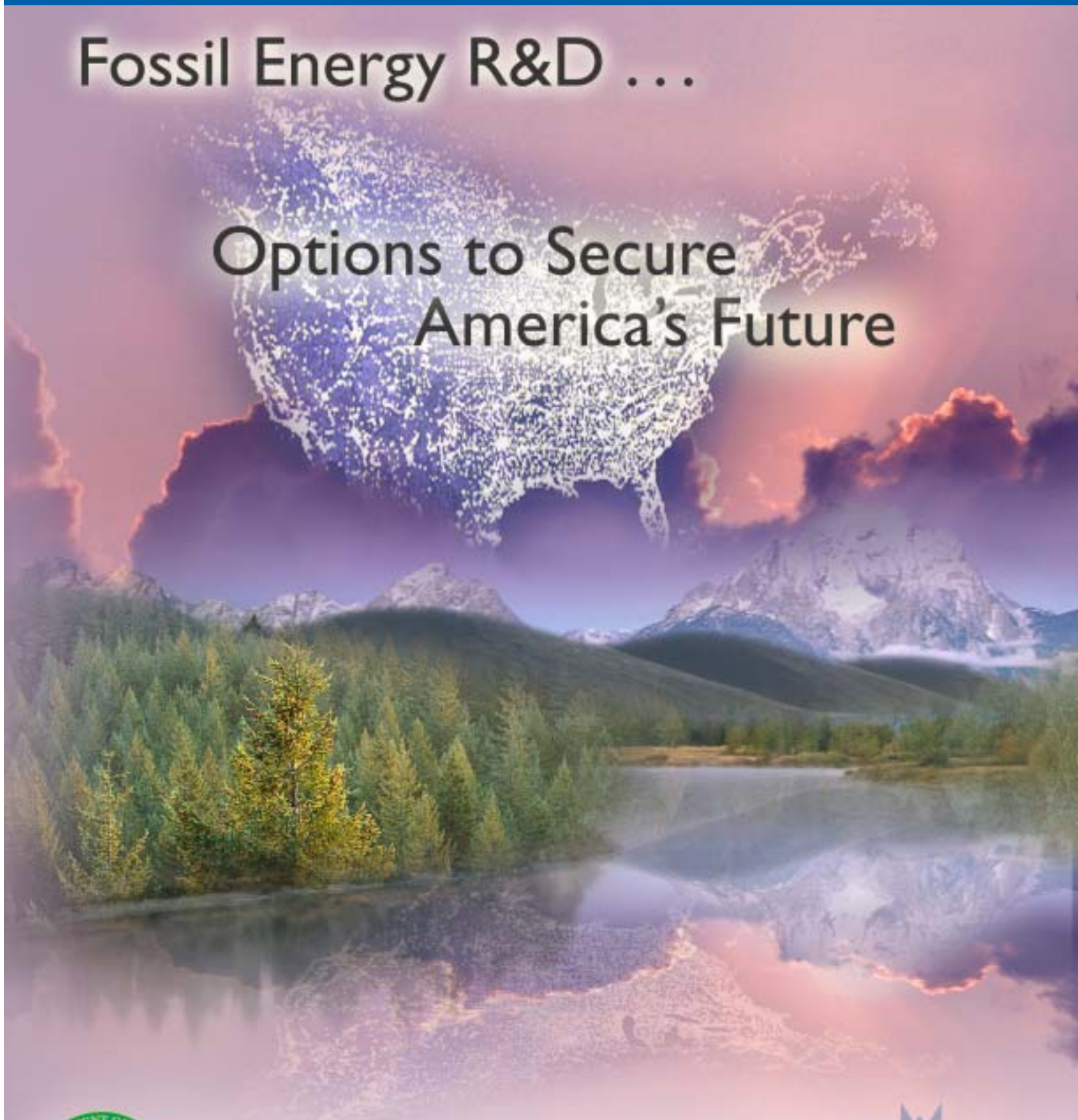
U.S. Department of Energy • Office of Fossil Energy
National Energy Technology Laboratory

Fossil Energy R&D . . .

