One time initial % increase	**3.11%**	**3.35%**	**11.68%**	**7.66%**
One time average cost increase - offshore	$167,355	$164,160	$8,289	$7,999
Average costs per offshore well	$6,349,000	$7,041,000	$371,933	$371,933
One time initial % increase	**2.64%**	**2.33%**	**2.23%**	**2.15%**

Drilling success rates. Assumptions for improvements in drilling success rates over time for two categories of success rates – those associated with exploration and development drilling – are assumed in OGSM for the AEO 2003 Reference Case; and drilling success parameters in TORIS and GSAM directly comparable to these also exist. Based on assumptions in the most recent program metrics, the following values for OGSM drilling success parameters for the No FE R&D Case were assumed:

Annual Percentage Reduction in Drilling Success Rates

	Reference Case	No FE R&D Case
Development Success Rates	0.67%	0.62%
Exploratory Success Rates	2.62%	2.41%

Initial production rates. Several technology factors in GSAM and TORIS (e.g., reservoir skin factor, productivity index) relate to well productivity. While not traditionally a factor in OGSM that changes due to technology improvement, for purposes of this exercise, it was recommended that initial production rates be adjusted downward in the No FE R&D Case, to account for technology advances resulting in improved well productivity. The following downward adjustments (annually) in initial well production rates were assumed to occur in the No FE R&D Case:

Annual Percentage Change in Initial Production Rates

Region	Oil (%/year)	Shallow Gas (%/year)	Deep Gas (%/year)
Northeast	0.42	0.42	1.12
Gulf Coast	1.10	1.10	1.12
Mid-Continent	0.42	0.42	1.12
Southwest	0.42	0.42	1.12
Rocky Mountain	0.42	0.42	1.12
West Coast	0.42	0.42	1.12

Production-to-reserves ratios. To be consistent with the adjustments made to initial production rates, comparable adjustments were also made to the reserves-to-production ratio assumptions in OGSM for the No FE R&D Case.

Inferred reserves development pace. One of the major areas of focus for the O&G Programs addresses extending the life of existing oil and gas fields, which in turn increases the ultimate recovery of oil and/or gas resources from these fields. One factor in OGSM that was determined to be the best to represent this type of program activity specifies the pace that inferred reserves can be developed over time. To represent the No FE R&D case, the extent of inferred reserves development was reduced, assuming that without FE, growth in inferred reserves will stop after 40 years; whereas with FE programs, inferred reserves growth continues for up to 80 years. This is intended to represent the contribution of O&G Program activities to the development of additional resources in known fields. This results in the following growth assumptions (ranges represent the variations by region):

Inferred Reserves Growth Relative to Initial Discovery

	Reference Case	No FE R&D Case
Crude Oil	From 5 to 16 times	From 4 to 8.5 times
Natural Gas	From 4 to 15 times	From 3 to 10 times

Table 5.1 summarizes the relative parameter changes proposed to represent FE's O&G Programs for conventional oil and gas resources.

Table 5.1

Summary of Technology Progress Levers – Changes for NEMS Runs for Oil and Gas Program Metrics Conventional Oil and Gas Resources	
Technology	**Currently Estimated Impacts of DOE R&D**[4]
1. Finding Rates	
Exploration	No change
Delineation	Reduce by 0.5%/year
Development	No change
2. Baseline Costs	
Drilling Costs	Reduce by from 0.06% to 0.93%/year*
Lease Equipment Costs	Reduce up to 0.75%/year*
O&M Costs	Reduce by 0% to 0.57%/year*
3. Environmental Costs	
Capital Costs	Reduce costs by 2.3% to 3.4%*
O&M Costs	Reduce costs by 2.2% to 11.7%*
4. Drilling Success Rates	
Development	Reduce by 0.05%/year
Exploration	Reduce by 0.11%/ year
5. Initial Production Rates	Reduce by 0.42% to 1.12%/year*
6. Production-to-Reserves Ratio	Reduce by 0.42% to 1.12%/ year*
7. Inferred Reserves Development Rate	Reduce ultimate level of inferred reserves growth by 20% to 47%*
**Various by region, depth, and/or resource type*	

5.1.2. Unconventional Gas Resources

For unconventional natural gas, OGSM uses its unconventional gas submodule to project the production and economics of natural gas from tight sands, coal seams, and gas shales. This submodule models the impacts of technology progress on unconventional gas using 11 "technology parameters," which in some cases are different from those used for conventional oil and gas resources in OGSM. For this exercise, recommended adjustments for the following unconventional gas technology parameters were proposed:

1. Year hypothetical plays become available
2. Decrease in extended portion of development schedule for emerging plays (per year)
3. Expansion of existing reserves (per year)
4. Increase in percentage of wells drilled successfully (per year)
5. Year that best 30 percent of basin is fully identified
6. Increase in estimated ultimate recovery (EUR) per well (per year)
7. Decrease in drilling and stimulation (D&S) costs per well (per year)
8. Decrease in water and gas treatment costs per well (per year).

[4] Representing the difference between the Reference Case and the No DOE R&D Case.

The adjustments in technology progress levers for unconventional natural gas in OGSM used to represent the difference between the Reference Case and the No FE R&D Case are described in Table 5.2. In the table, next to each "lever" is the technology progress impact currently assumed to represent the FE programs focused on unconventional gas resources.

Table 5.2
Summary of Technology Progress Levers –
Changes for NEMS Runs for Oil and Gas Program Metrics
Unconventional Natural Gas Resources

	Technology Lever	**Currently Estimated Impacts of DOE R&D[5]**
1	Basin Studies and Assessments	Makes hypothetical plays studied by DOE available for development 10 years earlier than otherwise. (Pending)
2	Play-Specific Extended Resource Characterization	Accelerates the pace of development in emerging plays characterized by DOE by 10 years.
3	Improved Well Performance Diagnostics and Remediation	Improves the rate of reserve growth, by 0.5% to 1.5% per year, for mature plays with proved reserves.
4	Advanced Exploration and Natural Fracture Detection Technology	a. Doubles the success rate (from 1.25 to 2.5%/year, in half the time (from 40 to 20 years)
		b. Helps define the most productive areas ("best 30%") of naturally fractured plays seven years earlier.
5	Geology/Technology Modeling and Matching	No impact. Improves reserves per well by 2.5% in 30 years.
6	More Effective, Lower Damage Well Completion and Stimulation Technology	a. Improves EUR per well by 5% in 30 years.
		b. Reduces R/P ratio by 1 unit for plays with high R/P ratios.
7	Targeted Drilling and Hydraulic Fracturing R&D	Reduces D&C costs per well by 2.5% in 30 years.
8	New Practices and Technology for Gas and Water Treatment	Reduces O&M costs for water and gas treating by 5% in 30 years.
9	Advanced Water Drilling and Completion Technology	Introduces technology that improves EUR per well by 5% to 10% and five years earlier than otherwise.
10	Other Unconventional Gas Breakthrough Technologies	No impact by 2026.
11	Mitigation of Access and Development Constraints	Reduce development time constraints by 1% per year.

Source: Memorandum to Brad Tomer, NETL, from Vello Kuuskraa and Mike Godec, ARI, entitled "Measuring the Impacts of DOE/FE's R&D Program for Unconventional Gas Resources,' dated November 25, 2002.

[5] Representing the difference between the Reference Case and the No DOE R&D Case.

5.2 *Adjustments Corresponding to Proposed FY04 Budget Cuts*

The recommended changes in technology parameters described above were assumed to apply to FY2002 budget levels. However, in the middle of this effort, the Bush Administration proposed reductions in O&G Program budgets for FY2004. Consequently, comparable adjustments to the assumed technology input parameters were required. Therefore, analyses were performed based on two budget levels – the proposed FY2004 budget and the FY2002 budget level. The extent and nature of the proposed budget cuts for the FY2004 case is compared to the FY2002 budget in Table 5.3.

Table 5.3
Comparison of Oil and Natural Gas Program Budgets for FY2002, FY2003, and FY2004

Summary of Budget ($ in thousands)

	FY 2002 Conference Mark	FY 2003 Base Settlement	FY 2004 Cong. Request	FY 2004 % of FY 2002	
NATURAL GAS TECHNOLOGIES					
Exploration and Production	20,500	15,450	14,000	68%	
Gas Hydrates	9,800	4,500	3,500	36%	
Infrastructure	10,050	0	0	0%	
Emerging Process Tech.	2,250	0	6,555	291%	Includes H_2 from Gas in FY2004
Eff. Env. Protection	2,600	2,640	2,500	96%	
TOTAL	**45,200**	**22,590**	**26,555**	**59%**	
OIL TECHNOLOGY					
Exploration and Production	32,350	16,400	2,000		
EOR/CO2 Injection			1,980		
Reservoir Life Ext./Mgt.	6,756	9,500	5,000	31%	Based on ratio of sum for first 3 rows
Eff. Env. Protection	10,700	9,500	8,000	75%	
TOTAL	**49,806**	**35,400**	**15,000**	**30%**	

To represent the technology assumptions corresponding to the proposed FY2004 budgets, the following adjustments were made:

- For the Oil Technology Program, technology parameters for the FY2004 budget case were adjusted to 50 percent of the values assumed in the FY2002 budget case.
- For the Natural Gas Technologies Program, technology parameters for the FY2004 budget case were adjusted to 75 percent of the values assumed in the FY2002 budget case.
- For the Effective Environmental Protection Program (oil and natural gas, combined), technology parameters for the FY2004 budget case were adjusted to 70 percent of the values assumed in the FY2002 budget case.

These adjustments assume that some diminishing returns exist for the O&G program, so the adjustments in technology parameters are not quite as large as the comparable adjustments in program budgets.

In the spring of 2003, the O&G Program introduced its proposed budget for FY2005. A comparison of the oil and gas E&P program areas in FY2005 showed that the target budget for these areas in FY2005 was approximately the same as comparable areas for FY2002. Consequently, it was assumed that the parameter adjustments in NEMS for the FY2002 case would be applicable for determining program benefits for this proposed FY2005 budget scenario.

Chapter 6. Benefits

6.1 NEMS Forecast Results and Benefits by Scenario

6.1.1 Electricity Generation and Fuel Use

Compliance with the Clear Skies caps on SO_2, NO_x and Hg is generally achieved through adding emissions controls to existing coal-fired electricity plants and through switching some generation from coal to natural gas.

In the Clear Skies Initiative Scenario (Scenario 1), generation, with both coal and natural gas, increase through 2025. Use of natural gas in Case 1B is slightly lower (four percent) than in Case 1A as a cheaper supply of natural gas is made available with FE R&D in Case 1B (Figure 6.1) In the higher gas price scenario (Scenario 2), significant reductions in generation with natural gas use are forecast by 2025 (Figure 6.2). By 2025, higher natural gas prices cause more than 400 billion kilowatt hours (kWh) of electricity generation to switch from natural gas to coal, which is a 33 percent decrease in natural gas and about 15 percent increase in coal to generate power.

Compliance with the Climate Change Technology Initiative (through the cap on CO_2 emissions used in this study) is generally achieved by building new coal plants with carbon sequestration. With FE R&D, in Case 3B, generation with coal increases steadily even with the carbon cap that stabilizes carbon emissions at 2012 levels. Generation with coal is 22 percent higher than in year 2000. Figure 6.3 illustrates that without FE R&D, in Case 3A, generation with coal steadily decreases to six percent below the year 2000 level in 2025.

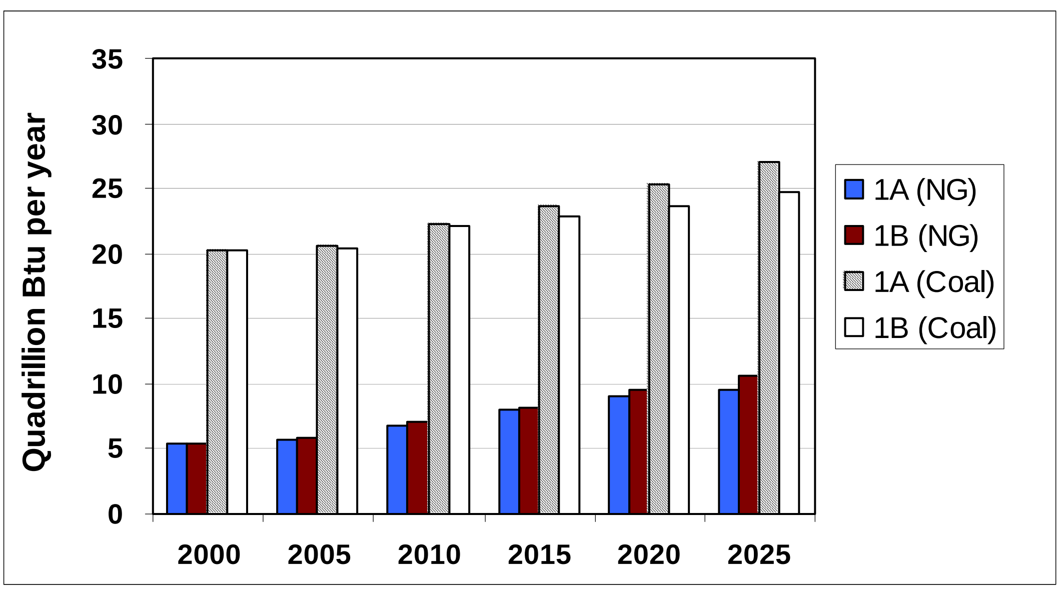

Figure 6.1 Fuel Use Scenario 1: Clear Skies

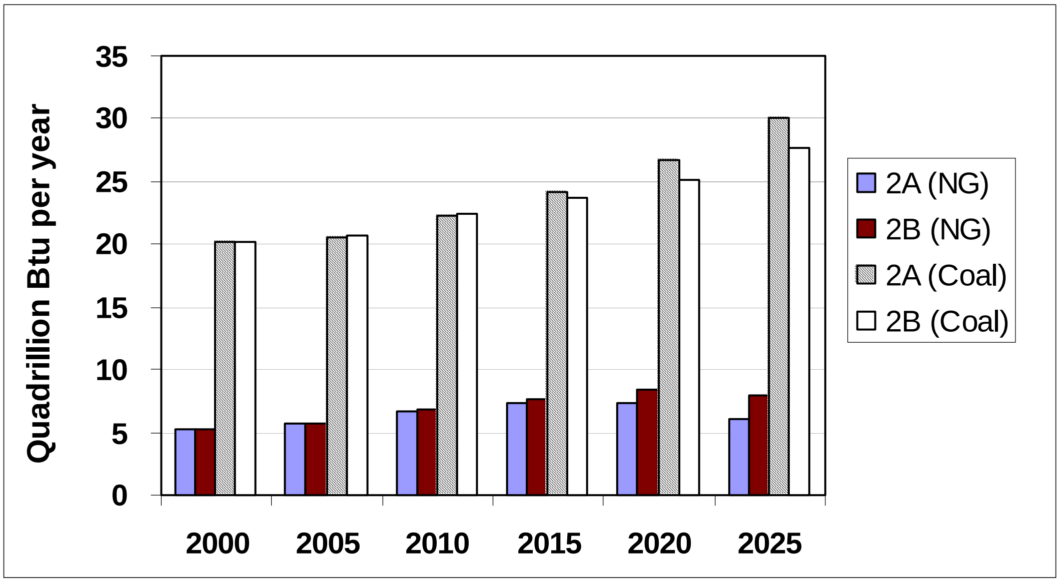

Figure 6.2 Fuel Use Scenario 2: High Gas Price

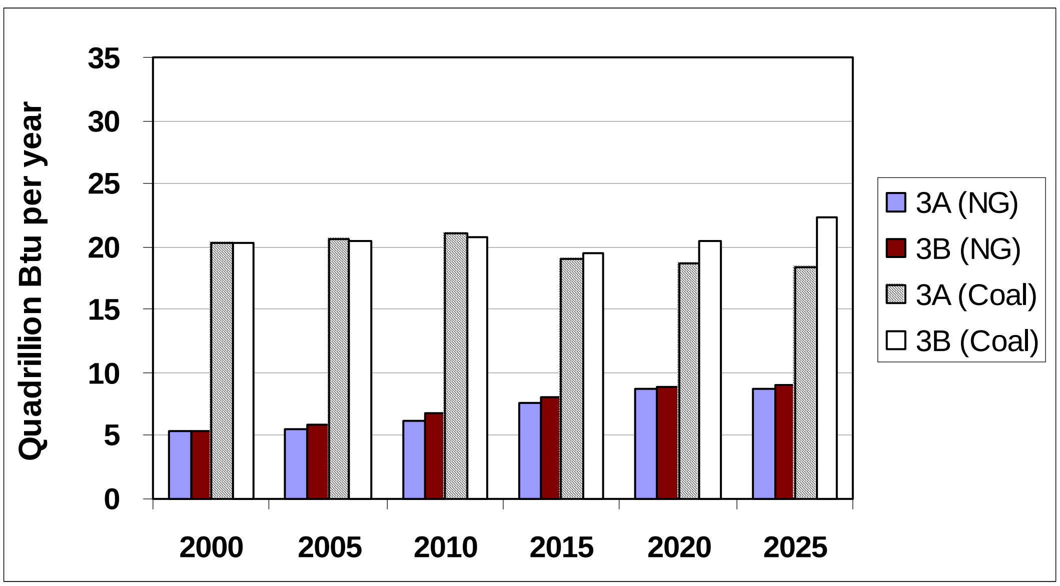

Figure 6.3 Fuel Use Scenario 3: Carbon Constraint

6.1.2 Builds of New Electricity Generating Plants

FE research changes the mix of technologies used to generate electricity in the United States. Figures 6.4 – 6.6 show the new plant builds (unplanned) forecasted in all cases. Certain trends become apparent from viewing these figures. Builds of natural gas-fired turbines, both single-cycle and combined-cycle, are about the same in all cases. In the”B”cases (with FE R&D), builds of pulverized coal plants decrease and are replaced by advanced coal plants and fuel cells.

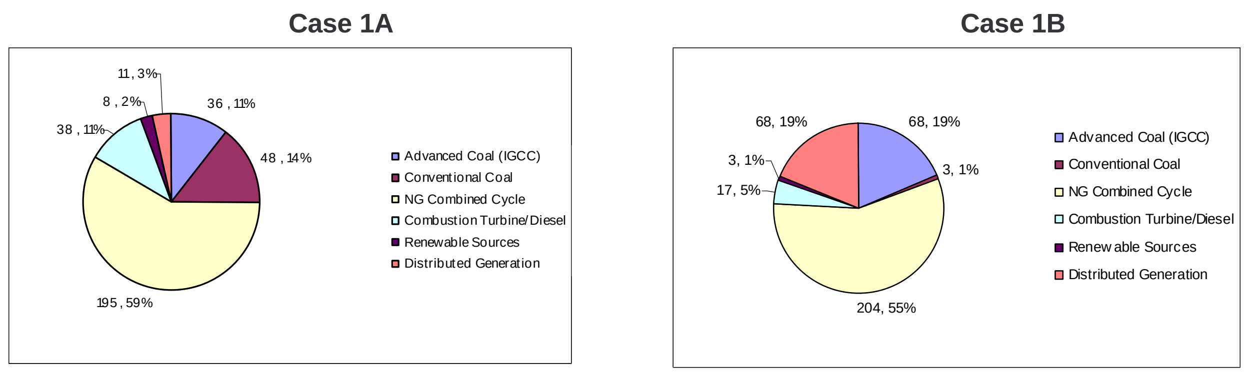

Figure 6.4 Scenario 1 (Clear Skies): Cumulative Unplanned Additions

In Scenario 2 with higher natural gas prices, builds of coal plants increase 16 percent over Scenario 1. In Case 2B, advanced coal plants show the largest increase, reaching 125 GW by 2025.

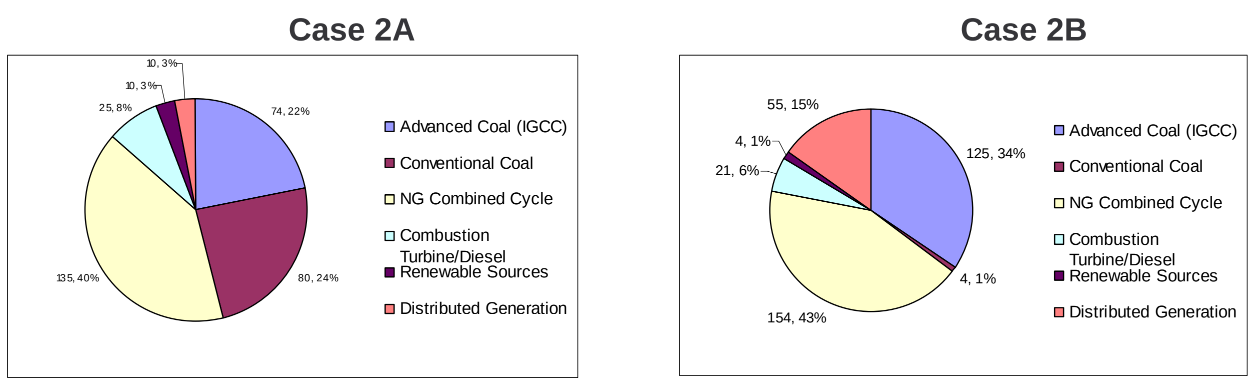

Figure 6.5 Scenario 2 (High Gas Price): Cumulative Unplanned Additions

In Scenario 3 with a carbon cap, builds of renewables increase significantly. No coal plants, either pulverized or advanced, are built in Case 3A without FE R&D. In Case 3B, 78 GW of advanced coal plants with carbon sequestration are built. No natural gas plants with carbon sequestration are built, because they are not economically competitive. Builds of fuel cells are about the same in all the “B” cases, but they are significantly higher than the builds of fuel cells predicted in the case without FE R&D.