Options to Secure America's Future



2004 Analysis Highlights of Prospective FE R&D Program Benefits

What Does the U.S. Department of Energy Fossil Energy R&D Mean to America's Energy and Economic Future?

Methodology for Estimating Research & Development (R&D) Benefits

The primary tool used to estimate future R&D benefits is the National Energy Modeling System (NEMS) developed by the Energy Information Administration (EIA). Benefits are based on the difference between certain parameters for NEMS runs made with and without the impacts of FE R&D. For cases with FE R&D, it is assumed that program R&D goals are met and funding is consistent with FY2004 appropriations and program plans. Multiple scenarios are used to examine the impact of selected regulatory and fuel energy price assumptions. Other than inputs reflecting FE R&D goals and alternative scenarios, NEMS inputs are based on EIA's FY2004 Annual Energy Outlook (AEO). Reducing emissions of pollutants to comply with regulations is not counted as a benefit, although lowering costs of emissions reduction is an important benefit that is counted. All benefits are cumulative from 2003 through 2025 to the United States, and dollar amounts are reported in 2002 dollars at a 5 percent discount factor.

Affordable Energy for a Variety of Possible Futures

By 2025, U.S. Department of Energy (DOE) Office of Fossil Energy (FE) R&D contributes to electricity and natural gas price reductions of up to 12 percent, relative to prices projected to occur absent this R&D. These price reductions contribute to electricity savings between $96 billion and $127 billion, and natural gas savings between $22 billion and $59 billion.

Clean Options to Meet Future Energy Demand

Future regulatory conditions may require additional significant emission reductions. FE technologies help meet these requirements, while at the same time contributing to a total energy savings of between $118 billion and $186 billion for consumers by 2025. As has been the case in the past, there will likely be an interplay between technology and future regulation. Technology advances will allow greater regulated emission reductions, which, when monitized, can translate to very large benefits. Such benefits are not considered in this report.

Energy Security

FE R&D results in a more diversified oil supply portfolio by extending domestic production of crude oil and reducing reliance on imports by more than 2 billion barrels through 2025. FE R&D, consistent with the FY2004 program, improves the economics of developing domestic natural gas supplies from a variety of challenging resources, resulting in a more diversified natural gas supply portfolio that can support an additional 30 trillion cubic feet (Tcf) of demand through 2025.

A Diversified Energy Supply Portfolio

- FE R&D contributes to an increase in advanced coal-fired generating capacity, more than two times greater than without R&D. New capacity is primarily integrated gasification combined-cycle (IGCC), which for R&D scenarios that assume "moderately priced" fuels ranges from 60 to 70 gigawatts (GW) by 2025. IGCC penetration is considerably higher when higher fuel prices (i.e., for natural gas) are assumed.
- In a carbon-constrained future, FE R&D enables 65 GW of IGCC plants equipped with carbon dioxide (CO_2) capture and sequestration technology to be built by 2025, versus negligible capacity without R&D.
- FE R&D contributes to the installation of 56–87 GW of Solid State Energy Conversion Alliance (SECA) fuel cell capacity by 2025. This includes baseload and distributed power applications, and is a ten-fold increase, on average, in fuel cell capacity compared to a case absent FE R&D.

The benefits described in this report represent a subset of the overall benefits of the programs and are based upon prospective funding levels in 2004. Benefits for several important program elements were not modeled due to limitations of the modeling system used in this analysis. These program elements include:

Coal: Hydrogen, Non-utility Greenhouse Gas Sequestration, and Power Plant By-product Utilization

Gas: Hydrates, Deep Gas, Delivery Reliability, and Advanced Storage

Oil: Environmental (scheduled for 2005 Analysis), selected aspects of reservoir life extension (e.g. micro-hole drilling), and Enhanced Oil Recovery

Efforts are underway to include these in subsequent rounds of analyses because external estimates indicate their benefits to be substantial.