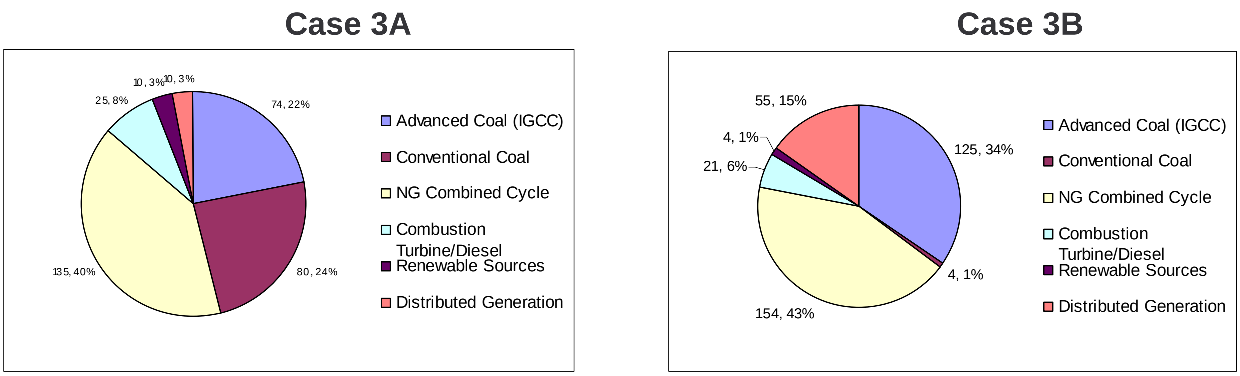

Figure 6.6 Scenario 3 (Carbon Cap): Cumulative Unplanned Additions (Advanced Coal includes sequestration)

6.1.3 Emissions

6.1.3.1 Environmental Benefits from FE CPS R&D Programs

In all scenarios, Clear Skies emissions caps were applied. Therefore, all cases meet the same emission limits, and environmental benefits cannot be measured as emission reductions. Instead, the emission benefits of advanced technologies are determined by a savings in the cost to generate electricity given a standard emission requirement. A savings in cost of electricity indicates that FE technologies more cost-effectively achieve the CSI caps, resulting in both environmental and economic benefits.

Figure 6.7 illustrates how the greatly enhanced efficiency of FE's advanced technologies with sequestration enables coal use to increase while at the same time stabilize greenhouse gas intensity and increase savings to consumers due to reduced natural gas prices. The greenhouse gas intensity is an economy-wide measure of GHG emissions, defined as million tons of carbon equivalent per million dollars of GDP output. The economic benefit of reduced natural gas prices, as the result of keeping the fuel mix diversified, is called the fuel diversity benefit in Figure 6.7.

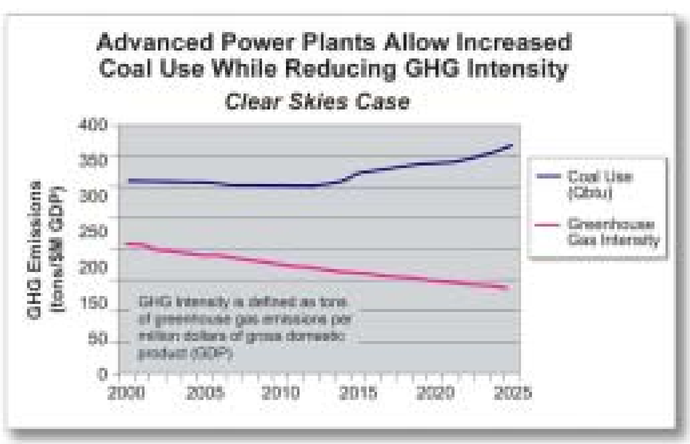

Figure 6.7 Coal Use, Greenhouse Gas Intensity and Natural Gas Cost Savings Scenario 3, Carbon Cap

The FE CPS program also provides environmental benefits in the area of mercury emissions and NO_x reduction costs for existing pulverized coal plants.

Shown in Figure 6.8, the NEMS forecasts indicate that, using the EIA's cost and performance numbers for Hg control technologies, *the U.S. will not be able to meet the actual 26 ton and 15 ton Hg caps of the CSI.* NEMS forecasts that with the $35,000 per pound safety valve, the U.S. will be able to lower its Hg emissions only to about 30 tons per year -- twice the level sought by the Clear Skies Initiative. This is shown by the green line with diamond symbols in Figure 6.8.

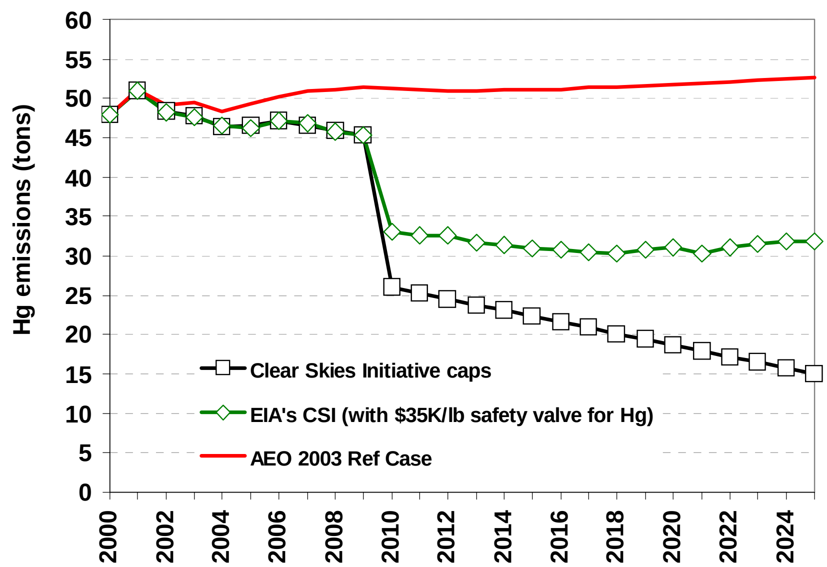

Figure 6.8 NEMS Forecast for Hg Removal

With the reduced cost of Hg control provided by FE's technologies, it is possible to meet the 15 ton/year goal of the CSI without exceeding the $35,000 per pound trading price. The blue line with solid circles in Figure 6.9 shows the forecast of Hg emissions using FE's advanced technologies. National Hg emissions are 30 tons in 2010, slightly above the 26 ton CSI cap. After 2013, the CSI caps (with banking) are met exactly.

Therefore, environmental benefits in terms of additional Hg emissions *avoided* are realized. The environmental benefit (*167 tons of Hg emissions avoided between 2010 and 2025)* is represented by the area between the blue line with solid circle symbols and the green line with diamond symbols.

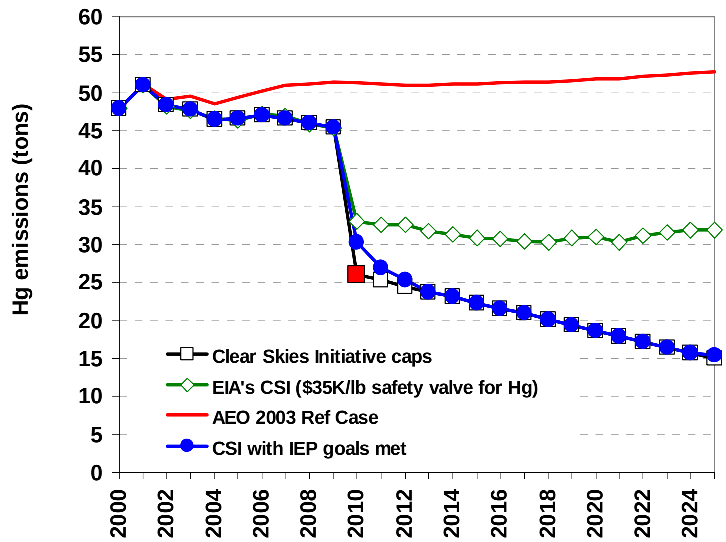

Figure 6.9 Environmental Benefit of Avoided Hg Emissions

6.1.3.2 Environmental Benefits from FE Oil & Gas R&D Programs

In an attempt to better characterize the environmental benefits of technological advances achieved by the Oil and Natural Gas Program; preliminary, quantitative estimates of the environmental benefits attributable to program activities were developed. The methodology used to develop the estimates based on NEMS results is a variation of one used in support of a study conducted in 2001 by the National Research Council.[6]

This analysis concludes that over the 2003 to 2025 time period, DOE's Oil Technology Program and Natural Gas Technologies Program will provide the following environmental benefits, depending on budget levels and program areas considered:

- Reduced drilling waste volumes – from 240 to 370 million barrels
- Fewer impacts to surface acres – 110,000 to 210,000 acres
- Reduced air emissions
    - Reduced CO_2 emissions from E&P operations – 2 to 6 million tons
    - Reduced CO_2 emissions from greater use of natural gas in power generation – up to 190 million tons.
    - Other reduced emissions (CO, NO_x, SO_x, hydrocarbons) – 11,000 to 32,000 tons

These results are summarized in Table 6.1.

[6] These data were developed as part of National Research Council (NRC) report entitled, *Energy Research at DOE: Was It Worth It? Energy Efficiency and Fossil Energy Research 1978 to 2000*, Report of the National Research Council, Committee on Benefits of DOE R&D on Energy Efficiency and Fossil Energy, Board of Energy and Environmental Systems, Division on Engineering and Physical Sciences, National Academy Press, July 2001.

Table 6.1

Overall Environmental Benefits Associated with Oil and Natural Gas Program Activities – Proposed FY2004 and $100 Million Budget Cases – Clear Skies Scenario

	Units		Benefits (2004 - 2025) O&G FY04	$100 Million	All FE FY04	All FE $100 Million
Reduced Oil Spills	**(Barrels)**	**- High**	**55,531**	**103,692**	**55,531**	**104,724**
		- Low	**19,867**	**37,097**	**19,867**	**37,466**
Reduced Drilling Waste Volumes	**(Million barrels)**		**329**	**neg**	**370**	**238**
Fewer Surface Acres Impacted	**(Acres)**		**180,502**	**neg**	**210,628**	**110,249**
Reduced Air Emissions				**neg**		
CO_2 from E&P	**(MM tons CE)**		**5**		**6**	**2**
CO_2 from less use	**(MM tons CE)**		**126**	**190**	**-137**	**-26**
Other emissions	**(Thousand tons)**		**26**	**neg**	**32**	**11**

n.e. = Not estimated;

6.1.4 Energy Prices

In this study, monetary benefits are calculated in terms of savings in energy costs to U.S. consumers. The goal of FE R&D is to provide cleaner energy at lower prices to U.S. consumers. FE R&D directly influences the price of electricity, natural gas, oil and coal. Table 6.2 shows the impact on electricity and natural gas prices for each case. The natural gas prices shown in the table are the average natural gas prices to all sectors.

Table 6.2 Impact of FE's R&D Program on Electricity and Natural Gas Prices by 2025

	Average Price of Electricity (¢/kWh)	**Average Price of Natural Gas ($/MMBtu)**
Year 2002	6.9	4.6
Case 1A: CSI *without* FE R&D	7.0	6.4
Case 1B: CSI *with* FE R&D	6.6	5.8
Case 2A: CSI, high natural gas prices, *without* FE R&D	7.2	7.5
Case 2B: CSI, high natural gas prices, *with* FE R&D	6.7	6.5
Case 3A: CSI with carbon cap *without* FE R&D	8.6	7.1
Case 3B: CSI with carbon cap *with* FE R&D	7.4	6.0

Case 1A, the Clear Skies Act without FE R&D, shows a significant increase in electricity prices as plants add costs by either switching from coal to natural gas or installing pollution control retrofits for SO_2, NOx and Hg on existing coal plants to meet Clear Skies Act emissions caps .

Case 1B, the Clear Skies Act with FE R&D, yields lower electricity prices, by effectively achieving the stringent Clear Skies emissions caps without increased costs to U.S. consumers. The difference in electricity prices between Case 1A and Case 1B is solely attributable to FE R&D. Monetary benefits due to FE R&D can be calculated simply by multiplying the price reduction from Case 1A to Case 1B by the amount of electricity consumed. The reduced demand for natural gas, as coal plants can cost-effectively meet the CSI caps, puts downward pressure on natural gas prices.

Case 2A, the Clear Skies Act with higher natural gas prices and without FE R&D, shows slightly higher electricity prices than Case 1A after 2015, and is 0.2 ¢/kWh higher by 2025. Due to the effects of FE R&D, electricity prices in Case 2B are lower than in Case 2A by about 0.5 ¢/kWh. Although Scenario 2 assumed restrictions on gas supply which increased the price of natural gas across the board, it is clear from Table 6.2 that in the case with FE R&D (Case 1B), the advanced technologies of the R&D program dampen the price increase.

Case 3A, the Clear Skies Act with a carbon cap and without FE R&D, shows a large increase in electricity prices as the carbon cap begins in 2009. The impact of FE's R&D is revealed after 2013, when Case 3B prices start to decrease dramatically as the first advanced coal with carbon sequestration plants enter the market. Table 6.2 indicates that by 2025, Case 3B prices are 1.2 ¢/kWh lower than Case 3A prices.

6.1.5 Monetary Benefits

The annual monetary benefits produced by FE R&D can be calculated simply by multiplying the annual reductions in energy prices (between the "A" and "B" cases as shown in Table 6.2) by the annual consumption of electricity or natural gas. Figures 6.10 – 6.13 show cumulative benefits for savings in electricity costs, natural gas costs to all consumers, and total cost savings (electricity plus natural gas[7]) for all cases.

In Scenario 1, benefits of lower electricity costs steadily increase through 2025. In Scenario 2, which is the same as Scenario 1 except natural gas prices are higher, benefits in electricity costs are shifted upward from Scenario 1 levels. In Scenario 3, electricity benefits are similar to Scenario 1 up to 2018, but increase dramatically as carbon sequestration technologies enter the marketplace at about that time. The cumulative electricity benefits of Scenario 3 are nearly $500 billion (in year 2002 dollars) by 2025.

[7] Because cost of electricity includes any reduction in natural gas price, total benefits must use, the natural gas price to all sectors excluding the electricity sector to avoid double counting benefits. Therefore, the totals shown in Figures 6.12 and 6.13 do not exactly match the sum of the savings in Figures 6.10 and 6.11, which includes all sectors in the average gas price.

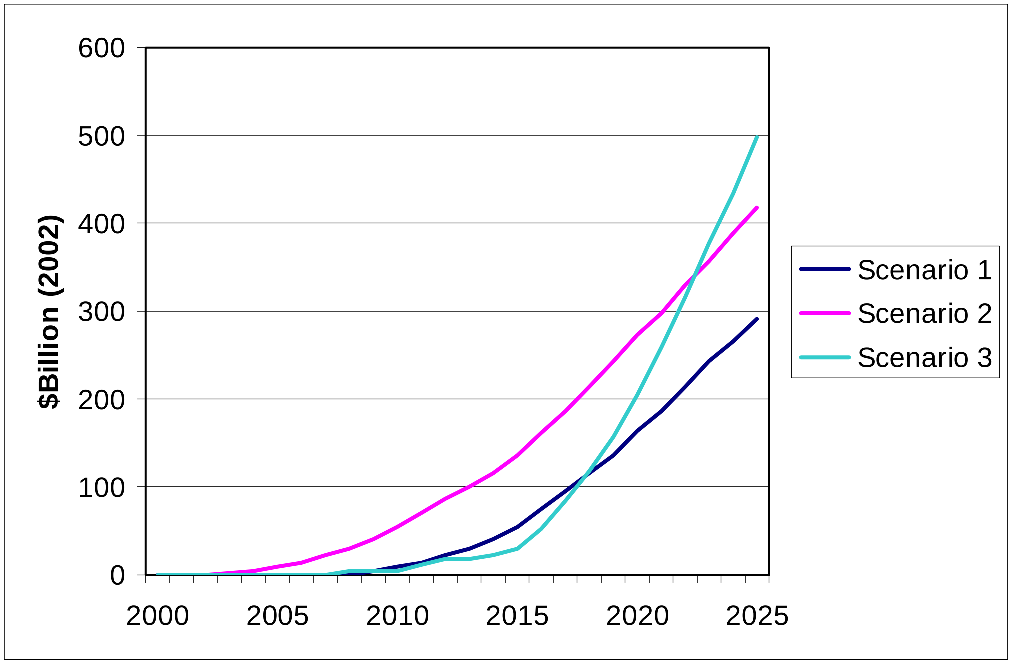

Figure 6.10 Cumulative Cost of Electricity Savings for all Scenarios Non-discounted

The benefits of lower natural gas costs gradually increase for all scenarios. Scenario 2 yields the largest benefits for natural gas prices, exceeding $200 billion (in 2002 dollars) by 2025. Scenarios 1 and 3 have nearly the same benefit since they both have similar gas consumption.

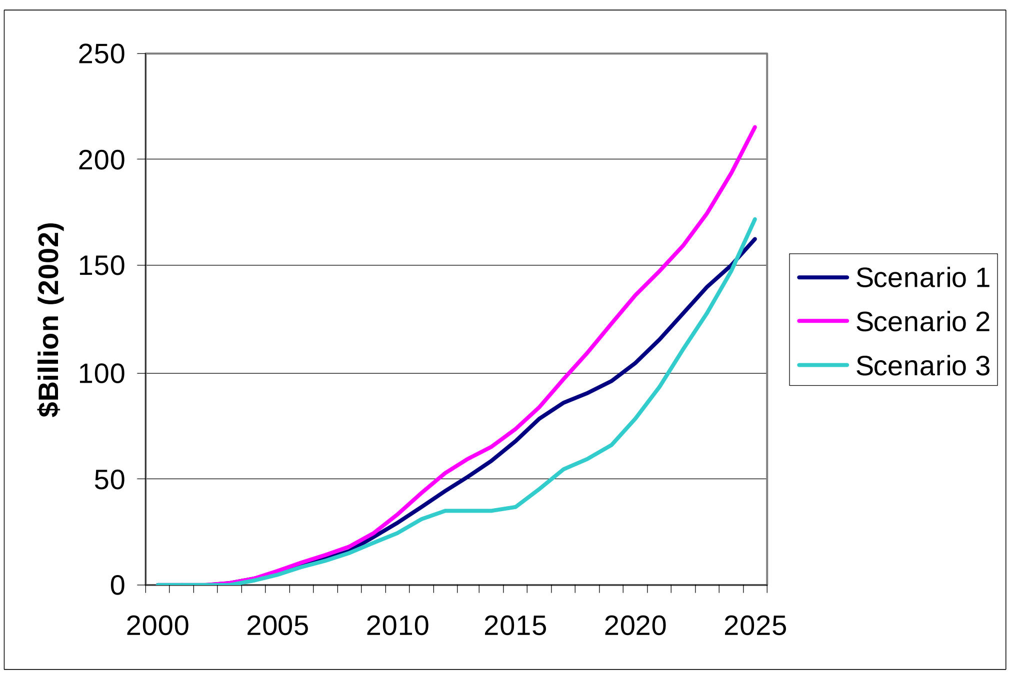

Figure 6.11 Cumulative Natural Gas Savings for all Scenarios Non-discounted

Figure 6.12 compares the total cumulative benefits (electricity plus natural gas benefits) for all scenarios. The benefit trends are similar to those of electricity benefits. Scenario 1 benefits are $450 billion (2002 dollars) by 2025. Scenario 2 benefits are higher than Scenario 1, and Scenario 3 benefits rise dramatically after 2018 as carbon sequestration enters the marketplace. Benefits for Scenario 2 and Scenario 3 each exceed $600 billion (2002 dollars) by 2025.

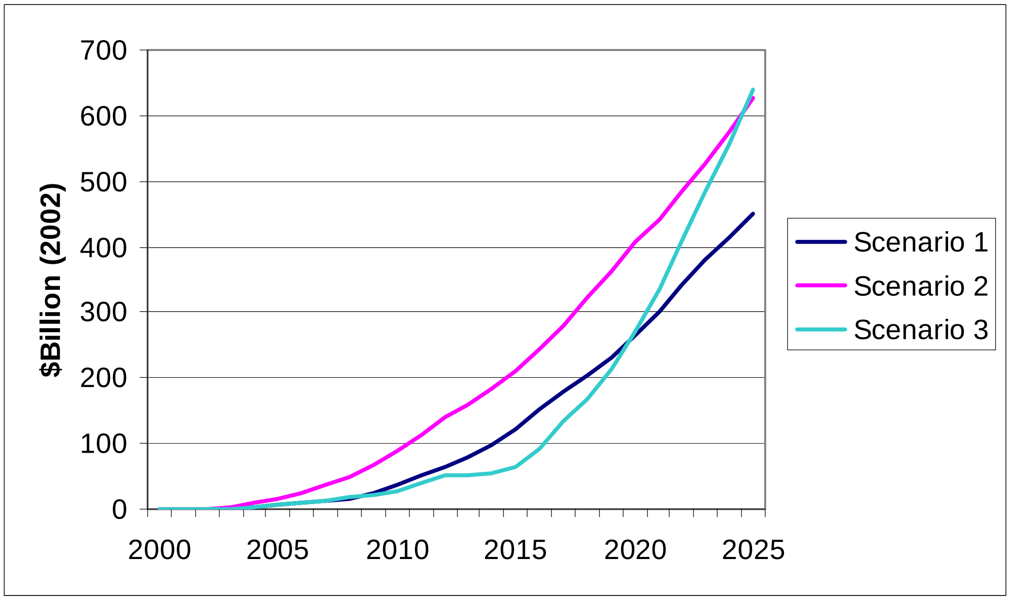

Figure 6.12 Total Cumulative Monetary Benefits for all Scenarios Non-discounted

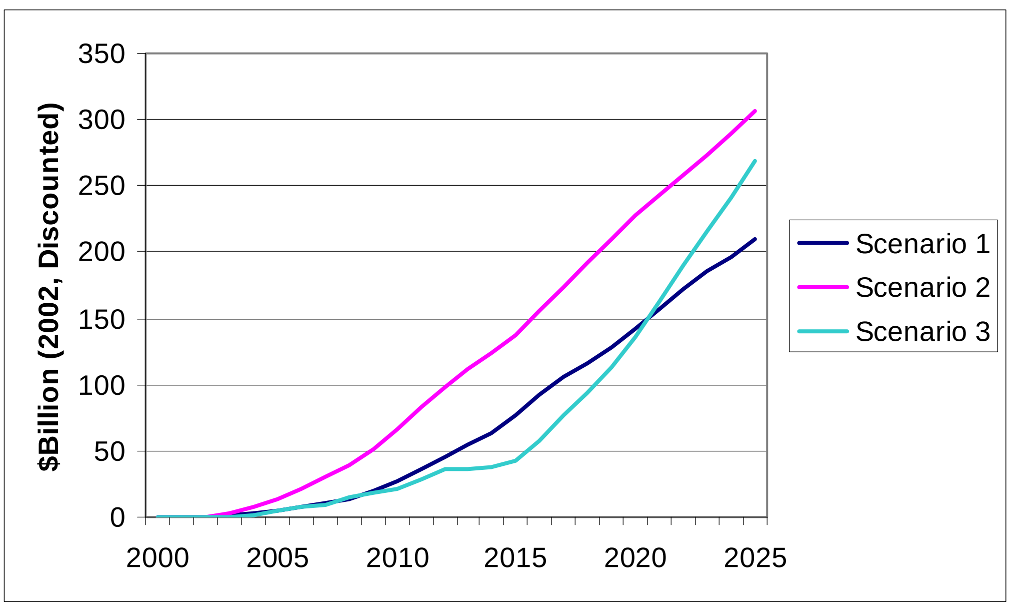

Figure 6.13 Total Cumulative Monetary Benefits for all Scenarios Discounted at 5 percent

If the benefits are discounted at five percent, Scenario 1 benefits are $209 billion. Whereas the benefits for Scenarios 2 and 3 were similar in Figure 6.12, Figure 6.13 illustrates how the effect of when benefits accrue can make a difference. Because the benefits of Scenario 2 start accruing earlier, the discounted cumulative benefit is larger than that for Scenario 3. Total cumulative benefits for Scenario 2 are $307 billion and for Scenario 3 are $267 billion (2002 dollars) by 2025.

6.2 NEMS Forecast Results and Benefits by Technologies

In this section monetary benefits produced by each FE technology are presented as forecasted by NEMS. The following technologies are discussed:

- Advanced Coal Plants
- Carbon Sequestration
- SECA Fuel Cells
- Innovations for Existing Plants (IEP)
- Natural Gas Supply
- Oil Supply

The forecast results include:

- Major Impacts
- Monetary Benefits
- Environmental Benefits
- Energy Security Benefits

Results are presented for the three defined scenarios of this study:

- Scenario 1: The Clear Skies Act
- Scenario 2: The Clear Skies Act with restricted natural gas supply/higher natural gas prices
- Scenario 3: The Clear Skies Act with a carbon cap meeting the goals of the Climate Change Technology Initiative

6.2.1 Benefits of FE's R&D Programs for Advanced Coal Plants

6.2.1.1 Major Impacts

FE's advanced coal technologies represent plants that will be a hybrid of many advanced technologies. These plants will likely be based on IGCC technology that includes advanced turbine and fuel cell technologies using coal-derived syngas. FE has many programs addressing these technologies, including the demonstration FutureGen project and Vision 21 programs. In addition to generating power, these plants may also produce hydrogen. Hydrogen from coal is handled separately by an independent study performed outside the NEMS framework, and is discussed in Section 6.3.1. Advanced coal plants are represented explicitly in NEMS with the cost and performance specifications described in Chapter 4 and Appendix C for advanced IGCC plants. These cost and performance numbers are dependent on the successful cost and performance of syngas turbines and fuel cell/turbine hybrids.

The R&D program discussed in this section does not include carbon sequestration. Advanced coal plants with carbon sequestration are discussed in Section 6.2.2.

The improved performance and cost achieved as the result of FE R&D, results in a significant increase in advanced coal plants in Case 1B of over the AEO 2003 forecast (Figure 6.14). Without FE R&D (Case 1A) 35 GW of advanced coal plants are built by 2025. This is a considerable increase over the AEO 2003 forecast of only seven GW. This is because the cost and performance specifications for advanced coal without FE R&D in this study were better than those forecast by the AEO 2003. In Case 1B, the builds of advanced coal plants grows to 68 GW, or nearly 20 percent of all new plant builds.

In Case 2B with higher natural gas prices, 125 GW of advanced coal plants are built by 2025. This represents about one-third of all new electricity generating plants.

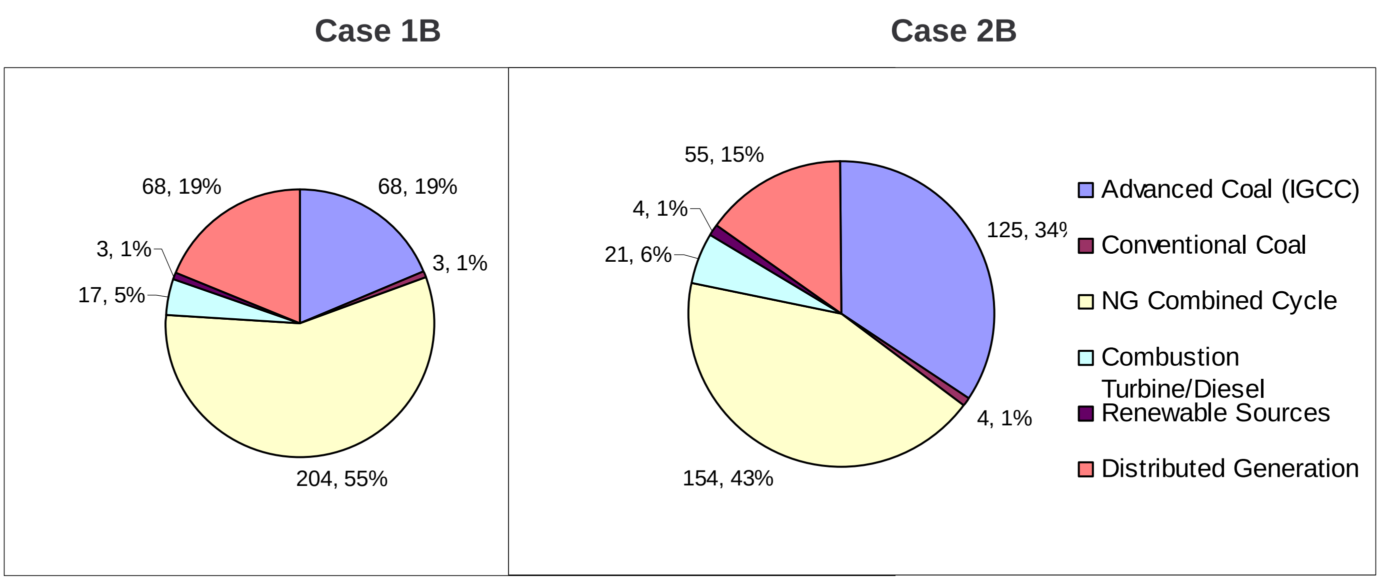

Figure 6.14 Builds of Advanced Coal Plants

To assess the monetary benefits attributable to the programs developing advanced coal plants, the "B" cases were rerun without the impacts of FE's R&D program for advanced coal plants. This means that the cost and performance specifications for IGCC plants in the "A" cases (without FE R&D) were used in the "B" cases. These are called "subtractive" cases and are explained in Chapter 2.

Without FE R&D for advanced coal plants, electricity prices are considerably higher in Scenarios 1 and 2. The increase in electricity costs can be attributed to FE R&D, and thus can be used to calculate the benefits in cost savings for FE R&D for advanced coal plants. The benefit of reduced electricity prices is larger for Scenario 2 because advanced coal plants play a larger role with higher natural gas prices. In Scenario 3, only advanced coal plants that include carbon sequestration are built, so benefits for this scenario are described in the next section.

Just as the case with electricity prices, there is a change in natural gas prices caused by the "subtraction" of FE R&D for advanced coal plants technology. Again, the increase in natural gas prices can be attributed to FE R&D for advanced coal plants, and thus can be used to calculate the benefits in cost savings for this program. The increase in natural gas prices is significant for Scenarios 1 and 2, and begins at the time advanced coal plants enter the marketplace about 2014. In Scenario 3, only advanced coal plants that include carbon sequestration are built, so benefits for this scenario are described in the next section.

6.2.1.2 Monetary Benefits

Figure 6.15 shows cumulative benefits of FE's R&D program for advanced coal plant R&D as the result of decreased cost of electricity. The average cost of electricity to all consumers is reduced by 0.24 – 0.53 ¢/kWh for Scenarios 1 and 2, respectively. This results in cumulative benefits of $85 to $274 billion dollars (2002 dollars). The higher natural gas prices assumed in Scenario 2 result in benefits that are significantly higher than Scenario 1 benefits. This indicates that advanced coal plants market penetration and impacts are very sensitive to natural gas prices.

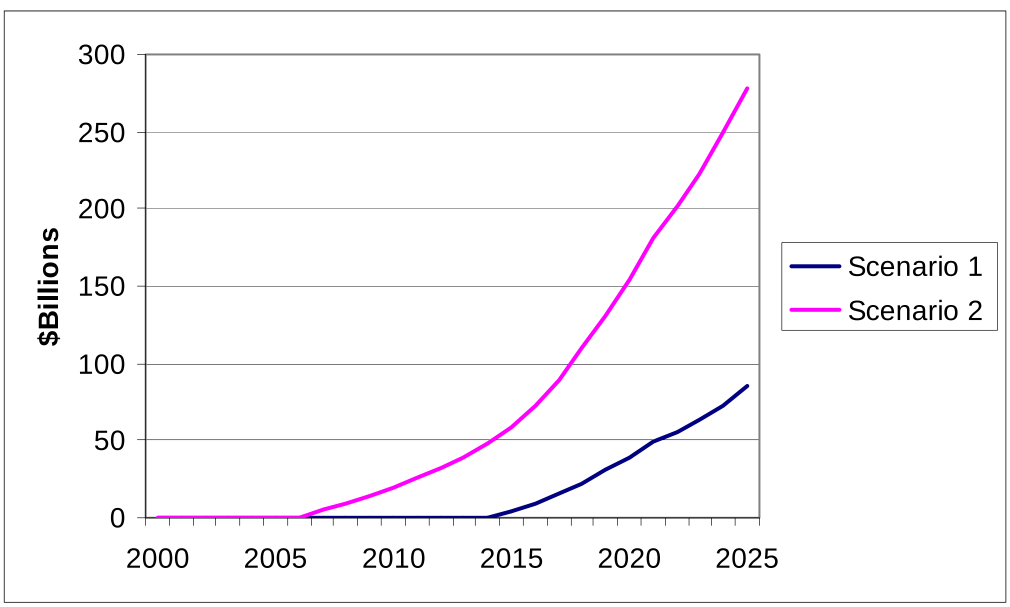

Figure 6.15 Cumulative Electricity Cost Savings Advanced Coal Plant R&D Program, Scenarios 1 & 2

Figure 6.16 shows the cumulative benefits of FE advanced coal plant R&D as the result of decreased natural gas prices. As the increased use of coal in the fuel mix drives down the demand for natural gas power generation, natural gas prices to all sectors are reduced. To calculate this benefit, the reduced natural gas price was multiplied by the natural gas consumption to determine total savings. In this figure, the savings include reduced natural gas prices to all sectors, including the electricity sector.

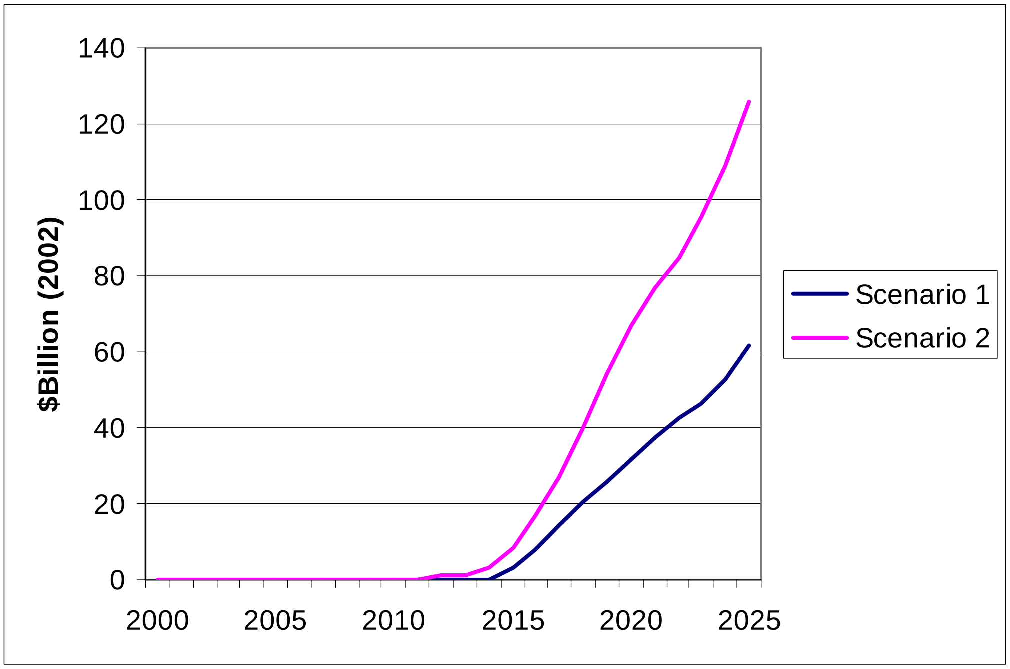

Figure 6.16 Cumulative Natural Gas Cost Savings Advanced Coal Plant R&D Program, Scenarios 1 & 2

Total monetary benefits (the sum of electricity and natural gas cost savings) is shown in Figure 6.17. These curves are not simply the sum of those in Figures 6.15 and 6.16. Figure 6.17 shows natural gas cost savings to all sectors, which includes the electricity sector. To avoid double counting benefits, the natural gas cost savings were determined for all sectors excluding the electricity sector. This is because the cost of electricity already accounts for the reduced natural gas price to utilities in the electricity sector.

The results reported thus far were calculated using the "subtractive method" explained in Chapter 2. This is considered a more conservative estimate since other advanced technologies still remain in the market place and can compete to replace the advanced coal plant technology that was removed from the NEMS run. To get an estimate of the maximum potential benefits of the advanced coal technology, Case 1A was rerun with the cost and performance specifications of advanced coal plants *with* FE R&D. This is called the additive method of determining benefits and is explained in Chapter 2. The range of benefits for advanced coal plant R&D using both methods are shown in Table 6.3.

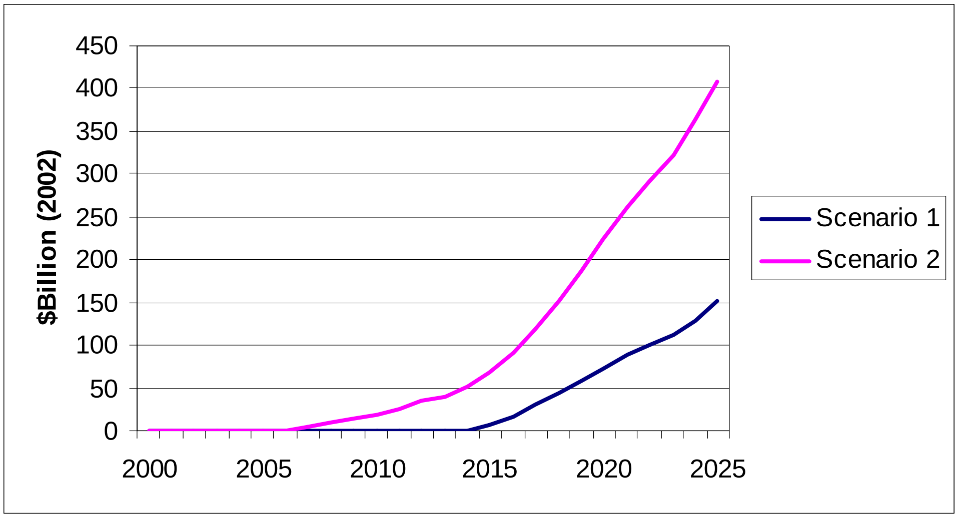

Figure 6.17 Total Cumulative Monetary Savings Advanced Coal Plant R&D Program, Scenarios 1 & 2

Table 6.3 Total Cumulative Monetary Benefit for Advanced Coal Plant R&D Program ($billion, 2002 dollars)

Subtractive Method		**Electricity**	**Natural Gas**
	Scenario 1	85	67
	Scenario 2	274	130
Additive Method			
	Scenario 1	250	155
	Scenario 2	286	165

6.2.2 Benefits of FE's R&D Programs for Carbon Sequestration

6.2.2.1 Major Impacts

FE's Carbon Sequestration R&D Program contains many elements for the stabilization of CO_2. In this section, the impacts and benefits of only one element of the Carbon Sequestration Program, sequestration of CO_2 from the power sector, is discussed. Additional benefits determined by an independent analysis are also included in Section 6.3.2. The sequestration of CO_2 from the power sector is represented explicitly in NEMS with the cost and performance specifications described in Chapter 4. The technology consists of an IGCC plant, discussed in the previous section, but with carbon capture and sequestration integrated into the plant. FE has many programs addressing carbon sequestration, including the FutureGen demonstration project.

Coal-fired sequestration plants will only be built if a constraint on carbon emissions is imposed, such is the assumption in Scenario 3. Figure 6.18 shows builds of new advanced coal plants with sequestration forecast by NEMS in Scenario 3.

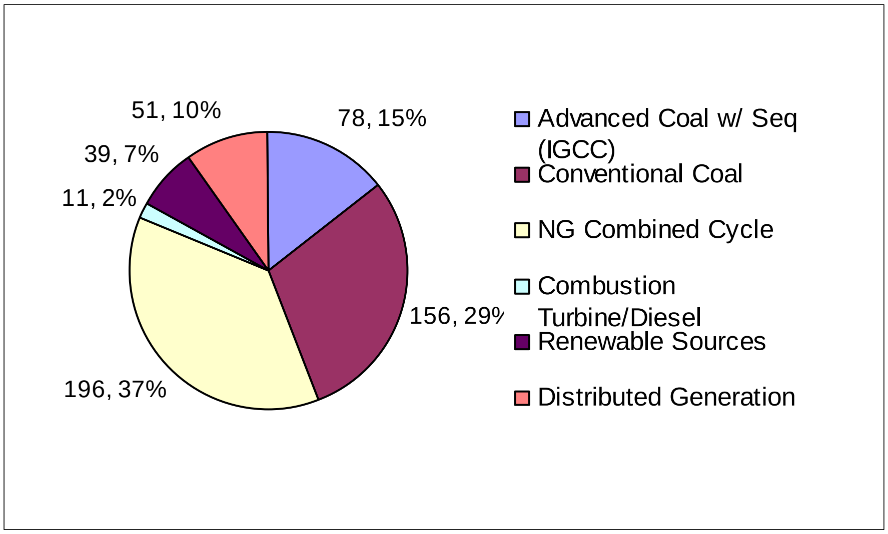

Figure 6.18 Builds of IGCCs with Sequestration, Scenario 3 (Carbon Constraint)

Advanced coal plants come on line after 2015. A total of 78 GW of these plants are operating by 2025, representing 15 percent of the new electricity generating capacity operating in 2025. Natural Gas Combined Cycle (NGCC) plants with carbon sequestration are available in the Case3B case, but none are built.

As seen in Figure 6.19, this differs from the EIA's forecast of the Climate Stewardship Act of 2003, also known as the McCain-Lieberman Bill [EIA, S139], in which more NGCC plants with carbon sequestration were built than advanced coal plants with carbon sequestration. The difference between Case3B of this study and the McCain-Lieberman Bill forecast can be explained by the fact that this study used similar capital costs for NGCC plants with carbon sequestration, but better capital costs for advanced coal plants with carbon sequestration. The McCain-Lieberman case also forced much deeper reductions in carbon emissions from the electricity sector, reducing emissions to 200 mmtce by 2025. This required more builds of plants with carbon sequestration. The carbon cap of this study (Scenario 3) is 600 mmtce.

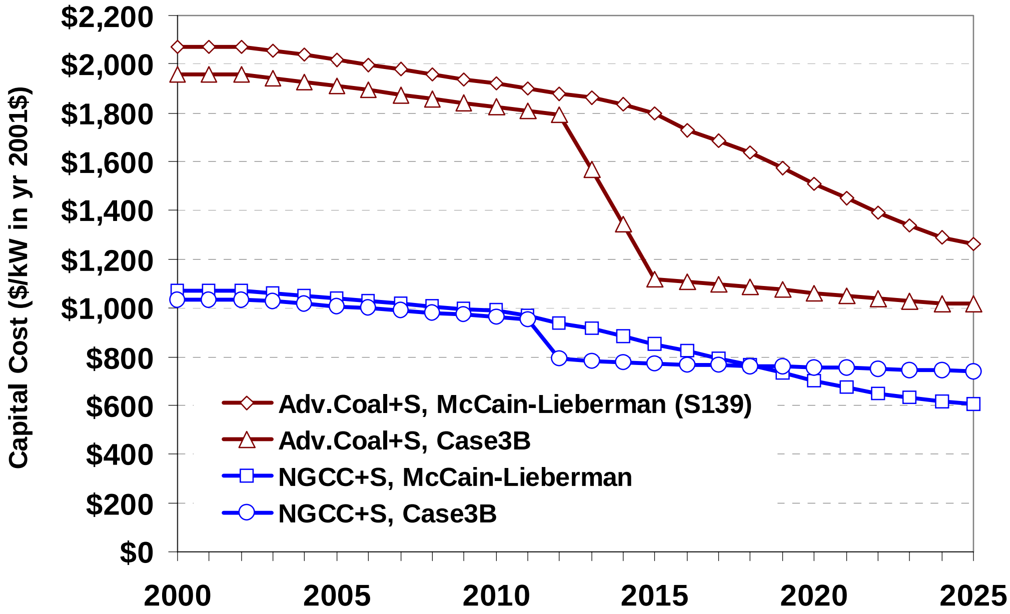

Figure 6.19 Total capital costs of Advanced Coal Plants with carbon sequestration (IGCC+S) and NGCC plants with carbon sequestration (NGCC+S) in Case3B and in the EIA's McCain-Lieberman case [EIA, S139, 2003].