2004 Analysis Highlights of Prospective FE R&D Program Benefits

FE R&D Is Designed to Deliver Benefits

FE R&D Portfolio Supports Current Administration Priorities

Clean Coal R&D Program

- Advancing Power Efficiency
- Developing Pollution Controls
- Diversifying Fuel Sources
- Ensuring Energy Security

Fuel Cell R&D

- Enabling Coal-Based Distributed and Baseload Applications

Carbon Sequestration

- Providing New, Affordable Options for CO_2 Capture and Storage

Hydrogen from Coal

- Supplying Tomorrow's Clean Fuels

Gas Supply R&D

- Diversifying Domestic Supplies
- Exploring the Potential of Hydrates
- Ensuring Pipeline System Reliability

Oil Supply R&D

- Extending the Life of Mature Domestic Reservoirs
- Developing Enhanced Oil Recovery for Marginal or Abandoned Domestic Reservoirs
- Improving Environmental Stewardship and Accessibility to Federal Lands

FE's R&D Portfolio

The U.S. Department of Energy (DOE) Office of Fossil Energy (FE) conducts research and development (R&D) in the areas of coal and power systems, carbon sequestration, hydrogen and clean fuels, and oil and natural gas supply and delivery. FE fosters the development and demonstration of advanced, clean, affordable fossil-based energy technologies through internal government research and external partnerships with industry and academia. In addition, FE's role in technology development is to eliminate any detrimental environmental effect of energy production and use and maintain U.S. leadership in promoting the effective use of fossil energy technologies on an international scale.

Federal R&D Role

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 necessary government role. It is driven by the need for technology innovation to achieve economic, environmental, and energy security goals resulting in public good that market forces and policy and regulations alone cannot provide. The main focus of this report is to quantify and highlight the significant economic and energy sector benefits attributable to FE R&D programs. Estimated impacts on oil and gas production, oil imports, power generation technology market penetration, carbon intensity, and fuel prices are the basis for estimating economic, environmental, and energy security benefits from FE's R&D programs.

Considering Alternate Future Scenarios

The future benefits and impacts of R&D programs are inherently uncertain, as are future economic, geopolitical, and regulatory conditions. Thus, this study considers a range of scenarios that reflect these uncertainties. To represent the most important potential domestic futures that would be addressed by FE technologies, four scenarios were evaluated—(Business-As-Usual, Clear Skies, High Fuel Prices, and Carbon Cap).

FE R&D Benefit Methodology

The methodology used in this study to quantify program benefits assumes hypothetical conditions that represent potential future domestic energy scenarios. The primary tool for determining the impacts of FE programs is the U.S. Energy Information Administration (EIA) National Energy Modeling System (NEMS). NEMS is the model used by EIA to generate its Annual Energy Outlook (AEO). NEMS was configured by the EIA for four scenarios, each of which were run with and without the impact of FE R&D. Any changes in the model's predictions were then used as the basis for calculating benefits. For some FE technologies, the limitations of the NEMS model made it unsuitable or incapable of evaluating the impact of the R&D. In these cases, independent studies were performed, based on NEMS results when possible, to determine benefits. The benefit estimates in this report that were determined using an alternative method to the NEMS model are specifically noted.

Accounting for risk is an important part of projecting benefits from any R&D program, since future markets and program outcomes can never be known with absolute certainty. For new technologies in NEMS that compete with an incumbent technology (*e.g.*, IGCC competing with conventional power plants), program goals for the new technology are used directly in NEMS. To perform a risk assessment of the new technology, the output generated from NEMS must be evaluated by assigning probabilities of meeting the program goals. Risk weighted goals are used directly in NEMS when advances in multiple incumbent technologies combine to produce an overall benefit (*e.g.*, the combined impact of various exploration and production (E&P) technologies on prices paid by consumers for natural gas).