To assess the monetary benefits to attribute to the sequestration program, the"B"cases were rerun without the impacts of FE R&D for sequestration. This means that the cost and performance specifications for IGCCs with sequestration in the "A" cases (without FE R&D) were used in the "B" cases. These are called "subtractive" cases and are explained in Chapter 2.

Without FE R&D for sequestration, electricity prices are considerably higher in Scenario 3. The increase in electricity costs can be attributed to FE R&D, and thus can be used to calculate the benefits in cost savings for FE R&D for sequestration systems.

As is the case with electricity prices, there is a change in natural gas prices caused by the "subtraction" of FE R&D for sequestration technology. Again, the increase in natural gas prices can be attributed to FE R&D for sequestration, and thus can be used to calculate the benefits in cost savings for this program. The increase in natural gas prices is significant, and begins at the time advanced IGCC plants with sequestration enter the marketplace, about 2015. In Scenario 3, only advanced coal plants that include carbon sequestration are built, so benefits for this scenario do not include IGCC plants that are not capturing and sequestering carbon.

6.2.2.2 Monetary Benefits

Figure 6.20 shows cumulative benefits of FE Sequestration R&D as the result of decreased cost of electricity. The average cost of electricity to all consumers is reduced by 0.5 ¢/kWh. This results in a cumulative benefit of $127 billion dollars (2002 dollars).

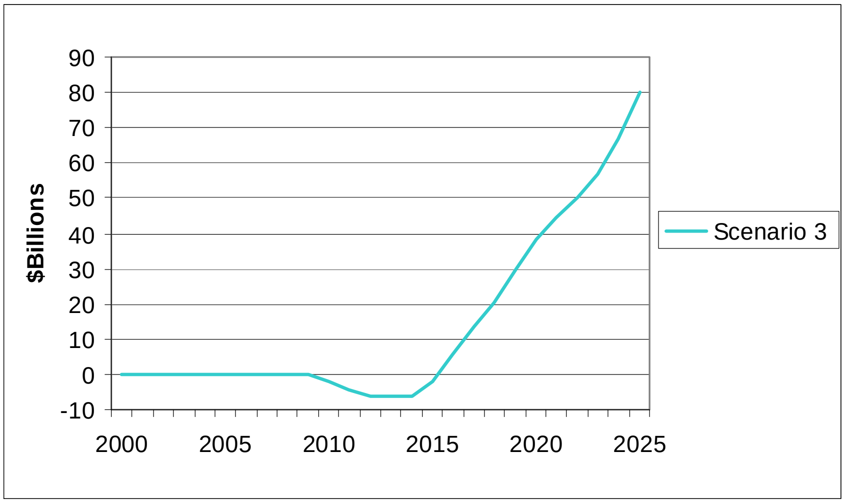

Figure 6.20 Cumulative Electricity Cost Savings
Advanced Coal Plants with Sequestration R&D Program, Scenario 3

Natural gas prices are higher after 2013 without sequestration because the electricity sector uses more natural gas to comply with the carbon emission cap. In this scenario, advanced coal plants with sequestration reduce the demand for natural gas in the electricity sector and consequently natural gas prices decrease significantly after the sequestration plants enter the market. Figure 6.21 shows the cumulative savings due to reduced natural gas expenditures throughout all sectors, which are from FE's Sequestration R&D program.

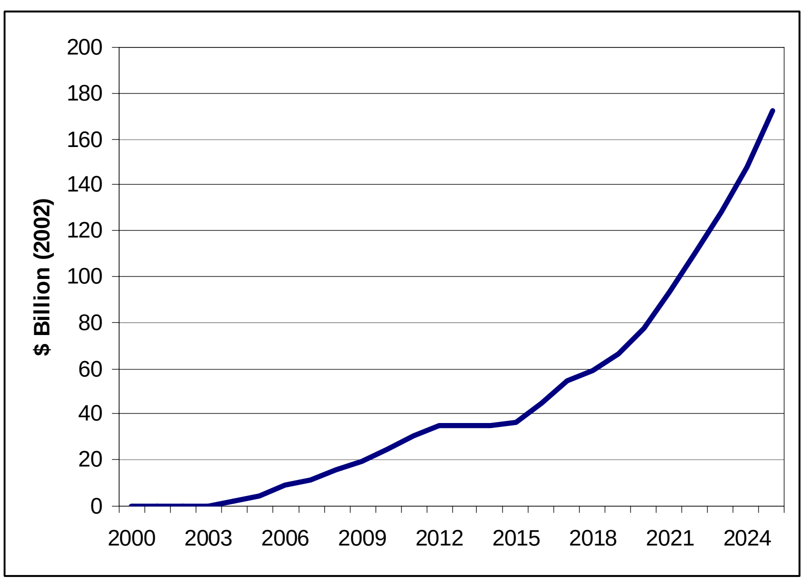

Figure 6.21 Cumulative Natural Gas Cost Savings
Advanced Coal Plants with Sequestration R&D Program, Scenario 3

Benefits of sequestration power plants arise in later years of the forecast horizon. The upward trend of benefits approaching 2025 suggests that benefits would continue on an upward trend after 2025, although benefits after 2025 were not considered in this study.

Total monetary benefits (the sum of electricity and natural gas cost savings) is shown in Figure 6.22. This curve is not simply the sum of those in Figures 6.20 and 6.21. Figure 6.21 shows natural gas cost savings to all sectors. This includes the electricity sector. To avoid double counting benefits, the natural gas cost savings were determined for all sectors excluding the electricity sector. The cost of electricity already takes into account the reduced cost of natural gas to utilities in the electricity sector.

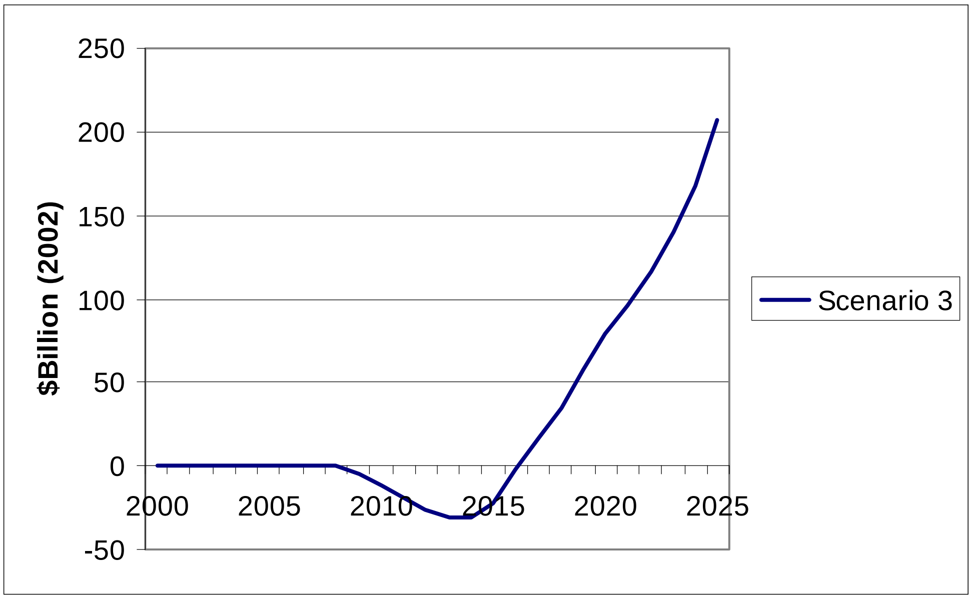

Figure 6.22 Total Cumulative Monetary Savings Sequestration R&D Program, Scenario 3

The results reported thus far have been calculated using the "subtractive method" explained in Chapter 2. This is considered a more conservative estimate since other advanced technologies still remain in the market place and can compete to replace the advanced coal plant technology that was removed from the NEMS run. Unintentionally, the additive method was not performed for Scenario 3. Table 6.3 summarizes the total cumulative monetary benefits for the Sequestration R&D Program.

Table 6.3 Total Cumulative Monetary Benefit for Sequestration R&D Program ($billion, 2002 dollars)

		Electricity	Natural Gas
Subtractive Method			
	Scenario 3	127	80
Additive Method			
	Scenario 3	Not calculated	Not calculated

6.2.3 Benefits of FE's R&D Programs for Fuel Cells (SECA)

The cornerstone of FE's fuel cell R&D is SECA [SECA, 2003]. SECA plans to develop a solid-oxide fuel cell that is versatile and cost-competitive, overcoming technical and cost barriers to make fuel cells available for a wide range of applications, from utility-owned local, grid-connected fuel cell plants, to powering homes and businesses, to providing auxiliary power in cars and trucks.

Several types of fuel cells are modeled in NEMS. Utility owned, grid connected fuel cells in the 10-20MW capacity range are modeled in EMM of NEMS. The EMM also separately models fuel cells as baseload DG applications with a smaller size in the range of 1-2MW. Fuel cells for buildings are modeled in the commercial and residential modules of NEMS. The forecasts in this study show that most fuel cells will be, as modeled in the EMM: either grid-connected utility-owned fuel cells or baseload distributed generator fuel cells. For purposes of discussing results, these two fuel cell applications are combined into one category simply called fuel cells. Fuel cells in the transportation sector are modeled in NEMS, but the cost and performance of these fuel cells were not varied in this study.

6.2.3.1 Major Impacts

Figure 6.23 shows builds of new fuel cells forecast by NEMS in all cases. For all of the "B" cases, with FE R&D, fuel cells have about the same market penetration at around 50 GW. This is a much larger market penetration than the A cases without FE R&D. Fuel cells start to penetrate the market at an early date, around 2007, and steadily increase market share through 2025. In all cases, fuel cells are built instead of pulverized coal plants in the "B" cases. The upward trend approaching 2025 suggests that market penetration of fuel cells would continue to increase significantly after 2025.

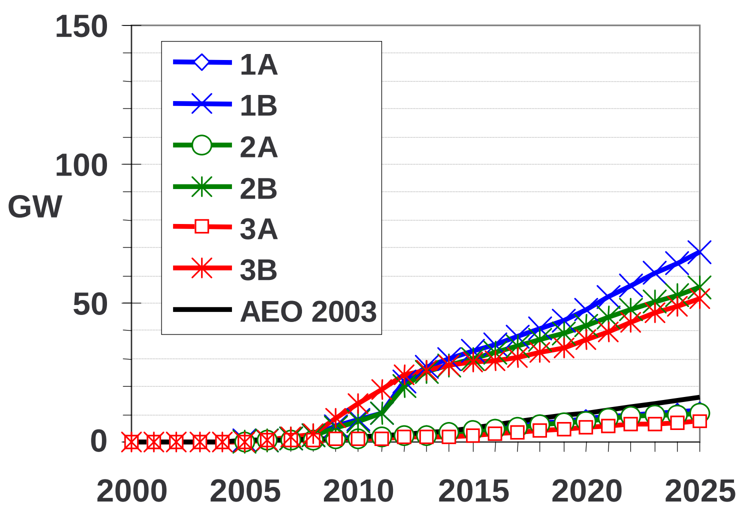

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Figure 6.23 Builds of Fuel Cell plants in all "A" and "B" cases

To assess the monetary benefits attributable to the Fuel Cell R&D Program, the "B" cases were rerun without the impacts of FE R&D for fuel cells. This means that the cost and performance specifications for fuel cells in the "A" cases (without FE R&D) were used in the "B" cases. These are called "subtractive" cases and are explained in Chapter 2.

Without FE R&D for fuel cells, electricity prices are higher. The change in electricity costs can be attributed to FE R&D, and thus can be used to calculate the benefits in cost savings for FE R&D for fuel cells. The benefit of reduced electricity prices is larger for Scenario 2 because the efficiency of fuel cells mitigates the effect of higher priced natural gas on the cost of electricity. In Scenario 3, fuel cells are utilized in the generation mix to meet the carbon emission limits.

Fuel cells generally have a smaller market penetration and impact on energy prices than do advanced coal plants. It should be noted that the advanced coal plant technology described in this study will depend on the use of fuel cells to reach high efficiencies in later years of the forecast horizon. Therefore, some of the benefits for advanced coal plants should be attributed to fuel cells, but this was not done in this study.

In all cases, natural gas prices *decrease* when fuel cells are "subtracted" from Case 1B. This gives rise to the calculation of *negative* benefits. Without FE R&D for fuel cells, market penetration of fuel cells drops from around 50 GW to around 10 GW by 2025. The 40 GW of fuel cells that are not built are replaced by pulverized coal plants. Recall that in all "B" cases, fuel cells are built instead of pulverized coal plants. The switch from fuel cells to coal plants causes a reduction in demand for natural gas. The reduction in demand for natural gas causes natural gas prices to decrease.

Advanced fuel cells are necessary for the high efficiencies achieved by advanced coal plants. A forecast could be done in which the efficiency of advanced coal is lessened to account for the absence of advanced fuel cells, but that was not done in this study.

6.2.3.2 Monetary Benefits

Figure 6.24 shows cumulative benefits of FE R&D for fuel cells. In Scenario 1, Clear Skies, although a significant market penetration of fuel cells occurs, there is no change to electricity prices. However, in Scenarios 2 and 3, when gas prices are high or a carbon constraint is imposed, fuel cells have a significant impact. After 2007, the high efficiency and significantly reduced costs of SECA fuel cell more than compensate for the increased cost of natural gas. Cumulative savings range from $41 to $107 billion (2002 dollars) by 2025 for these two Scenarios.

To get an estimate of the maximum potential benefits of the fuel cells, Case 1A was rerun with the cost and performance specifications of fuel cells *with* FE R&D. This is called the additive method of determining benefits and is explained in Chapter 2. The benefits of fuel cells using the additive method are shown in Table 6.4. For fuel cells, the additive method gives negative values for natural gas price benefits and for total benefits. This is because if fuel cells alone are available in the market place, the demand for natural gas increases significantly, raising prices for both natural gas and electricity.

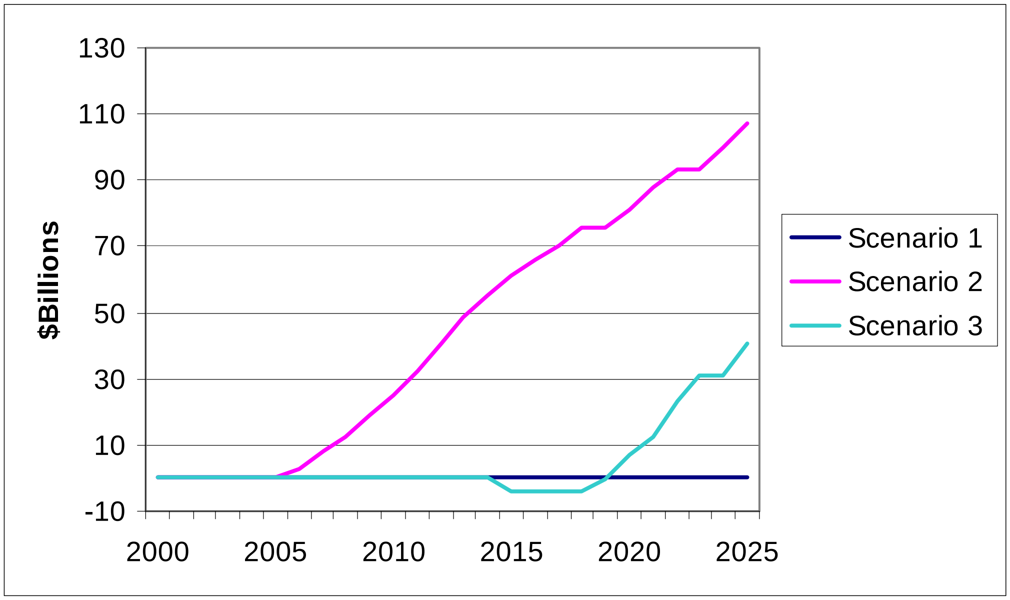


Figure 6.24 Cumulative Electricity Cost Savings Fuel Cells R&D Program

Table 6.4 Total Cumulative Monetary Benefit for SECA Fuel Cells R&D Program ($billion, 2002 dollars)

Subtractive Method		Electricity	Natural Gas
	Scenario 1	0	-33
	Scenario 2	107	-40
	Scenario 3	41	0
Additive Method			
	Scenario 1	-9	-96
	Scenario 2	0	-73
	Scenario 3	0	0

The addition and subtraction methodology used in this study is intended to give an estimate of the range of benefits for each FE technology. However, because most builds of new electricity generating plants are expected to be natural gas plants, and because the natural gas supply is near its maximum supply potential, the addition of more natural gas plants results in higher total energy costs to U.S. consumers. It is unlikely that FE R&D goals will be achieved for fuel cells but not for any other FE technology. Although the "A" cases were intended to give an estimate of the maximum potential benefits of a technology, this methodology does not produce the intended result for fuel cells.

However, the additive forecast for fuel cells does raise an important issue, that is, that there is a strong cause-and-effect relationship between the types of electricity plants built and natural gas prices outside the electricity sector, and that this relationship can cause unintended, negative consequences. The additive fuel cell case shows that a cheap, less efficient natural gas electricity technology can compete and win market share in the electricity sector and, because of the increased demand for natural gas, cause additional expenses to natural gas consumers outside the electricity sector. Natural gas consumers have no direct influence on the decision to build electricity plants. However, the decision to build certain types of electricity plants can and does influence natural gas prices to consumers outside the electricity sector.

6.2.4 Benefits of FE's Innovations for Existing Plants (IEP) R&D Program

FE's Innovations for Existing Plants (IEP) R&D program develops "retrofit" technologies to reduce emissions of NOx, Hg, acid gas (SO_3), and particulates from existing coal-fired power plants. The IEP program also develops technologies to utilize coal by-products. The EMM of NEMS explicitly models the retrofit of technologies to reduce emissions of SO_2, NOx, and Hg under various environmental regulations, including Maximum Achievable Control Technology (MACT) regulations and the national cap-and-trade regulations of CSI. The retrofit technologies modeled in the EMM include

- Flue Gas Desulfurization (FGD) Scrubbers for SO_2
- Combustion controls for NOx
- SCR Post-combustion Control for NOx
- SNCR Post-combustion Control for NOx
- Activated Carbon Injection (ACI) for Hg
- ACI with spray cooling for Hg
- ACI with fabric filter for Hg

The EMM does not model retrofit technologies for SO_3 and particulates. Neither does the EMM model the utilization of coal by-products. These technologies are not modeled because the additional environmental regulations required to force the implementation of these technologies are not known at this time. EIA uses NEMS to model environmental regulations already in place. Occasionally a member of Congress requests that EIA use NEMS to model proposed environmental legislation. The benefits of SO_3 and particulate control technologies will depend on the nature and magnitude of the environmental regulations covering them. Because of time constraints, because NEMS does not model them, and because of the uncertainly of environmental regulations to cover them, the benefits of SO_3 control technologies, particulate control technologies, and coal by-products were not included in this study. They will be included in future benefits studies by FE. Previous estimates of IEP benefits by Feeley and Hoffman are included in Appendix D. Their estimates show that most of the benefits from the IEP program will come from Hg and NOx control technologies.

For this study EIA modified the EMM to reduce the costs of Hg and NOx retrofit technologies to meet the goals of the IEP program. These goals are:

- IEP Goal 1: reduce the cost of Hg and NOx removal 25 percent by 2010
- IEP Goal 2: reduce the cost of Hg and NOx removal 50 percent by 2015

EIA's NEMS forecasts for this and other studies [EIA S485, 2003; EIA 2001-04; EIA 2001-05] show that the primary compliance strategy under the CSI and other three pollutant (3P) (SO_2, NOx and Hg) regulations is to add emissions control technologies to existing coal-fired power plants. Fuel switching from coal to natural gas is a secondary compliance strategy. Many of the retrofit technologies for SO_2 and NOx also remove some mercury from the flue gas of coal plants [EIA 2001-03]. To comply with the CSI Hg caps, the primary compliance strategies are to add SO_2 or NOx retrofit technologies that also remove Hg and, when SO_2 and NOx retrofits do not remove enough Hg or are not available, to add ACI. If a coal plant does not have existing particulate controls that are adequate to capture the activated carbon particles, an additional fabric filter must be added to capture the activated carbon particles.

After examining initial NEMS forecasts of electricity prices with and without FE program goals for Hg and NOx retrofit controls, it was determined that the reductions in electricity prices created by meeting IEP goals were not seen in the results because they are within the convergence tolerance of NEMS. Because NEMS models the entire energy economy of the U.S., small changes in energy prices (< 1 percent) are not always resolved. This is explained below.

The AEO 2003 Reference Case showed that the total annual cost paid for electricity by U.S. consumers was $250 billion in 2002, and is expected to increase to $275 billion in 2010 (year 2002 dollars) and $370 billion (year 2002 dollars) by 2025. These amounts could increase significantly if regulations to reduce carbon emissions are implemented.

The benefits of meeting IEP goals for Hg and NOx retrofits were previously estimated by Hoffman and Feeley [NETL P1, 2003] to be $1 billion to $2 billion annually (see Appendix I1?). This represents less than one percent of the total annual cost of electricity to U.S. consumers

The reduction in electricity prices created by the IEP goals may be significantly less than one percent because, under deregulated markets, the cost savings created by IEP goals may be adsorbed by power producers rather than consumers. The cost of emissions compliance is first realized by power producers who must pay for their chosen method of reducing emissions. Under regulated market conditions, the cost of compliance is usually passed on to consumers in terms of higher electricity prices. In deregulated markets however, electricity prices are determined by marginal pricing and the cost of emissions compliance may not always be passed on to the consumer. This is the case for coal-fired units in deregulated markets when electricity prices are being determined by natural gas-fired turbines. Natural gas-fired turbines do not need to control SO_2 or Hg emissions; consequently, the additional cost of controlling SO_2 or Hg emissions is not included in the market price of electricity. In deregulated markets, the cost of emissions compliance for coal-fired units may be passed on to investors (in terms of lower profits) rather than to consumers in terms of higher electricity prices. Thus, the reduction in electricity prices created by the IEP goals may be significantly lower than one percent and will not be resolved by NEMS.

Since the reduction in electricity prices created by the IEP will be less than one percent, and since changes in electricity prices of one percent or less will not necessarily be resolved by NEMS forecasts [EIA P1, 2003], an alternative method was used to estimate the benefits of the IEP program. Some data from NEMS was used in the calculations, as is discussed below in Section 6.2.4.1.

6.2.4.1 Monetary Benefits of IEP Hg Control R&D

Calculation of the monetary benefits of the IEP program for Hg control is based on the following assumptions:

- The cost of Hg removal is reduced by 25 percent in 2010 and 50 percent in 2015
- The average cost of removing one pound of Hg is $60,000
- National Hg emissions are reduced to meet the caps of the CSI (26 tons in 2010 and 15 tons in 2018)

To estimate the benefits of Hg control outside of NEMS, the cost to remove each pound of Hg was assumed to be at the low end of the forecast of Hg allowance prices as shown in Figure 6.25. The forecast in Figure 6.25 is for Case 1B, the Clear Skies Act with FE R&D, but without the $35,000/lb safety valve, and thus the actual Hg emissions caps of the CSI (26 tons in 2010 and 15 tons in 2018) are met. EIA's cost estimates for ACI were used in this forecast. The cost of $60,000/lb is at the low end of the forecast of Hg allowance prices, so a cost of $60,000/lb was assumed in this calculation of the benefits created by meeting the R&D goals of the IEP program.

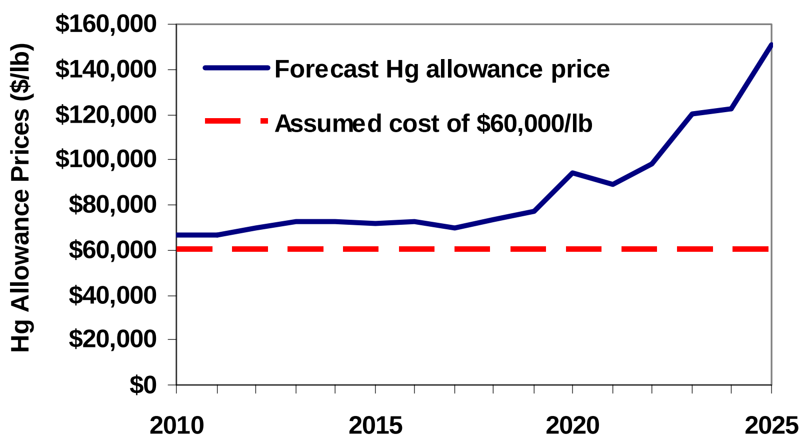


Figure 6.25 Forecast Hg allowance trading price without the $35,000/lb safety valve.

The calculation of the annual monetary benefits for Hg control, A_k, in year k, is simply:

$$A_k = (\text{cost/lb Hg removal}) \times (1 - \%\ \text{cost reduction})_k \times (\text{total pounds of Hg removed to meet CSI caps})_k$$

The cost of Hg removal is assumed to be $60,000/lb. The "% cost reduction" comes from the goals of the IEP program (cost is reduced by 25 percent in 2010 and 50 percent in 2015). The "total pounds of Hg removed to meet CSI caps" is illustrated in the Figure 6.26. Figure 6.26 shows national Hg emissions in the AEO 2003 Reference Case and the actual Hg caps as set by EIA for NEMS cases used in this study. Under CSI, EIA assumed that actual Hg emissions in 2018 will be higher than the 15 ton cap of the CSI because of allowance banking. EIA used estimates of allowance banking from EPA [EIA P1, 2003].

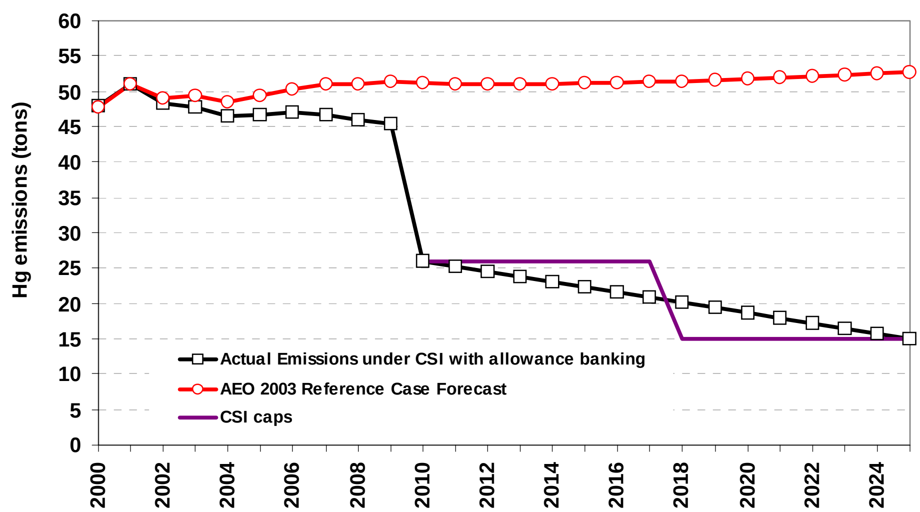


Figure 6.26 Mercury emissions and emissions cap under the CSI with allowance banking

Under CSI, Hg emissions begin to decrease before the 2010 cap on Hg emissions because power producers begin to add additional SO_2 and NOx controls before 2010 in anticipation of CSI's 2008 NOx and 2010 SO_2 caps. When compared to the AEO 2003 Reference case, 40 GW of coal plants add additional SO_2 controls and 90 GW of plants add additional NOx controls before 2010. The total Hg that must be removed each year to meet the CSI caps is given by the difference between emissions in the AEO 2003 Reference case and the actual emissions under the CSI with allowance banking.

Using the equation above, the cumulative benefit between 2010 and 2025 can be calculated by summing the annual benefits, A_k, between 2010 and 2025. This gives a total cumulative benefit of $25.9 billion (in year 2001 dollars) for the IEP's Hg control R&D program through 2025. At a discount rate of five percent, the total Present Value is $11.5 billion (in year 2001 dollars).

6.2.4.2 Environmental Benefits of the IEP Hg Program

The general methodology of this study is to calculate monetary benefits realized by U.S. consumers under the fixed CSI emissions caps. Under fixed national emissions caps, the benefits of improved energy technologies are only measured in the cost to meet the emissions caps. Environmental benefits are determined by CSI regulatory caps. Therefore, the benefits are solely monetary and are in terms of savings in energy costs to U.S. consumers while meeting CSI emissions caps . However, the Clear Skies Act (S.485, HR. 999) includes a "safety valve" provision that limits allowance trading prices for SO_2, NOx, and Hg and therefore can change CSI emissions caps. The safety valve limits are not reached for SO_2 and NOx, but the safety valve limit of $35,000/lb is reached for Hg. Once the Hg allowance trading price reaches $35,000/lb, no further reductions in emissions are required. This changes the national emissions cap for Hg. Because the Hg allowance trading price is a function of the cost and performance of Hg removal technologies, environmental benefits may be calculated for the IEP's Hg program.

The NEMS forecasts showed that, using EIA's cost and performance numbers for Hg control technologies, *the U.S. will not be able to meet the actual 26 ton and 15 ton Hg caps of the CSI.* NEMS forecasts that when the $35,000/lb safety valve is in place, the U.S. will be able to lower its Hg emissions only to about 30 tons per year -- twice the level sought by the Clear Skies Initiative. This is shown by the green line with diamond symbols in Figure 6.27.

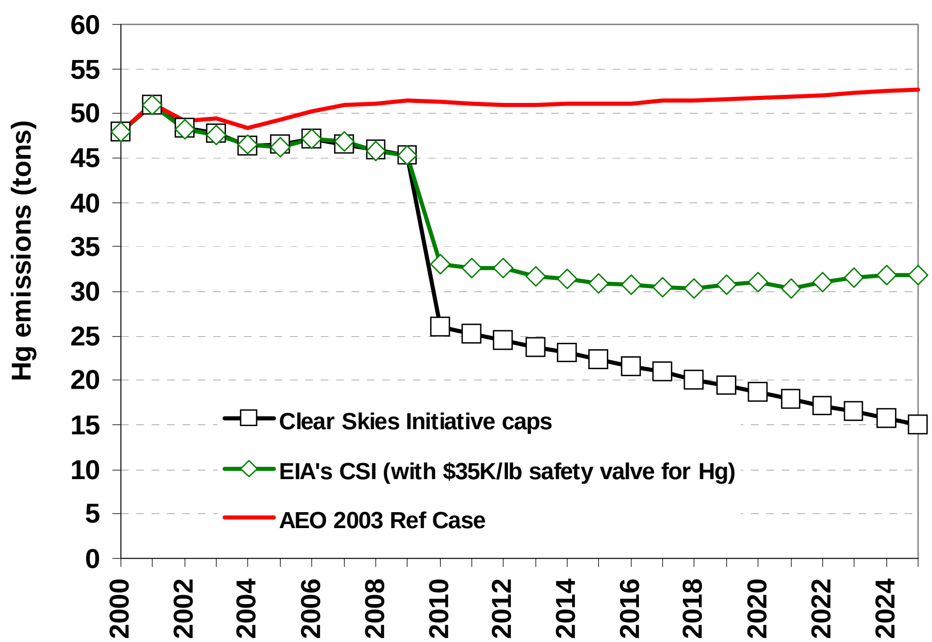


Figure 6.27 Mercury Emissions

If the IEP goals for Hg control technology cost reductions are met , then it is possible to meet the 15 ton/year goal of the CSI without exceeding the $35,000/lb trading price. The forecast of Hg emissions using the cost reduction goals of the IEP program is shown by the blue line with solid circles in Figure 6.28. National Hg emissions are 30 tons in 2010, slightly above the 26 ton CSI cap. After 2013, the CSI caps (with banking) are met exactly.

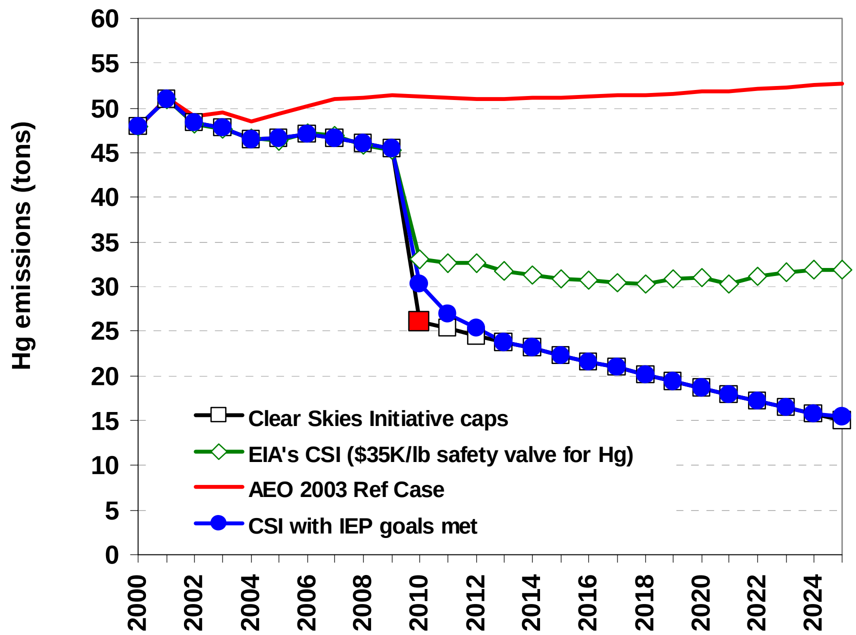


Figure 6.28 Avoided Emissions due to IEP R&D Program

In this case, the benefits of the IEP program are both *monetary and environmental*. The environmental benefits are in terms of additional Hg emissions *avoided*. The environmental benefit is represented by the area between the blue line with solid circle symbols and the green line with diamond symbols. *The environmental benefit is 167 tons of Hg emissions avoided between 2010 and 2025.*

In summary, the following benefits have been calculated for the IEP's Hg control R&D between 2010 and 2025:

- a cumulative total of $25.9 billion (in year 2001 dollars)
- a total Present Value of $11.5 billion assuming a discount rate of five percent
- an environmental benefit of 167 tons of Hg emissions avoided

6.2.4.3 Monetary Benefits of IEP NOx Control R&D

The previous study of Hoffman and Feeley used other models (MC^2 and CUECost) to the predict benefits of the IEP's NOx program. The benefits were predicted to be $0.3 to $0.4 billion/year. Alternatively, IEP NOx benefits can also be estimated by assuming a cost for removing each ton of NOx. The monetary benefit calculation is the same as was used for Hg. NEMS forecasts

NOx allowance trading prices in the range of $1,000/ton to $3,000/ton under the CSI. Using the lower value of $1,000/ton, and following the procedure described above for Hg, NOx benefits are in the range of $0.5 to $1 billion/year. Therefore, we assume that the Hoffman and Feeley's estimates of NOx benefits of $0.3 to $0.4 billion/year are reasonable.

For this study, it is assumed that the benefits for NOx control are $0.3 billion/year from 2010 to 2017, and $0.4 billion/year from 2018 to 2025. Using the cost reduction goals of the IEP program for NOx, calculations show a cumulative benefit of $5.6 billion from 2010 to 2025. At a discount rate of five percent, the total Present Value is $2.6 billion.

6.2.4.4 Total Benefits of the IEP R&D Program

Figures 6.29 and 6.30 show the cumulative benefits and the present values of the cumulative benefits for the IEP program.

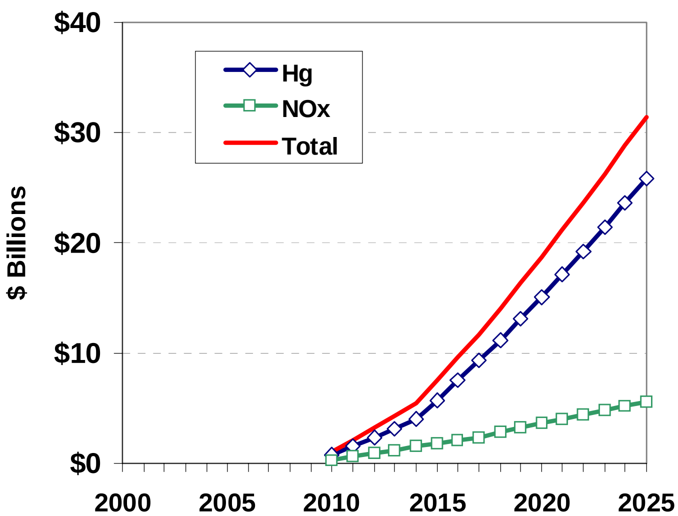


Figure 6.29 Cumulative benefits of the IEP program.

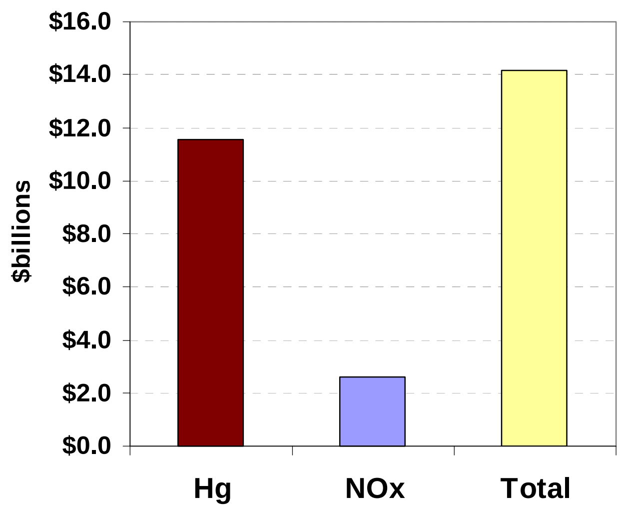


Figure 6.30 Present values of cumulative benefits of the IEP programs using a 5% discount rate.

Thus, the combined benefits of the IEP Hg and NOx control programs through 2025 are:

- cumulative benefits: $25.9 billion
- Present Value of benefits (five percent discount rate): $14.1 billion
- an additional environmental benefit of 167 tons of Hg emissions avoided

6.2.5 Benefits of FE's R&D Programs for Natural Gas

6.2.5.1 Benefits of FE's R&D Programs for Natural Gas Supply

Considerable natural gas-related benefits can also be realized as a result of DOE programs, regardless of scenario. As summarized in Table 6.5, assuming the Clear Skies Scenario and the proposed FY2004 budget at the time of the analysis, these benefits include:

- Average wellhead natural gas prices will be reduced by as much as $0.46 to $0.59 per Mcf based on Oil and Gas Program activities. Somewhat larger reductions ($0.65 per Mcf) are realized as a result of all FE programs. Comparable reductions in the overall average price paid for natural gas by all users are also realized.
- Lower prices result in reductions in expenditures for natural gas of $5 to $8 billion per year as a result of only the Oil and Gas Programs, and over $14 billion as a result of all FE programs. This is despite the higher gas consumption that results from lower prices.
- Incremental annual domestic natural gas production will increase by amounts ranging from over one Tcf/year by 2010 to nearly 2.6 Tcf/year by 2025. Over the 2003 to 2025 time frame, the U.S. will produce over 32 Tcf more domestic natural gas in the Lower 48. In this case, with other FE programs also in place, incremental production due to FE programs is reduced, since more efficient coal-fired generation technologies begin to displace what would otherwise be natural gas-fired generation.

Assuming $100 million budget levels, the benefits are as follows:

- Average wellhead natural gas prices will be reduced by as much as $0.50 per Mcf by 2010, and by as much as $0.67 per Mcf by 2025 (Figure 6.31) due to Oil and Gas Programs, and as much as $0.78 per Mcf with all FE programs contributing, again with comparable reductions in the overall average price paid for natural gas by consumers.
- Lower prices results in reduced expenditures for natural gas in the U.S. by $5 to $9 billion per year in 2025 due to Oil and Gas Program activities, and up to over $15 billion annually by 2025 when the benefits of all FE programs are realized.
- Cumulatively, this implies that U.S. consumers will spend $40 billion less on natural gas by 2010, and over $90 billion less on natural gas over the 2002 to 2025 time period, as a result of DOE Oil and Gas R&D programs (Figure 6.32).

Incremental annual domestic natural gas production will increase by amounts ranging from 1.3 to 1.4 Tcf/year by 2010 to nearly 3.4 Tcf/year by 2025. Over the 2003 to 2025 time frame, the U.S. will produce over 46 Tcf more domestic natural gas in the Lower 48, 12 Tcf more than under the assumed FY2004 budget. Incremental production is reduced somewhat when all FE programs are considered.

Relative to 2002 levels, without DOE's Oil and Gas Program, domestic natural gas production will increase modestly, growing by two Tcf annually by 2015, and by four Tcf/year by 2005. In contrast, with DOE's Oil and Gas Programs, domestic natural gas production will increase by as much as four Tcf annually by 2015, and by over seven Tcf/year by 2025, compared to production in 2002 (Figure 6.33).