Three benefit categories were estimated:

1. **Economic benefits** result primarily from reduced fuel and energy prices to consumers. In a subsequent analysis, these public sector benefits will be combined with producer surplus effects to enable net benefits analyses.

2. **Environmental benefits** are primarily realized in terms of lower energy costs for U.S. consumers, though some environmental benefits from selected programs, such as Innovations for Existing Plants and Oil and Gas Supply and Delivery R&D, are explicitly estimated.

   Market-based cap-and-trade limits on national emissions are applied to all scenarios, requiring that all cases achieve the same overall emission profile. Because all scenarios have the same emission profile, the environmental impacts of FE R&D are captured in terms of economic benefits resulting from the reduction in energy prices when FE R&D clean energy technologies are implemented. When NEMS predicts that emission reductions occur from FE R&D that are above and beyond that required by the regulation, these avoided emissions are attributed to FE's program.

3. **Energy security benefits** are measured as an increase in domestic oil and natural gas production, or a reduction in fuel costs such that domestic resources displace imports.

FE R&D Benefits Scenario Definitions

Business-As-Usual

Assumes current regulatory framework as described in the Energy Information Administration's Annual Energy Outlook (EIA's AEO) 2004.

Clear Skies

The Clear Skies Initiative (CSI) as set forth in the U.S. Senate's Clear Skies Act of 2003, Senate Bill 485.

High Fuel Prices

The Clear Skies Initiative coupled with EIA-AEO 2004 High World Oil Price and constrained natural gas supplies.

Carbon Cap

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

R&D Benefits Provide Important Savings for U.S. Consumers and the Economy

Billions of Dollars in Public Benefits Result from FE R&D

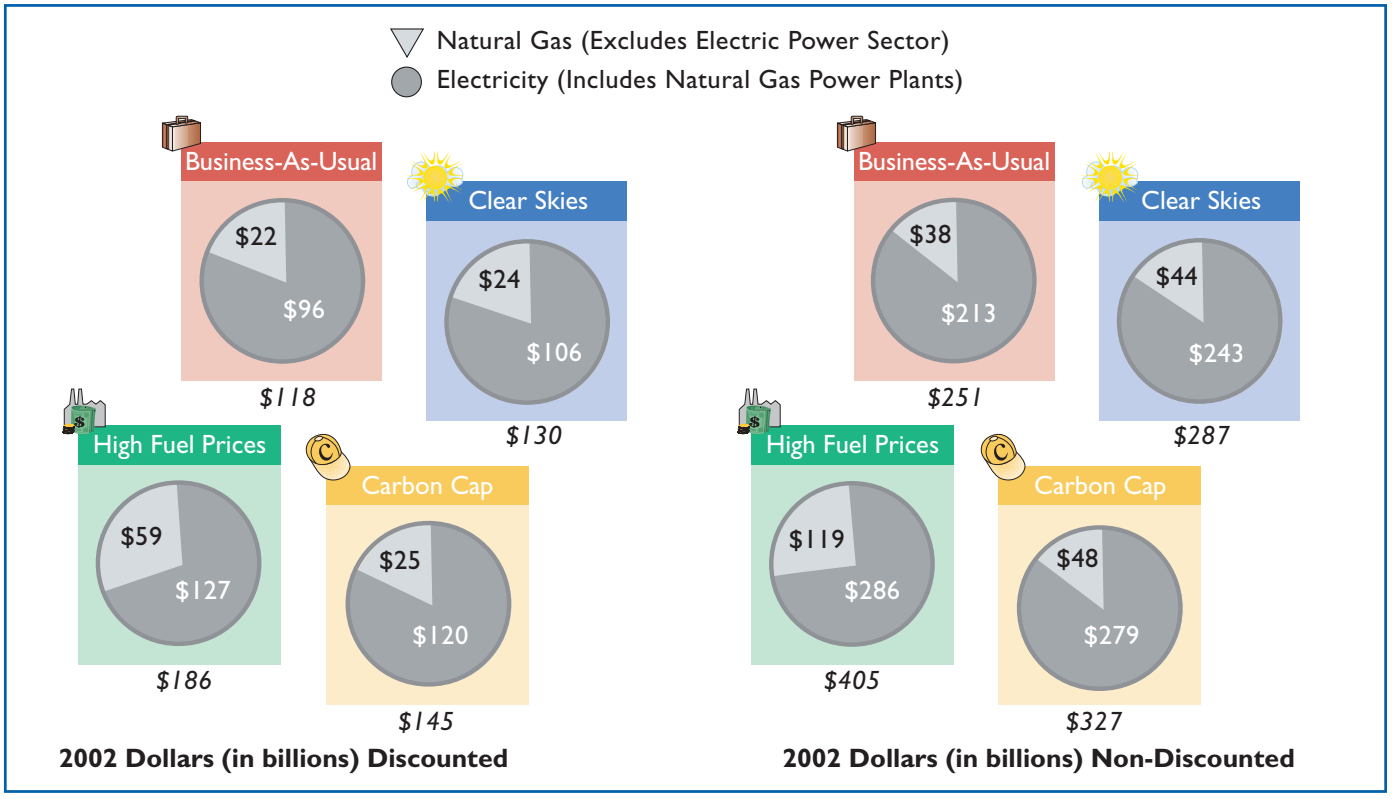
The goal of FE R&D is to provide clean and affordable energy to U.S. consumers. To achieve this, FE R&D is designed to develop and facilitate the adoption of advanced technologies and practices in all segments of the U.S. energy sector. The long-term operation of these technologies and practices generates the aggregate benefits discussed in this study, including lower electricity costs and reduced natural gas prices. These cost savings include lower electric prices from high efficiency and lower capital cost power plants, reduced costs for environmental compliance, reduced costs for exploration and production of domestic hydrocarbon resources, reduced expenditures on imports, and increased royalties to the U.S. government.

Fuel and electricity cost reductions are just two components of the overall significant public benefits resulting from FE's collaborative R&D program.

Discounted economic benefits in terms of reduced energy expenditures exceed $100 billion through 2025 in all scenarios. In the High Fuel Prices Scenario, FE R&D produces the highest discounted savings among the four scenarios studied, with electricity costs accounting for $127 billion and natural gas costs accounting for $59 billion, for a total of $186 billion in public benefits. On a non-discounted basis, the economic benefits exceed $200 billion in each scenario. The High Fuel Prices Scenario FE R&D produces the most savings on a non-discounted basis, with electricity savings of $286 billion and natural gas savings of $119 billion for a total exceeding $400 billion.

FE R&D enables coal to remain the primary fuel in the U.S. energy fuel mix, and also increases domestic oil and natural gas production. The final results are: more affordable energy for the U.S. economy, improved domestic energy security via the clean use of coal for power generation and increased domestic hydrocarbon production, and savings on oil and natural gas import payments approaching $50 billion in proportion to world oil prices.

FE R&D Economic Benefits* Through 2025



* Represented in terms of reduced consumer energy expenditures.

Key Benefits of the FE R&D Program

Significant Benefits Result Under Reference Conditions

FE's R&D Program provides over $100 billion (discounted) in savings to the American consumer by reducing energy prices (electricity and natural gas) by 2025, assuming current environmental restrictions and AEO 2004 reference case fuel projections. Driven by extended domestic production, crude oil imports fall by almost two billion barrels through 2025, and almost 30 Tcf of added natural gas demand is met by domestic supplies through 2025.