Table 6.5

Summary of Natural Gas Program Benefits -- Clear Skies Scenario
Comparison of Proposed FY2004 vs. $100 Million Budget Cases

	Differences Attributable to DOE R&D					
	2002	2005	2010	2015	2020	2025
Natural Gas - Annual Consumption (Tcf)						
All FE -- FY2004 O&G Budget	0.00	0.19	0.58	0.55	0.75	1.30
O&G Only (FY 2004 Bud) - No FE + O&G	0.01	0.20	0.58	0.83	1.55	2.18
O&G Only (FY 2004 Bud) - All FE - O&G	0.00	0.20	0.52	0.98	1.48	1.84
All FE -- $100 Million O&G Budget	0.00	0.33	0.77	0.85	1.13	1.86
O&G Only ($100 Million - No FE + O&G	0.01	0.27	0.77	1.20	2.06	2.76
O&G Only ($100 Million) - All FE - O&G	0.00	0.26	0.70	1.31	1.76	2.34
Est. Expenditures for Natural Gas ($ Billion)						
All FE -- FY2004 O&G Budget	-0.39	-3.04	-6.98	-8.47	-8.97	-14.23
O&G Only (FY 2004 Bud) - No FE + O&G	-0.38	-2.99	-7.02	-4.41	-0.02	-7.64
O&G Only (FY 2004 Bud) - All FE - O&G	-0.40	-2.94	-7.47	-2.09	0.86	-4.91
All FE -- $100 Million O&G Budget	-0.47	-3.39	-9.67	-7.76	-10.00	-15.35
O&G Only ($100 Million) - No FE + O&G	-0.47	-4.04	-9.35	-3.14	2.57	-5.40
O&G Only ($100 Million) - All FE - O&G	-0.49	-4.11	-9.06	-0.15	-1.89	-8.77
Dry Natural Gas - Annual Production (Tcf)						
All FE -- FY2004 O&G Budget	0.01	0.32	1.03	1.04	1.53	2.12
O&G Only (FY 2004 Bud) - No FE + O&G	0.02	0.33	1.04	1.32	1.97	2.58
O&G Only (FY 2004 Bud) - All FE - O&G	0.01	0.33	0.98	1.33	2.02	2.35
All FE -- $100 Million O&G Budget	0.02	0.49	1.34	1.87	2.18	2.91
O&G Only ($100 Million) - No FE + O&G	0.02	0.45	1.35	2.18	2.76	3.42
O&G Only ($100 Million - All FE - O&G	0.01	0.44	1.27	2.18	2.59	3.10
Dry Natural Gas - Lower 48 Cum. Prod (Tcf)						
All FE -- FY2004 O&G Budget	0.01	0.57	4.19	10.02	18.14	28.80
O&G Only (FY 2004 Bud) - No FE + O&G	0.02	0.59	4.18	10.30	20.10	32.27
O&G Only (FY 2004 Bud) - All FE - O&G	0.01	0.59	4.09	10.42	20.41	32.20
All FE -- $100 Million O&G Budget	0.02	0.93	5.77	14.68	27.37	41.69
O&G Only ($100 Million) - No FE + O&G	0.02	0.81	5.67	14.85	29.72	46.28
O&G Only ($100 Million) - All FE - O&G	0.01	0.81	5.64	15.08	29.40	44.50
Natural Gas Wellhead Prices ($ / Mcf) ($01)						
All FE -- FY2004 O&G Budget	-0.02	-0.18	-0.37	-0.42	-0.41	-0.65
O&G Only (FY 2004 Bud) - No FE + O&G	-0.02	-0.18	-0.37	-0.32	-0.25	-0.59
O&G Only (FY 2004 Bud) - All FE - O&G	-0.02	-0.18	-0.38	-0.27	-0.21	-0.46
All FE -- $100 Million O&G Budget	-0.02	-0.22	-0.51	-0.45	-0.50	-0.78
O&G Only ($100 Million) - No FE + O&G	-0.02	-0.24	-0.50	-0.33	-0.24	-0.62
O&G Only ($100 Million) - All FE - O&G	-0.02	-0.24	-0.48	-0.25	-0.34	-0.67

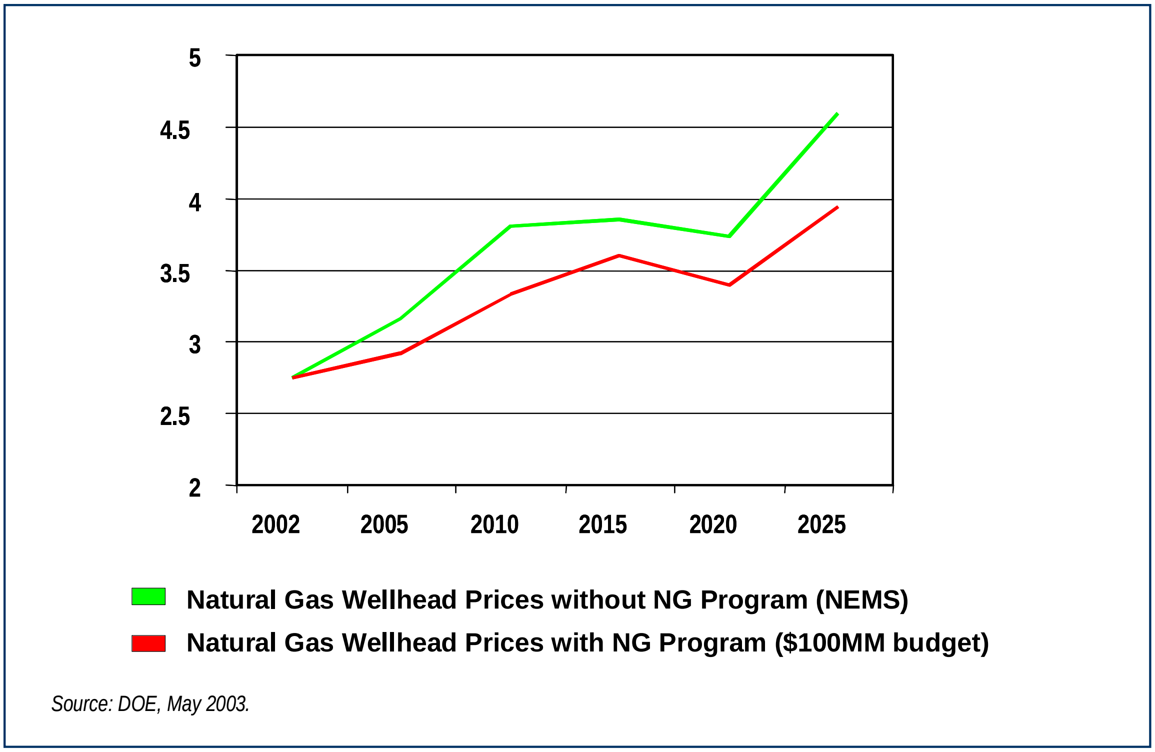


Figure 6.31 Natural Gas Wellhead Prices – Clear Skies Scenario ($/Mcf)

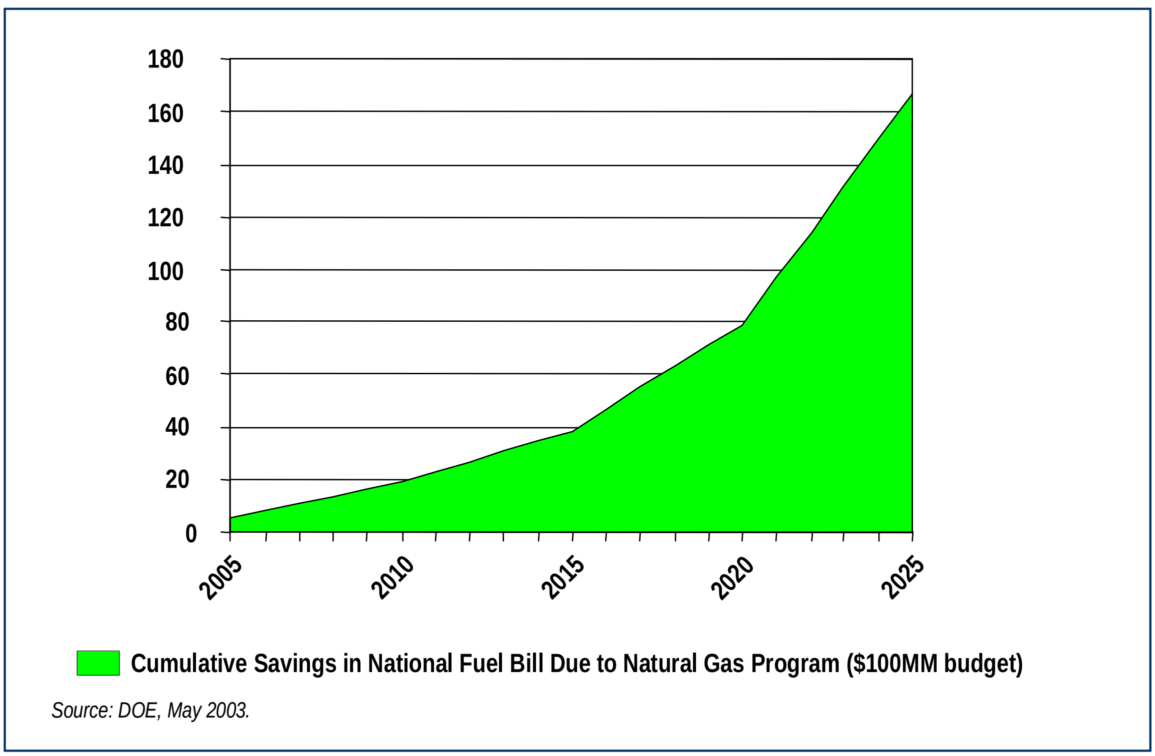


Figure 6.32 Cumulative Savings in National Gas Fuel Bill – Clear Skies Scenario (Billion $)

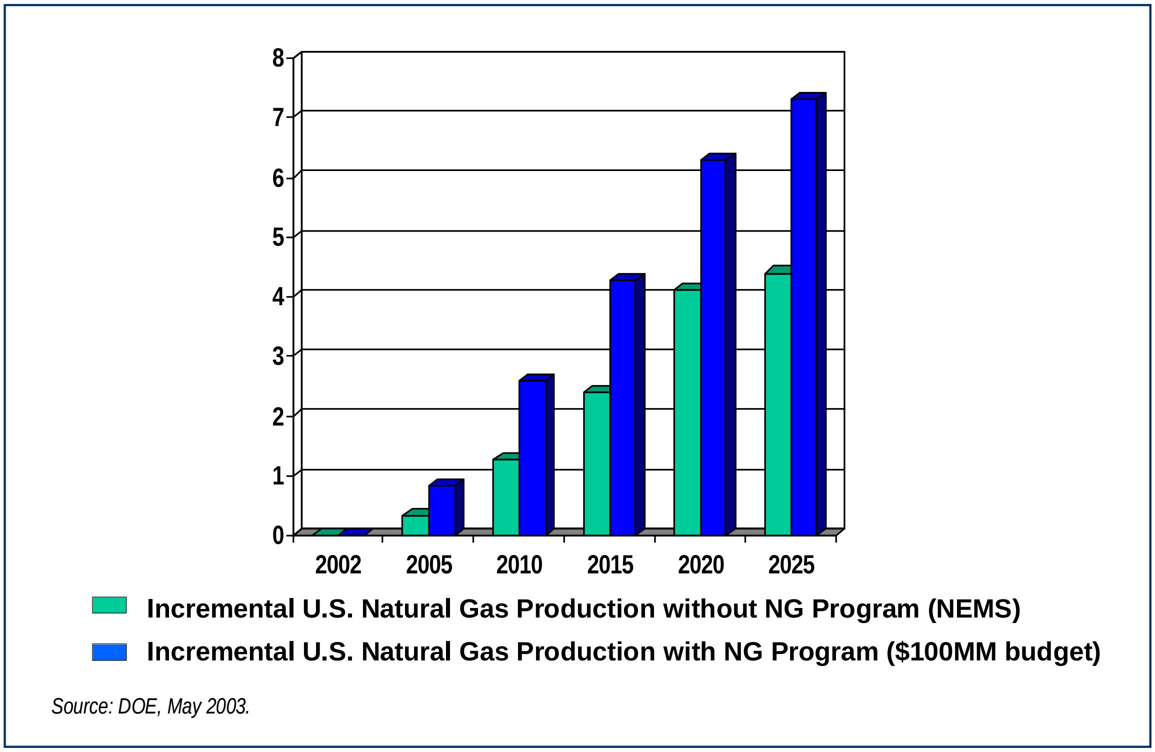


Figure 6.33 Incremental U.S. Natural Gas Production – Clear Skies Scenario (Bcf/Year)

Impact of Lower Natural Gas Supply Alternatives and Higher Oil Prices (Scenario 2)

Considerable natural gas-related benefits can also be realized as a result of DOE programs, even if the domestic natural gas resource base turns out to be 25 percent smaller than that assumed under Scenario 1, and higher oil prices are assumed. For example, for the assumed FY2004 budget case:

- Reductions in average wellhead natural gas prices are considerably more erratic over time than under Scenario 1, since the impact of large sources of alternative supplies (e.g., LNG, Alaska) are much more disruptive of the market.
- Domestic natural gas production benefits are comparable in the constrained resource scenario, but the timing of incremental production is altered somewhat, depending primarily on when these alternative supplies become available.
- Because of the overall lower impact on prices, and comparable impact on production, this constrained supply scenario does not provide the same type of consumer savings that would be realized under Scenario 1.

Under a scenario where alternative, non-Lower48 supplies of natural gas are most constrained, average wellhead natural gas prices are as much as $1.00 per Mcf higher than prices under Scenario 1 in the 2020 to 2025 time frame. However, the differences in prices between DOE R&D and No DOE R&D are somewhat smaller under these conditions, on the order of $0.15 for the two budget cases.

In terms of production, on the other hand, incremental domestic production as a result of Oil and Gas Program activities is somewhat higher under the constrained supply cases than for Scenario 1, particularly in the post-2015 timeframe. Similarly, incremental annual consumption is also somewhat higher under the constrained supply case than for Scenario 1. However, in the constrained supply cases, the decrease in price is generally not proportionally larger than the increase in consumption; so when supplies are constrained, estimated expenditures for natural gas increase due to program activities, whereas under Scenario 1, these expenditures decrease. This demonstrates the importance of these alternative, non-Lower 48 sources of supply in keeping gas prices affordable.

The results for the constrained supply scenario are summarized in Table 6.6.

A final interesting outcome to note is that the Natural Gas Technologies Program can impact future expenditures for crude oil and product imports. This impact is significant under scenarios where alternative, non-Lower48 supplies of natural gas are most constrained. Without DOE R&D, natural gas prices can be considerably higher than with DOE R&D. Higher natural gas prices result in fuel switching from gas to distillate for those electric generation facilities that have the capability to burn either fuel, resulting in greater demand for oil. This greater demand is primarily satisfied by increased imports of petroleum products. Consequently, without DOE R&D, the U.S. will pay considerably more for imported petroleum products than would be the case with the DOE programs (Table 6.7):

- For example, crude oil imports could increase from 540,000 barrels per day under Scenario 1 to as much as 1.1 million barrels per day where alternative natural gas supplies are constrained, due to the Natural Gas Technologies Program assuming the proposed FY2004 budget.
- Similarly, assuming a $100 million oil and gas program budget, imports grow from 940,000 barrels per day under Scenario 1 to over 1.3 million barrels where alternative natural gas supplies are most constrained.
- As a result, estimated savings in U.S. expenditures for imports of crude oil and petroleum products grow to $7 to $11 billion annually by 2025 assuming proposed FY2004 budget levels, and from $11 to $13 billion annually by 2025 assuming a $100 million budget.

For most scenarios considered, the greatest annual benefits attributable to the Oil and Natural Gas Programs were realized in the 2010 to 2020 time period. The size and duration of these impacts depended primarily on the availability of and accessibility to alternative sources of non-Lower-48 natural gas supplies (i.e., supplies from Alaska, Canada, and Mexico and supplies of LNG). This leads to several important considerations concerning DOE's Natural Gas Technologies Program:

- U.S. policies ensuring the availability of and accessibility to non-Lower 48 sources of natural gas supply become even more important if investments in R&D decline, reducing the benefits resulting from improved natural gas E&P technologies.

The interim 2010 to 2020 period becomes a critically important time frame for reaping the benefits of natural gas R&D, since most of the alterative sources of supply cannot reasonably be expected to be available at significant scale until towards the end of this time period.

Table 6.6
Summary of FE R&D Under Constrained Non-Lower-48 Natural Gas Supplies
Comparison of Proposed FY2004 vs. $100 Million Budget Cases

	Differences Attributable to DOE R&D					
	2002	**2005**	**2010**	**2015**	**2020**	**2025**
Natural Gas - Annual Consumption (TCF)						
All FE -- FY2004 O&G Budget	0.00	0.18	0.45	0.88	2.04	2.97
O&G Only (FY 2004 Bud)	-0.05	0.13	0.49	1.62	2.59	3.22
All FE -- $100 Million O&G Budget	0.00	0.25	0.81	0.91	2.21	3.61
O&G Only ($100 Million)	0.05	0.32	0.89	1.44	2.71	3.70
Est. Expenditures for Natural Gas ($ Billion)						
All FE -- FY2004 O&G Budget	-0.41	-3.15	0.34	11.73	12.66	15.96
O&G Only (FY 2004 Bud)	-0.72	-3.61	1.07	25.27	25.56	22.40
All FE -- $100 Million O&G Budget	-0.47	-4.16	-9.90	-10.19	-16.68	-0.96
O&G Only ($100 Million)	-0.15	-3.69	-8.60	-3.95	-2.67	7.26
Dry Natural Gas - Annual Production (Tcf)						
All FE -- FY2004 O&G Budget	0.01	0.31	0.80	1.20	2.09	3.05
O&G Only (FY 2004 Bud)	-0.03	0.28	0.84	1.70	2.41	3.17
All FE -- $100 Million O&G Budget	0.02	0.43	1.25	1.68	2.52	3.77
O&G Only ($100 Million)	0.06	0.48	1.31	2.07	2.87	3.81
Dry Natural Gas - Lower 48 Cum. Prod (Tcf)						
All FE -- FY2004 O&G Budget	0.01	0.57	3.75	9.63	17.87	31.40
O&G Only (FY 2004 Bud)	-0.03	0.49	3.64	10.63	21.23	35.87
All FE -- $100 Million O&G Budget	0.02	0.78	5.52	14.32	24.43	41.03
O&G Only ($100 Million)	0.06	0.91	5.88	15.53	27.34	45.34
Natural Gas Wellhead Prices ($ / Mcf) ($01)						
All FE -- FY2004 O&G Budget	-0.02	-0.18	-0.43	-0.33	-0.36	-0.45
O&G Only (FY 2004 Bud)	-0.03	-0.20	-0.41	0.00	-0.03	-0.35
All FE -- $100 Million O&G Budget	-0.02	-0.25	-0.52	-0.53	-0.93	-0.71
O&G Only ($100 Million)	-0.02	-0.24	-0.48	-0.40	-0.59	-0.51

Table 6.7
Summary of FE R&D Under Constrained Non-Lower-48 Natural Gas Supplies
Comparison of Proposed FY2004 vs. $100 Million Budget Cases

	Differences Attributable to DOE R&D					
	2002	**2005**	**2010**	**2015**	**2020**	**2025**
Crude Oil/Liquids - Daily Production (MMBD)						
All FE -- FY2004 O&G Budget	0.00	0.22	0.32	0.26	0.28	0.41
O&G Only (FY 2004 Bud)	0.00	0.22	0.31	0.30	0.34	0.45
All FE -- $100 Million O&G Budget	0.00	0.33	0.56	0.53	0.58	0.70
O&G Only ($100 Million	0.00	0.34	0.59	0.65	0.70	0.84
Crude Oil - Cumulative Production (billion barrels)						
All FE -- FY2004 O&G Budget	0.00	0.11	0.49	0.84	1.09	1.36
O&G Only (FY 2004 Bud)	0.00	0.11	0.49	0.84	1.11	1.40
All FE -- $100 Million O&G Budget	0.00	0.17	0.90	1.71	2.48	3.27
O&G Only ($100 Million)	0.00	0.18	0.90	1.72	2.48	3.29
Net Imports of Crude Oil and Petroleum Products (MMBD)						
All FE -- FY2004 O&G Budget	0.00	-0.22	-0.47	-0.54	-0.77	-1.11
O&G Only (FY 2004 Bud)	0.00	-0.21	-0.43	-0.44	-0.49	-0.70
All FE -- $100 Million O&G Budget	0.00	-0.35	-0.65	-0.65	-0.95	-1.34
O&G Only ($100 Million)	0.00	-0.35	-0.67	-0.70	-0.91	-1.20
Crude Oil/Petroleum Products Import Bill (Bill $01)						
All FE -- FY2004 O&G Budget	0.00	-1.91	-4.16	-4.86	-7.16	-10.75
O&G Only (FY 2004 Bud)	0.00	-1.76	-3.81	-3.97	-4.56	-6.81
All FE -- $100 Million O&G Budget	0.00	-2.94	-5.65	-5.84	-8.84	-13.03
O&G Only ($100 Million)	0.00	-2.99	-5.86	-6.36	-8.49	-11.59

6.2.6 Benefits of FE's R&D Programs for Oil Supply Technologies

6.2.6.1 Clear Skies Initiatives Benefits – Scenario 1

The characteristics and variability of the estimated benefits attributable to the Oil and Natural Gas Programs depends fundamentally on assumptions about the future, as represented under the various scenarios and assumed budget levels. Some of the benefits determined to result from DOE/FE R&D programs Clear Skies Scenario conditions are highlighted below.

The possible range in oil-related program benefits is primarily (but not exclusively) dependent on future crude oil prices and R&D program budget levels. Under the assumed FY2004 Oil and Natural Gas Programs budget and the Clear Skies Scenario, these benefits include:

- Incremental domestic liquids production (crude oil, lease condensate, and natural gas liquids (NGLs)) increased by over 300,000 barrels per day in 2010, growing to over 440,000 barrels per day by 2025.
- Incremental cumulative oil production over the 2003 to 2025 time period amounts to 1.4 billion barrels.
- Crude oil and petroleum products imports decline by as much as 540,000 barrels per day by 2025.
- U.S. expenditures for imports of crude oil and petroleum products are reduced by over $5 billion annually by 2025.
- Reductions in imported oil also result in environmental benefits -- in terms of reduced oil spills of 20,000 to 56,000 barrels over the 2003 to 2025 time period.

Under more expanded Oil and Natural Gas Program budgets, comparable to the proposed FY2005 target budget, greater oil-related benefits are realizable. Under the Clear Skies Scenario:

- Increased incremental domestic liquids production grows from as much as 440,000 barrels per day to over 830,000 barrels per day by 2025.
- Incremental cumulative crude oil production through 2025 more than doubles, from 1.4 billion barrels to over 3.3 billion barrels.
- The decline in crude oil and product imports grows to 940,000 barrels per day by 2025, compared to 540,000 barrels per day assuming the proposed FY2004 budget.
- Savings in U.S. expenditures for imports of crude oil and petroleum products grow to over $9 billion annually (Figure 6.34). One-third ($3 billion) is realized in the near term (by 2005), and two-thirds of this benefit (almost $6 billion) is realized by 2010.
- Reductions in oil spills associated with oil imports grow to a range of 37,000 to over 100,000 barrels over the 2003 to 2025 time period.