Business-As-Usual

Under Stringent Environmental Regulations Coal-Based Power Generation and Domestic Oil and Natural Gas Supply Provide Greater Benefits

Within NEMS, more stringent environmental regulations typically result in a switch from coal-based power plants to natural gas-fired ones. This in turn increases demand for natural gas resulting in higher gas prices. However, with the impact of the FE R&D, the cost of both electricity and natural gas is reduced to levels below that of the reference case. The FE Clean Coal Program provides cost-effective options for meeting the environmental constraints by making available cleaner, highly efficient coal-based technologies. Lower-cost options developed in the FE R&D program for mercury control make it possible to meet the Clear Skies cap without invoking the "safety valve," ultimately providing significantly reduced mercury emissions without negatively impacting the cost of electricity. The Gas Supply and Delivery R&D Program keeps natural gas prices affordable by providing additional economically recoverable natural gas resources in an environmentally sound manner. The result is a cumulative energy savings of $130 billion (discounted) by 2025. Not included in this estimate are benefits of the improved environmental aspects of domestic oil and gas extraction that effectively address waste management regulatory issues and federal lands access issues related to water rights and land use. (Preliminary estimates indicate these added benefits to be substantial, and an assessment will be pursued in the next round of analyses.)

Clear Skies

Options to Increase Domestic Natural Gas and Oil Production and Generate Electricity with Clean Coal Provide Largest Benefits when Fuel Prices are Elevated

The largest benefits are achieved when the tighter environmental restrictions of the Clear Skies Scenario on sulfur, nitrogen, and mercury emissions are coupled with high natural gas and oil prices. This situation benefits most dramatically from the availability of high-efficiency, clean advanced power generating technologies and additional economically recoverable natural gas resources that are both the result of FE's R&D Program. By 2025, more than $186 billion (discounted) in cumulative energy savings are estimated for this scenario. Increased domestic production of crude oil and natural gas are sustained in this scenario and, owing to the higher fuel prices, savings in the crude oil import bill though 2025 increase proportionally to over $35 billion (discounted).

High Fuel Prices

Keeping Coal in the Mix in a Carbon-Constrained World Benefits the Consumer and the Economy

A significant economic benefit also is realized when a carbon constraint is imposed to reduce GHG intensity by 18 percent of 2002 levels by 2012. In this case, the availability of a low-cost option for capture and sequestration of carbon dioxide (CO_2) greatly improves the economics of generating electricity from coal while still meeting all environmental goals. Keeping coal in the mix provides for an overall savings in the cost of electricity to consumers. Likewise, the reduction in natural gas prices, due to additional domestic natural gas production and reduced demand for natural gas in the utility sector, adds to consumer cost savings and is a benefit to the U.S. economy and energy security. By 2025, $145 billion (discounted) in electricity and natural gas cost savings are realized in this scenario.

Carbon Cap

Discounted benefits are reported in 2002 dollars at a 5 percent discount factor.

Benefits Result From Reduced Energy Costs

The table below illustrates that FE R&D reduces electricity and natural gas prices in all scenarios. Without FE R&D in the High Fuel Prices Scenario, electricity and natural gas prices are forecast to increase by 6 percent and 15 percent, respectively. In this scenario, electricity prices increase from 7.1 ¢/kWh in 2005 to 7.5 ¢/kWh in 2025, while natural gas prices jump from $7.5/MMBtu in 2005 to $8.6/MMBtu in 2025. With FE R&D, electricity prices fall by 7 percent (from 7.1 to 6.6 ¢/kWh) while the double-digit natural gas price increase is reduced to 3 percent (from $7.4 to 7.6/MMBtu).

In the Carbon Cap Scenario, a 23 percent increase in electricity prices without FE R&D (7.0 to 8.6 ¢/kWh) is reduced to 10 percent with FE R&D (7.0 to 7.7 ¢/kWh). For natural gas, a 5 percent decrease in prices without FE R&D ($7.3 to 6.9/MMBtu) accelerates to more than 10 percent with FE R&D ($7.2 to 6.5/MMBtu).

Clean Coal Program

The Clean Coal Program is designed to improve environmental performance, plant efficiency, and capital costs over conventional power generation technologies. The technologies under development in the program provide multi-pollutant control options for existing power plants, a new generation of advanced coal-based power generating systems, a new suite of carbon capture and storage technologies, electrochemical-based fuel cells operating on coal-derived fuels, and new methods of producing hydrogen from coal. A main driver of the program is to showcase a project to build the world's first integrated, zero-emissions, coal-based energy plant that will generate electricity, produce hydrogen, and sequester carbon. The major impact of the program is cleaner and cheaper power generating technology that ultimately results in reduced electricity costs for consumers without negative impacts on the environment. The reduced electricity costs produce an overall cumulative economic benefit in reduced energy expenditures of $70–99 billion (discounted) by 2025.

FE R&D Programs Reduce Electricity and Natural Gas Prices

	Average Price of Electricity (¢/kWh)*		Average Price of Natural Gas ($/MMBtu)†	
	2005	2025	2005	2025
Business- As-Usual				
Without FE R&D	7.1	6.9	7.3	6.8
With FE R&D	7.0	6.4	7.2	6.5
Clear Skies				
Without FE R&D	7.1	7.1	7.3	6.9
With FE R&D	7.0	6.6	7.2	6.5
High Fuel Prices				
Without FE R&D	7.1	7.5	7.5	8.6
With FE R&D	7.1	6.6	7.4	7.6
Carbon Cap				
Without FE R&D	7.0	8.6	7.3	6.9
With FE R&D	7.0	7.7	7.2	6.5

* Electricity costs consider all electric generators, including those fueled with natural gas.

† Excludes electric sector since the price of electricity takes into account natural gas fuel cost to utilities.

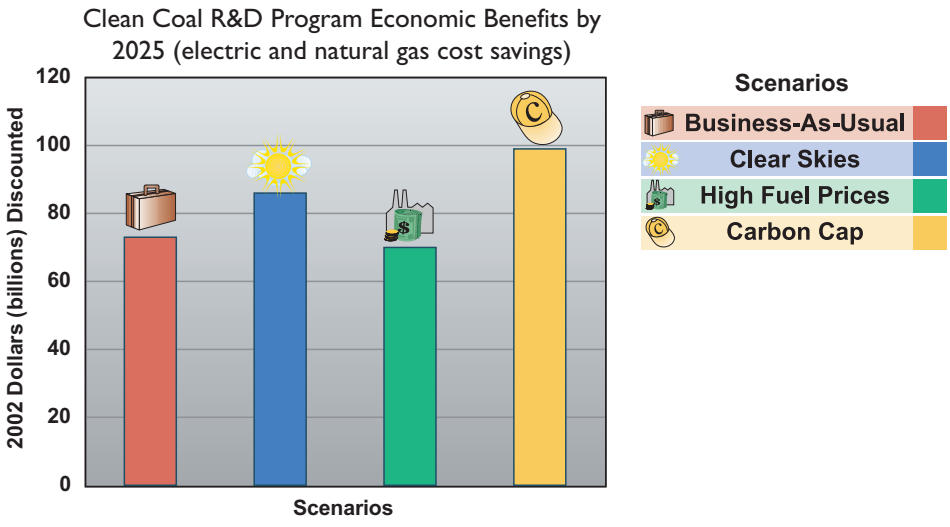
Gas Supply & Delivery R&D Program Benefits