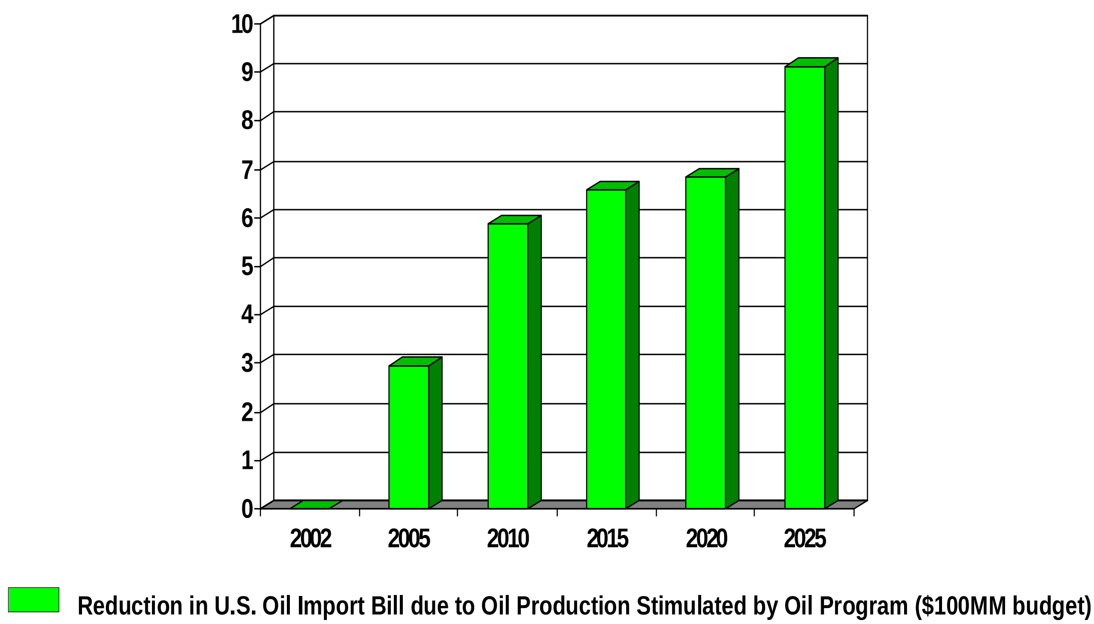
The results for Clear Skies Scenario are summarized in Table 6.8.

Table 6.8
Summary of Oil Program Benefits -- Clear Skies Scenario
Comparison of Proposed FY2004 vs. $100 Million Budget Cases

	Differences Attributable to DOE R&D					
	2002	**2005**	**2010**	**2015**	**2020**	**2025**
Crude Oil/Liquids - Daily Production (MMBD)						
All FE -- FY2004 O&G Budget	0.00	0.22	0.32	0.27	0.28	0.41
O&G Only (FY 2004 Bud) - No FE + O&G	0.00	0.22	0.32	0.30	0.33	0.44
O&G Only (FY 2004 Bud) - All FE - O&G	0.00	0.22	0.31	0.30	0.33	0.44
All FE -- $100 Million O&G Budget	0.00	0.35	0.59	0.62	0.65	0.80
O&G Only ($100 Million) - No FE + O&G	0.00	0.34	0.59	0.65	0.70	0.83
O&G Only ($100 Million) - All FE - O&G	0.00	0.34	0.58	0.65	0.69	0.82
Crude Oil - Cumulative Production (billion barrels)						
All FE -- FY2004 O&G Budget	0.00	0.11	0.49	0.85	1.15	1.42
O&G Only (FY 2004 Bud) - No FE + O&G	0.00	0.11	0.49	0.85	1.14	1.38
O&G Only (FY 2004 Bud) - All FE - O&G	0.00	0.11	0.49	0.85	1.15	1.41
All FE -- $100 Million O&G Budget	0.00	0.17	0.90	1.72	2.51	3.31
O&G Only ($100 Million) - No FE + O&G	0.00	0.17	0.90	1.72	2.49	3.28
O&G Only ($100 Million) - All FE - O&G	0.00	0.17	0.90	1.72	2.52	3.32
Net Imports of Crude Oil and Petroleum Products (MMBD)						
All FE -- FY2004 O&G Budget	0.00	-0.23	-0.37	-0.33	-0.37	-0.54
O&G Only (FY 2004 Bud) - No FE + O&G	0.00	-0.23	-0.37	-0.33	-0.38	-0.53
O&G Only (FY 2004 Bud) - All FE - O&G	0.00	-0.23	-0.37	-0.32	-0.36	-0.50
All FE -- $100 Million O&G Budget	0.00	-0.35	-0.65	-0.70	-0.75	-0.94
O&G Only ($100 Million) - No FE + O&G	0.00	-0.35	-0.65	-0.69	-0.74	-0.93
O&G Only ($100 Million) - All FE - O&G	0.00	-0.35	-0.62	-0.69	-0.73	-0.92
Crude Oil/Petroleum Products Import Bill (Bill $01)						
All FE -- FY2004 O&G Budget	0.00	-1.92	-3.35	-3.06	-3.35	-5.08
O&G Only (FY 2004 Bud) - No FE + O&G	0.00	-1.92	-3.39	-2.96	-3.31	-5.04
O&G Only (FY 2004 Bud) - All FE - O&G	0.00	-1.93	-3.34	-2.97	-3.25	-4.97
All FE -- $100 Million O&G Budget	0.00	-2.96	-5.86	-6.59	-6.83	-9.13
O&G Only ($100 Million) - No FE + O&G	0.00	-2.96	-5.79	-6.37	-6.85	-9.03
O&G Only ($100 Million) - All FE - O&G	0.00	-2.93	-5.60	-6.48	-6.68	-9.11

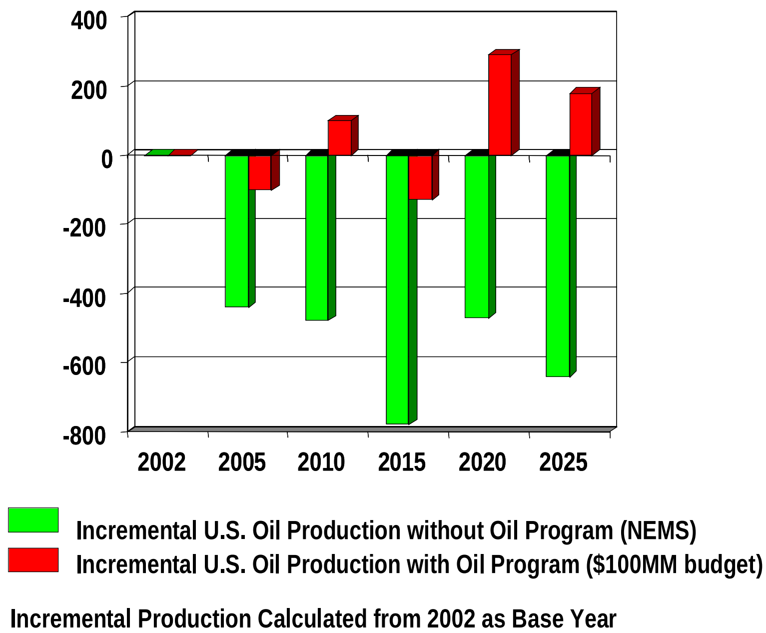
Another interesting way to present these results is in terms of the change relative to current conditions. For example, as shown in Figure 6.35, assuming the FY2005 proposed target budget, without DOE's Oil and Gas Program, domestic crude oil production will continue to decline over time, declining by 400,000 to 800,000 barrels per day over the 2015 to 2025 time period, compared to 2002. However, with DOE's Oil and Gas Programs, domestic production will be maintained or could increase by as much as 200,000 barrels per day by 2020, compared to production in 2002.

This translates to comparable changes in revenues received by the Federal Treasury from royalties on crude oil production from Federal lands. As shown in Figure 6.36, without DOE R&D, royalty revenues from oil production on Federal lands will drop by $135 million per year by 2005, and will continue to be well below 2002 levels until after 2015, where modest increases relative to 2002 levels will then be realized. In contrast, with DOE programs funded at the proposed FY2005 target budget level, while declining initially until after 2005, federal royalty revenues will increase by over $80 million per year, relative to 2002, by 2010, and grow to an increase of over $350 million over 2002 levels by 2025.



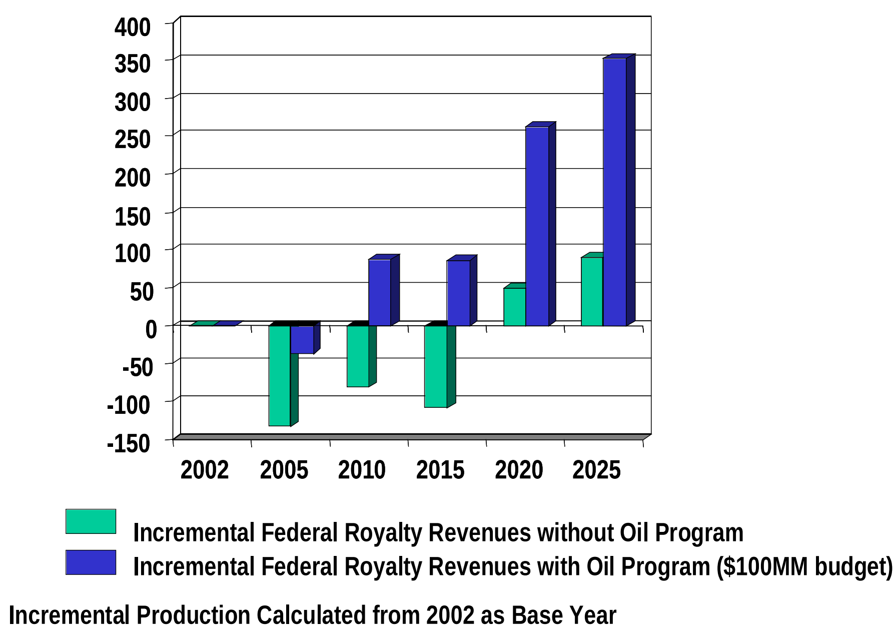
Source: DOE, May 2003.

Figure 6.34 Reduction in Growth in U.S. Oil Import Bill
Clear Skies Scenario (Billions, $2001)



Source: DOE, May 2003.

Figure 6.35 Incremental U.S. Oil Production – Clear Skies Scenario (Thousand Barrels/Day)



Source: DOE, May 2003.

Figure 6.36 Incremental Federal Oil Royalty Revenues Clear Skies Scenario (Millions, $2001)

6.2.6.2 Impact of Higher Crude Oil Prices

To determine the impact of higher oil prices on program benefits, a scenario was developed that was based on the proposed FY2004 Oil and Natural Gas Programs budget, but at higher crude oil prices consistent with those assumed in the AEO2003 High Oil Price case. The benefits attributable to Oil and Gas Program activities under this scenario would change as follows:

- Under a higher oil price scenario, greater levels of incremental production occur earlier, but are lower in later years. For example, under a higher oil price scenario, domestic oil production increased by over 380,000 barrels per day in 2015, declining to 310,000 barrels per day by 2025. In contrast, under Scenario 1, incremental production is 300,000 barrels per day in 2010, but grows to over 440,000 barrels per day by 2025.
- Incremental cumulative oil production over the 2003 to 2025 grows from 1.4 to 1.6 billion barrels at higher oil prices.
- Under higher oil prices, the impact of the program on imports is reduced in the later years as higher prices allow more resources to become economic without the benefits of improved technology. For example, under a higher oil price scenario, imports are reduced due to program activities by 380,000 barrels per day in 2015 and by 220,000 barrels per day by 2025. In contrast, under Scenario 1, imports are reduced by 330,000 barrels per day in 2015, and by 530,000 barrels per day by 2025.

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6.3 Non-NEMS Coal & Other Power Systems Benefits

6.3.1 Coal-to-Hydrogen

To estimate the benefits of a hydrogen economy, an estimate of hydrogen demand was determined from DOE's Hydrogen Posture Plan Scenario (internal DOE report). By comparing the efficiency of FCVs with internal combustion engine vehicles (ICEV), savings in fuel costs, energy, and emissions reductions can be determined.

A system analysis of a coal-fired central hydrogen plant [Mitretek, 2002] with pipeline delivery of hydrogen to refueling stations and use in efficient FCVs was compared to the most likely alternative, that is, oil refining and delivery of gasoline for use in ICEVs. The cumulative impact of centrally produced hydrogen from coal and use in light-duty FCVs is summarized in Table 6.9. By 2025, cumulative energy savings for this scenario are $61 billion dollars, and a reduction of 2.1 billion barrels of petroleum imports. Over the lifetime of the plant (through 2055), cumulative energy savings are $3.2 trillion dollars. As the table illustrates, coal use increases dramatically, yet emissions of criteria pollutants and carbon dioxide are reduced.

Table 6.9 Impact of Centrally Produced Hydrogen from Coal and Use in Light-Duty FCVs -- Cumulative Impact (a)

Year	2020(b)	2025	2030	2035	2040	Life-time (c)
Fleet LDV FCV Efficiency vs. ICEV	2.28	2.35	2.41	2.46	2.49	2.86
Number of Light Duty FCVs, million	9.5	55.2	134.0	235.1	324.8	474.7
Number of Hydrogen Plants	19	110	259	446	609	776
Cumulative Hydrogen Production, million short tons	3.8	49	175	416	770	2199
Capital Cost of Hydrogen Plants; $ billion (current dollars)	8	47	110	190	259	330
Emissions Reductions						
Cumulative SO_x, million tonnes	0	0.1	0.2	0.5	1.0	3.3
Cumulative NOx, million tonnes per year	0	0.1	0.5	1.3	2.5	8.2
Cumulative PM10, million tonnes per year	0	0.1	0.2	0.6	1.2	3.6
Cumulative CO_2, billion tonnes (no sequestration)	0.03	0.4	1.4	3.5	6.7	21.8
Cumulative CO_2, billion tonnes (with sequestration)	0.08	1.0	3.6	8.8	16.6	50.1
Other Impacts						
Cumulative Energy Savings, $ billion (current dollars)	5	61	226	550	1034	3152
Cumulative Reduced Petroleum Imports, billion barrels	0.2	2.1	7.6	18.4	34.4	103.9

Cumulative Reduced Natural Gas Consumption, trillion cubic feet	0.2	3	11	27	50	151
Cumulative Increased Coal Consumption, million short tons	27	347	1249	2973	5502	15716

(a) Based on a system analysis from a central hydrogen plant, pipeline delivery of hydrogen to refueling stations and use in efficient FCVs, compared with oil refining, delivery of gasoline and use in ICE vehicles.

(b) FCV sales, operation and benefits begin in year 2018.

(c) Lifetime impacts are through 2055.

Sources:
Argonne National Laboratory GREET 1.5a model, Per-Mile Fuel-Cycle Energy Use and Emissions for long-term technology light duty vehicles, assumed to be 55 percent passenger cars, 25 percent Light Duty Truck Class 1, and 20 percent Light Duty Truck Class 2. The GREET 1.5a model provides Btu/mile use of energy, broken down by fossil energy, petroleum energy and non-fossil energy, and SOx, NOx, and PM10, among other emissions, on a fuel-cycle basis. Except for the hydrogen from coal plant analysis, GREET 1.5a assumptions were used in the above table, including the assessment that FCVs use one third the energy per mile driven as ICE vehicles.

SAIC, March 2003 presentation, which indicates advanced coal-fired IGCC plants emit 0.09 lbs NOx/MMBtu of coal, and 0.08 lbs of SO2/MMBtu at 98 percent recovery. Estimates used in the above analysis assume SO_2 recovery is 99 percent with emission of only 0.04 lbs SO_2/MMBtu through more severe operation of a Rectisol unit.

6.3.2 Non-Energy Sequestration

Emission Reduction Needs

Carbon sequestration is one of many technologies used to meet emission reduction needs. The following equation shows technologies and approaches considered in the analysis of sequestration benefits for non-energy CO_2 and non-CO_2 greenhouse gases.

$$Q_{need} = Q_{eff\&rnew} + Q_{soil} + Q_{HTsoil} + Q_{nonCO2} + Q_{HTnonCO2} + Q_{VAgeoseq} + Q_{ADVseq}$$

Where

Q_{need}	The U.S. emissions reduction need
$Q_{eff\&rnew}$	Reduction achieved with efficiency and renewables
Q_{soil}	Reduction achieved with increased carbon storage in soils
Q_{HTsoil}	Reduction achieved with increased carbon storage in soils using advanced technologies
Q_{nonCO2}	Reduction achieved with non-CO_2 GHG abatement
$Q_{HTnonCO2}$	Reduction achieved with non-CO_2 GHG abatement using advanced technology
$Q_{VAgeoseq}$	Reduction achieved with value-added geologic storage (EOR and ECBM)
Q_{ADVseq}	Residual need for emissions reduction to be met with advanced sequestration technology

The possible contribution from each of the emissions reduction options, with the exception of $Q_{advanced}$, was estimated independently and then the sum was compared with the emissions reduction need. $Q_{advanced}$ is a residual need that is not met with the other options. The methodologies and assumptions behind the estimates for the contribution of each of the various options are contained below. It was assumed that the required emissions reduction would be achieved without purchase of GHG emissions reduction credits from foreign countries. Table 6.10 summarizes the results.

Table 6.10 Sources of GHG Emissions Reduction in the United States through 2050 (GHG emissions in million metric tons of carbon equivalents)

	2005	2012	2020	2050
*Emissions Reduction Need (from Table 1)**	*32*	*108*	*241*	*1,735*
Increased Energy Efficiency and use of Renewables	10	33	69	530
USDA soil carbon	10	15	30	60
High technology soil carbon		3	6	30
EPA reduction in non-CO_2 GHG	7	20	35	70
High technology reduction in non-CO_2 GHG		6	10	20
Early application of value-added geologic sequestration	3	12	50	100
Sub total	30	89	200	810
Residual emissions reduction need to be addressed by advanced carbon sequestration technology	2	19	41	925

Cost Savings, $Cost_{alt}$ – $Cost_{seq}$

Benefits are calculated for the value-added geologic and advanced carbon sequestration areas. The program is involved in terrestrial sequestration and reduction of non-CO_2 GHG emissions, but USDA and EPA respectively the lead organizations in those areas and the benefits are shared. Future analyses will quantify the program benefits from these areas as well.

Cost of non-sequestration options. The cost of non-sequestration options, beyond what is included in the reference case, the high technology efficiency and renewable energy emission reduction category, and the other categories, is estimated to be $50/ton carbon. This cost is assumed to remain constant throughout the analysis period.

Beyond 2020, advanced technology could lower the cost of CO_2 emissions reduction. On the other hand, the amount of reductions needed increases dramatically as emissions are stabilized and then reduced while the economy continues to grow. It is assumed that these two factors balance each other out and that the cost of non-sequestration CO_2 emissions reduction remains at 50 $/ton throughout the analysis period.

Cost of value-added sequestration. The value added geologic is assumed to cost $25/ton carbon, so the economic benefits equals $50/ton minus $25/ton (i.e., $25/ton) carbon multiplied by the quantity deployed.

The notion of a cost implies that incentives will be required to achieve the quantity of reductions presented in the analysis. Calculations show that an incentive of 25-50 $/ton carbon is comparable to other actions.

Cost of advanced sequestration. The current cost of advanced carbon sequestration is assumed to be $50/ton carbon. Again, incentives would be required to achieve the quantity of deployments required in the reduced emissions scenario. Calculations show that such a level of incentives is consistent with other existing and proposed regulations.

The cost of advanced sequestration is assumed to reduce, due to program funded R&D, at a rate of 4 percent per year, to $12/ton by 2050. The 4 percent rate is consistent with technology progress assumptions in other studies. For example the NPC natural gas study used 4 percent annual cost reductions for deepwater platforms and 3.5percent cost reductions for D&C cost (fast technology case). Also, EIA uses 3 percent annual cost reductions for offshore drilling and 4 percent to 8 percent annual improvements in new field discoveries (Rapid Technology Progress Case). The benefits from advanced sequestration for a given year equal $50/ton minus the cost during that year quantity multiplied by the amount of emissions reduced.

Based on the assumptions described above, the benefits of the sequestration program for non-energy CO_2 and non-CO_2 GHG reductions is estimated at $550 million/year by 2012 and $2000 million/yr by 2020.

6.4 References

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Chapter 7. Recommendations for Future Work

- **Continue to Improve the Benefit Analysis**
  Much of the work in FY2003 centered on establishing a methodology and verifying that the process being developed provides valid, credible, and useful results. In FY2004, the framework for the FE benefits analysis will continue to be enhanced, tested, and evaluated through a peer review of experts both internal and external to DOE, including the newly commissioned NRC committee that will be performing a prospective benefit analysis.

- **Investigate Possibility of Applying Methodology to Other DOE Programs**
  The methodology developed in this report could be applied to other DOE programs. In FY2004, it is anticipated that FE and DOE's Office of Energy Efficiency and Renewable Energy (EERE) will continue working together to establish consistent scenarios and methodologies for developing benefits that can be used for both intra-program comparisons (IGCC, fuel cells, gas supply), and inter-program comparisons (FE, EERE).

- **Account for Benefits Beyond 2025**
  An approach for accounting for benefits beyond 2025 was not developed during this study, but it is anticipated that future benefit analyses will account for these longer-term benefits. This is important since many of FE's programs do not begin accruing benefits until the latter years of the time horizon and may be shortchanged in terms of estimating benefits.

- **Consider Alternate Options for Comparing Benefits Occurring Over Differing Time Horizons**
  An approach for comparing program benefits over differing time horizons was not developed during this study. In future work, a fair method for evaluating programs that do not have similar time periods over which their benefits occur needs to be developed.

- **Incorporate Additional FE R&D Activities and Consider Additional Scenarios**
  It is also important to reiterate that the metrics results estimated in this study do not represent the benefits associated with all activities making up FE's R&D programs. Moreover, the benefits estimated using NEMS were developed for only a few scenarios. Therefore, further work is needed to incorporate these additional program areas into the NEMS modeling framework, such that a larger proportion of program activities are represented. Other scenarios may need to be considered for the results of the NEMS-based analyses to be useful for planning purposes.

- **Determine How to Partition Benefits Between Interdependent R&D Programs**
  It is difficult to separate benefits for the individual programs within the Coal & Other Power Systems R&D Program. For example, advanced fuel cells and syngas turbines are necessary for the high efficiencies achieved by advanced IGCC plants. Therefore, some of the benefits associated with advanced coal plants belong also to the fuel cell and turbine programs. A forecast could be done in which the efficiency of an advanced

IGCC is lessened to account for the absence of advanced fuel cells and/or the syngas turbine, but that was not done in this study. It should be investigated in future studies.

- **Develop Method for Assessing Budget Impacts**
  The benefits for the CPS program were estimated based on current planning budget levels. If the funding changes significantly, the benefits will be impacted. A method for assessing this impact was not developed in this study; however, developing a procedure for determining the affect of sufficient R&D funding should be investigated for use in future studies.

- **Assess the Risk and Uncertainty of FE R&D Program Success**
  The benefits were determined by both an additive and subtractive method, as described in Chapter 2, to get an estimate of the benefits of individual technologies. The subtractive method was viewed as the most conservative estimate of benefits, whereas the additive method generated much larger benefits. Further investigation of these methods is warranted to understand the differences between them and to determine if the range of benefits between the two methodologies is meaningful. There may be a more efficient and accurate way to assess the uncertainty of program success within the FE portfolio.

- **Investigate the Phenomenon of Negative Benefits**
  In some Scenarios, negative benefits were estimated in both the subtractive and additive methods. For the purposes of this study, negative benefits were not included in the calculation of monetary benefits. The phenomenon of negative benefits should be investigated further and the benefits methodology revised to account for this.

- **Determine the Meaningfulness of the Portfolio Effect**
  The synergism resulting from the success for all programs gives a benefit that is greater than the sum of the individual program benefits. This study calls this increased in total benefits the "portfolio effect." While this effect does not occur consistently, it indicates that there may be some measurable benefit of having multiple successful research programs. This study does not explore such an effect in depth, but it is suggested that it be further analyzed in future work.

Appendix A: Economic Benefits, Subtractive Method

R&D Program		Scenario	Cost Savings (cumulative to 2025): Discounted $2002 B	Cost Savings: $2002 B	Cost Savings: ¢/kWh in 2025	Fuel Diversity Benefit (cumulative to 2025): Discounted $2002 B	Fuel Diversity Benefit: $2002 B	Emissions Reduction (cumulative to 2025): Carbon (MMTCE)	Emissions Reduction: Carbon Intensity
Coal and Other Power Systems R&D	Advanced Power	Clear Skies	34	85	0.24	28	67	-772	-3
		Clear Skies /High gas	125	274	0.53	54	130	-362	-2
		Clear Skies/ Carbon							
	Sequestration	Clear Skies							
		Clear Skies /High gas							
		Clear Skies/ Carbon	45	127	.50	31	80		0
	DG- Grid Support (FC)	Clear Skies	0	0	0	-12	-33	-383	0
		Clear Skies /High gas	58	107	0.13	-17	-40	0	0
		Clear Skies/ Carbon	15	41	0.19	0	0		0
	IEP	Improvements to Existing Plants (IEP) reduce mercury emissions by 167 tons by 2025. Other benefit measurements do no apply to the IEP program.							
Oil & Gas R&D		Clear Skies	41	78	.14	64	117	-329	0
		Clear Skies /High gas	68	106	.04	68	132	0	0
		Clear Skies/ Carbon	29	50	.12	56	107		0
Total FE R&D Benefit		Clear Skies	128	291	.46	81	162	-208	1
		Clear Skies /High gas	204	419	.55	105	215	274	3
		Clear Skies/ Carbon	202	498	.91	66	172		0

Appendix B: Economic Benefits, Additive Method

		Cost Savings (cumulative to 2025)			Fuel Diversity Benefit (cumulative to 2025)		Emissions Reduction (cumulative to 2025)	
		Discounted $2002 B	$2002 B	¢/kWh in 2025	Discounted $2002 B	$2002 B	Carbon (MMTCE)	Carbon Intensity
Advanced Power	Clear Skies	102	250	.53	64	155	0	0
	Clear Skies /High gas	117	286	.50	70	165	28	0
	Clear Skies/ Carbon							
DG- Grid Support (FC)	Clear Skies	-4	-9	.13	-40	-96	21	0
	Clear Skies /High gas	0	0	.17	-33	-73	0	0
	Clear Skies/ Carbon							
Up Stream Oil & Gas	Clear Skies	50	103	.20	72	137	0	0
	Clear Skies /High gas	0	0	0	0	0	0	0
	Clear Skies/ Carbon							
IEP	Improvements to Existing Plants (IEP) reduce mercury emissions by 50 tons by 2025. Other benefit measurements do no apply to the IEP program.							
Total Benefit	Clear Skies	128	290	.46	81	160	-208	1.4
	Clear Skies /High gas	204	419	.55	105	207	274	2.8
	Clear Skies/ Carbon	202	498	.91	66	160		0

Notes: Total benefits are the same for both subtractive and additive methods.
In the additive method, fuel cells show negative cumulative costs savings from COE, but positive savings for ¢/kWh in 2025. This is occurs because fuel cells do not begin to reduce average COE to consumers until 2022.

Appendix C: CPS Cost and Performance Assumptions

Table C.1 IGCC Input Assumptions

FE IGCC (IG) Specs used as Input for NEMS Cases				
AEO 2003 Reference Case Assumptions: • Typical unit size (MW) – 550 • Variable O&M cost (year 2000 $ per 1000 kWh) – 1.997 • Fixed O&M cost (year 2000 $ per kW) – 32.951 • Emissions: 99% S removal; 0.02 lbs/mmBtu NOx • Capital costs include the project contingency factor (7%), as well as the technological optimism factor (0%), and the learning factor, which accounts for the changes over time. **FE Assumptions:** • Performance for a specified date is for a plant deployed on that date. • FE R&D accelerates deployment by 10 years. • Goals: **$1000/kW and 50% efficiency** by 2008 (design available, industry prototypes at 50% HHV by 2010 and widespread commercial use at $1000/kW by **2014**), and **$850/kW and 60% efficiency** by 2015 (design available, industry prototypes at 60% HHV by 2020, and widespread commercial use at $850/kW by **2024**.)				
Year	**Capital Cost (year 2000 $/kW)**		**Heat Rate (based on HHV)**	
	Without FE R&D	FE R&D	Without FE R&D	FE R&D
2000	1336	1336	8000	8000
2001	1336	1336	8000	8000
2002	1336	1336	8000	8000
2003	1330	1330	8000	8000
2004	1324	1324	7911	7911
2005	1318	1318	7822	7822
2006	1313	1313	7733	7733
2007	1307	1307	7644	7644
2008	1301	1301	7556	7556
2009	1295	1295	7467	7467
2010	1289	1289	7378	7378
2011	1284	1284	7289	7289
2012	1278	*1189	7200	*7194
2013	1272	*1095	7200	*7100
2014	1266	***1000**	7200	***6824**
2015	1260	*990	7200	*6710
2016	1255	*980	7200	*6597
2017	1249	*970	7200	*6483
2018	1243	*960	7200	*6370
2019	1237	*950	7200	*6256
2020	1231	*940	7200	*6142
2021	1226	*930	7200	*6029
2022	*1189	*920	*7194	*5915
2023	*1095	*910	*7100	*5802
2024	***1000**	***900**	***6824**	***5688**
2025	*990	*****900	*6710	*5688

*indicates values in table differ from AEO2003 input; bold values indicate PSPG

Table C.2 IGCC with Sequestration Input Assumptions

FE IGCC With Sequestration (IS) Specs used as Input for NEMS Cases

AEO 2003 Reference Case Assumptions:

- Typical unit size (MW) – 380
- Variable O&M cost (year 2000 $ per 1000 kWh) – 1.997*
- Fixed O&M cost (year 2000 $ per kW) – 32.951*
- Emissions: 99% S removal; 0.02 lbs/mmBtu NOx; 90% C sequestration efficiency
- Capital costs include the project contingency factor (7%), as well as the technological optimism factor (0%), and the learning factor, which accounts for the changes over time.

FE Assumptions:

- Performance for a specified date is for a plant deployed on that date.
- FE R&D accelerates sequestration technology development by 15 years.
- Goals: 10% increase in COE for sequestration over system without sequestration by 2015

Year	Capital Cost (year 2000 $/kW)		Heat Rate (based on HHV)	
	Without FE R&D	FE R&D	Without FE R&D	FE R&D
2000	1961	1961	10847	10847
2001	1961	1961	10847	10847
2002	1961	1961	10847	10847
2003	1944	1944	10847	10847
2004	1927	1927	10718	10718
2005	1910	1910	10589	10589
2006	1893	1893	10460	10460
2007	1876	1876	10331	10331
2008	1859	1859	10201	10201
2009	1842	1842	10072	10072
2010	1825	1825	9943	9943
2011	1808	1808	9814	9814
2012	1791	1791	9685	9685
2013	1773	*1567	9685	*8872
2014	1756	*1343	9685	*8060
2015	1739	***1119**	9685	*7247
2016	1722	*1107	9685	*7125
2017	1705	*1096	9685	*7002
2018	1688	*1085	9685	*6879
2019	1671	*1074	9685	*6756
2020	1654	*1062	9685	*6634
2021	1637	*1052	9685	*6511
2022	1620	*1040	9685	*6388
2023	1603	*1028	9685	*6266
2024	1586	*1017	9685	*6143
2025	1586	*1017	*9307	*6143

- indicates values in table differ from AEO2003 input; bold values indicate PSPG

Table C.3 Advanced Turbines Input Assumptions

Advanced Gas/Oil Combined Cycle (AC) Specs used as Input for NEMS Cases

AEO 2003 Reference Case Assumptions:

- Typical unit size (MW) – 400
- Variable O&M cost (year 2000 $ per 1000 kWh) – 1.997
- Fixed O&M cost (year 2000 $ per kW) – 9.985
- Emissions: 0.02 lbs/mmBtu NOx
- Capital costs include the project contingency factor (8%), as well as the technological optimism factor (0%), and the learning factor, which accounts for the changes over time.

FE Assumptions:

- Performance for a specified date is for a plant deployed on that date. A 2-year lead-time for construction is assumed.
- FE R&D accelerates deployment by 10 years.
- Current advanced combined cycle assumed to be 52% HHV. HEET Goals: 58% HHV (64% LHV) by 2010, 68% HHV (75% LHV) hybrid system by 2015

Year	Capital Cost (year 2000 $/kW)		Heat Rate (based on HHV)	
	No FE R&D	FE R&D	No FE R&D	FE R&D
2000	594	594	7000	7000
2001	594	594	7000	7000
2002	594	594	7000	7000
2003	589	589	6928	6928
2004	589	589	6856	6856
2005	586	586	6783	6783
2006	578	578	6711	6711
2007	572	572	6639	6639
2008	558	558	6567	6567
2009	550	550	6494	6494
2010	536	536	6422	6422
2011	525	525	6350	6350
2012	517	517	6350	***5882**
2013	511	511	6350	*5709
2014	506	506	6350	*5536
2015	501	501	6350	*5363
2016	499	499	6350	*5190
2017	498	498	6350	***5017**
2018	496	496	6350	*5017
2019	494	494	6350	*5017
2020	492	492	6350	*5017
2021	490	490	6350	*5017
2022	488	488	***5882**	*5017
2023	486	486	*5709	*5017
2024	483	483	*5536	*5017
2025	482	482	*5363	*5017

* indicates values that differ from AEO2003 input; bold values indicate program goals

Table C.4 Advanced Turbines with Sequestration Input Assumptions

Advanced Combined Cycle With Sequestration (CS) Specs used as Input for NEMS Cases

AEO 2003 Reference Case Assumptions:

- Typical unit size (MW) – 400
- Variable O&M cost (year 2000 $ per 1000 kWh) – 2.497
- Fixed O&M cost (year 2000 $ per kW) – 14.445
- Emissions: 0.02 lbs/mmBtu NOx; 90% C sequestration efficiency
- Capital costs include the project contingency factor (8%), as well as the technological optimism factor (10%), and the learning factor, which accounts for the changes over time.

FE Assumptions:

- Performance for a specified date is for a plant deployed on that date. A 2-year lead-time for construction is assumed.
- FE R&D accelerates sequestration technology development by 15 years.
- Although sequestration program goals are set for coal systems, gas-based cc are assumed to benefit from sequestration technology development.

Year	Capital Cost (year 2000 $/kW)		Heat Rate (based on HHV)	
	No FE R&D	FE R&D	No FE R&D	FE R&D
2000	1012	1012	8400	8400
2001	1012	1012	8400	8400
2002	1012	1012	8400	8400
2003	1003	1003	8314	8314
2004	994	994	8227	8227
2005	985	985	8140	8140
2006	977	977	8053	8053
2007	968	968	7967	7967
2008	959	959	7880	7880
2009	950	950	7793	7793
2010	941	941	7706	7706
2011	933	933	7620	7620
2012	924	*775	7620	*6985
2013	915	*766	7620	*6985
2014	906	*759	7620	*6985
2015	897	*752	7620	*6985
2016	889	*749	7620	*6985
2017	880	*746	7620	*6985
2018	871	*743	7620	*6985
2019	862	*741	7620	*6985
2020	853	*737	7620	*6985
2021	845	*736	7620	*6985
2022	836	*731	7620	*6470
2023	827	*729	7620	*6280
2024	818	*725	7620	*6090
2025	809	*724	7620	*5899

* indicates values that differ from AEO2003 input

Table C.5 SECA Fuel Cells for the Electricity Sector Input Assumptions

FE Fuel Cell (FC) and Baseload DG (DB) Specs used as Input for NEMS Cases

AEO 2003 Reference Case Assumptions:

- Typical unit size (MW) – 1 (DG) to 10 (grid)

FE Assumptions

- *Variable O&M cost (year 2000**$** per 1000 kWh) – 2.7
- *Fixed O&M cost (year 2000 **$** per kW) -- 0
- *Emissions: SO2 -- zero, NOx -- .04 pounds/MWh, CO2 should be calculated from fuel carbon content and fuel cell efficiency (just as in combustion)
- *Fuel cell installation costs for SECA do not include contingencies
- *Performance for a specified date is for fuel cells deployed on that date. A two year lead time for construction is assumed.
- *FE R&D Accelerates SECA Deployment by 15 Years
- SECA cost targets are met in 2005 ($800/kW) and 2010 ($400/kW) and are commercially available 2 years later with no additional cost reduction after reaching a low price of $400/kW. Between 2005 and 2010, a linear cost reduction is assumed for SECA.

Year	Capital Cost (year 2000 $/kW)		Heat Rate (based on HHV)	
	No FE R&D	FE R&D	No FE R&D	FE R&D
2000	2154	2154	7333	7500
2001	2154	2154	7333	7500
2002	2154	2154	7333	7500
2003	2154	2154	7333	7417
2004	2154	2154	7333	7333
2005	2136	2136	7250	7250
2006	2039	2039	7167	7167
2007	1884	*841	7083	7083
2008	1725	*841	7000	7000
2009	1558	*841	6917	6917
2010	1464	*629	6833	6833
2011	1430	*629	6750	6750
2012	1406	*420	6750	6750
2013	1389	*420	6750	6750
2014	1382	*420	6750	6750
2015	1376	*420	6750	6750
2016	1369	*420	6750	6750
2017	1364	*420	6750	6750
2018	1364	*420	6750	6750
2019	1364	*420	6750	6750
2020	1364	*420	6750	6750
2021	1364	*420	6750	6750
2022	1364	*420	6750	6750
2023	1364	*420	6750	6750
2024	1364	*420	6750	6750
2025	1364	*420	6750	6750

*indicates that this is a change from the original AEO2003 NEMS run input; shaded area is SECA

Table C.6 SECA Fuel Cells for the Buildings Sector Input Assumptions

FE Residential and Commercial Combined Heat and Power FC Applications used as Input for NEMS Cases

For combined heat and power in the residential and commercial models:

- Costs follow same trend as that above for electricity model, but $100/kW was added for additional heat recovery equipment
- Efficiencies of smaller units for commercial and industrial sector are assumed to reach a maximum of 50% LHV [6895 heat rate HHV] for SECA and non-SECA fuel cells

First Year	Last Year	Installed Equip Cost		Electrical Efficiency (LHV)		Overall Efficiency		Electricity Heat Rate (HHV)	
		No FE	**FE**	**No FE**	**FE**	**No FE**	**FE**	**No FE**	**FE**
1993	2001	$2188	2188	0.41	0.41	0.75	0.75	7500	7500
2002	2005	$2134	2134	0.41	0.41	0.75	0.75	7500	7500
2006	2009	$1584	700	0.41	0.50	0.75	0.80	7500	6895
2010	2014	$1416	500	0.43	0.50	0.78	0.80	7281	6895
2015	2019	$1399	500	0.43	0.50	0.78	0.80	7281	6895
2020	2025	$1399	500	0.43	0.50	0.78	0.80	7281	6895

Appendix D: IEP Benefit Assumptions

Analysis by Jeff Hoffman and Tom Feeley, 2002 for the PART FY04 Exercise

FE Program Area: Innovations for Existing Plants

Benefits	Key Assumptions
Economic Benefits	
Mercury Control Technology 1. \$600 – 840 million per year by 2005 2. \$1.1 - \$1.5 billion per year by 2010	Baseline Assumptions: 2000 aggregate annual Hg emissions = 48 tons Cost of existing mercury control: \$50,000 - \$70,000 per pound of mercury removed Potential market penetration: 300 GW by 2005 (PM control and/or wet scrubbers) 100-200 GW by 2010 (wet scrubbers and/or coals not amenable to sorbent injection) 1. By 2005, have technology available for commercial demonstration capable of achieving 50 – 70% removal at ¾ the cost of existing technology. Achieve 24-ton reduction from baseline annual aggregate emissions. 2. By 2010, have technology available for commercial demonstration capable of achieving $\geq$90% removal at ¾ the cost of existing technology. Achieve 19-ton reduction from mid-term annual aggregate mercury emissions of 20 tons.
NOx Control Technology 1. \$300 million per year by 2008 2. \$400 million per year by 2018	Baseline Assumptions: 1. NETL modeling (MC2) and CUECost projection: ~\$434 million savings of ULNB in place of SCR for CSI Phase I. Of the 110 GW eligible for ULNB to meet CSI Phase I, ULNB market penetration of 75GW. 2. NETL modeling (MC2) and CUECost projection: ~1.8 billion dollar savings of ULNB in place of SCR for CSI Phase I. Of the 110 GW eligible for ULNB to meet CSI Phase I - the additional 45 GW required to meet CSI Phase II, ULNB market penetration of 20 GW.
Acid Gas (SO_3) Control Technology 1. \$75 million dollars per year in 2008 2. \$15 million dollars per year in 2010	Baseline Assumptions: ULNB penetration as assumed for NOx benefit development, installations apportioned to smaller units. Remainder of NOx control is SCR, assume that DOE developed technology is applicable to SCR equipped units burning high sulfur coal. Assume cost reduction is \$30/kW and retrofits occur over 10 years. 1. Assume 25 GW of installed SCR burning high sulfur bituminous coal 2. Assume 5 GW of installed SCR burning high sulfur bituminous coal
Particulate Control Technology 1. \$150 million per year in 2010.	1. Assume 90% of 270 GW ESP capacity requires retrofit. Assume DOE technology results in a ~\$15/kW savings in retrofit to achieve reduced emission level of 0.01 lb/10^6 Btu. Assume retrofit occurs over 10 years and DOE technology is used for 50% of the applications.
Environmental Benefits	

1. $3.7 billion per year in 2010 2. $4.3 billion per year in 2020 3. $xx per year due to avoided landfill costs.	1.&2 Avoided environmental costs based on estimated savings in $/ton of pollutant. Actual costs for health, infrastructure, agriculture depends on geographic location, urban vs. rural, and many other factors. Estimates are made based on review of available projections. Assumes $200/ton for SO2, $803/ton NOx (based on Resources for the Future, July 2001), and $700/ton particulate. No value assigned to mercury. 3.
Coal By-products 1. $500 million - $1 billion per year in 2010 due to avoided disposal cost and revenue from sale of by-products 2. $13 billion per year due to avoided designation as RCRA Subtitle C hazardous waste.	Baseline assumptions: 2001 ACAA production and utilization statistics • 121 million tons of by-products produced annually • 40.5 million tons (33%) of byproducts currently utilized. • $16 - $25/ton solid waste disposal cost • $100/ton hazardous waste disposal. • $18/ton fly ash utilized for cement/concrete/grout • $2/ton all other by-product utilization • Assume current byproduct utilization ratio for future utilization (39% for cement/concrete/grout, 61% all other application. 1. Achieve 50% utilization of 2001 generation. 2. Avoided cost of hazardous waste disposal of by-products due to DOE research aimed at an avoided determination that by-products from utility coal combustion should be regulated as RCRA Subtitle C hazardous waste by EPA