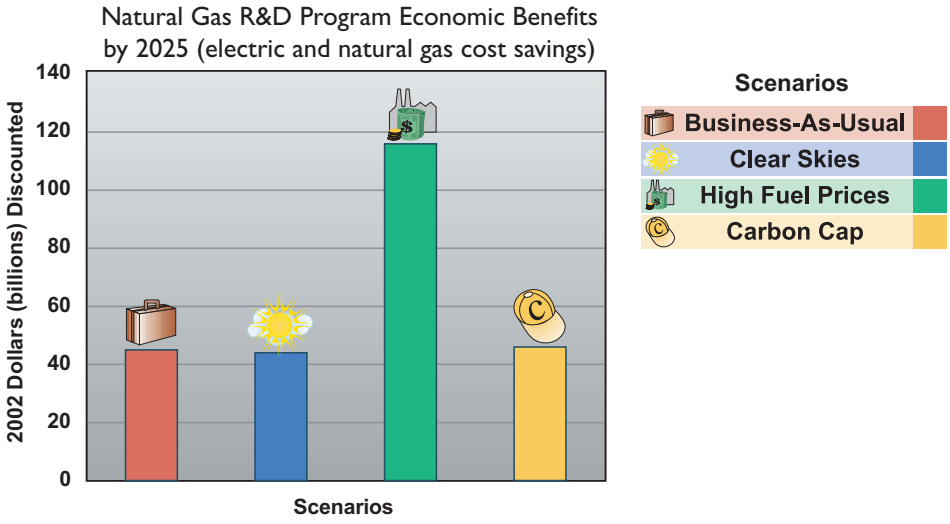
The Natural Gas Supply and Delivery R&D Program provides significant public benefits (both economic and environmental) by stimulating domestic natural gas production and increasing the domestic reserve base. Advances in exploration and drilling technologies and techniques expand the economically recoverable resource base, thereby enabling increased production. By improving the economic recoverability of domestic gas resources, the cost of natural gas to all consumers (including the utility sector) also declines, resulting in an energy savings in the

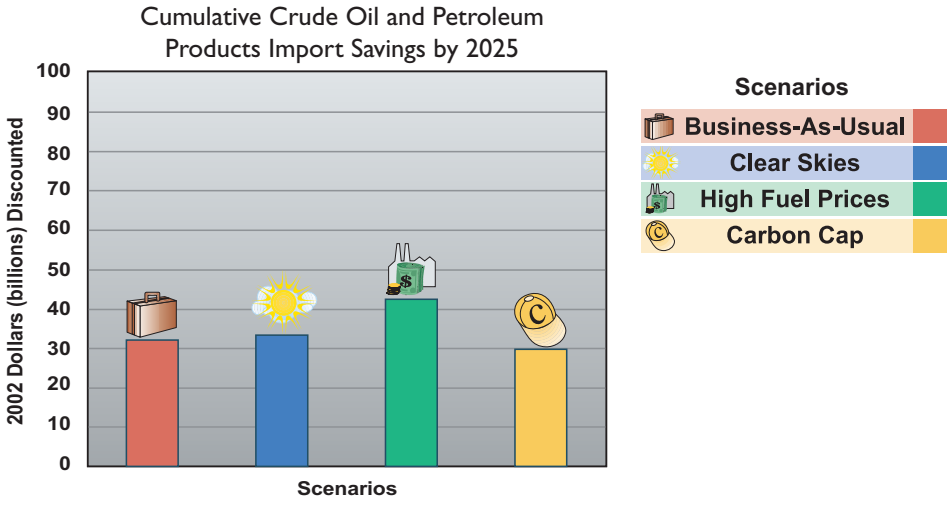
cost of electricity. The discounted benefits for the natural gas program range from $45–116 billion by 2025.

Oil Supply & Delivery R&D Program Benefits

The Oil Supply and Environmental Program shows significant public benefits by extending production of domestic crude oil from the Nation's aging reservoirs and by improving the stewardship of land and water resources that are impacted by oil and gas developments. Advances in diagnostics, imaging, and drilling contribute to increased production, while more efficient exploration and production practices, waste management technologies, and regulatory procedures contribute to improved cost savings. The nation imports a significant quantity of crude oil and petroleum products. In 2004, U.S. crude oil and petroleum product imports averaged nearly 13 million barrels per day, which is more than 60 percent of total U.S. demand. Increased domestic oil production can reduce the national bill for these imports. Successful oil R&D that increases supplies of domestic oil directly reduces crude oil and petroleum product imports, and in turn provides an economic benefit in terms of reduced expenditures on oil imports of between $30–43 billion (discounted) by 2025.







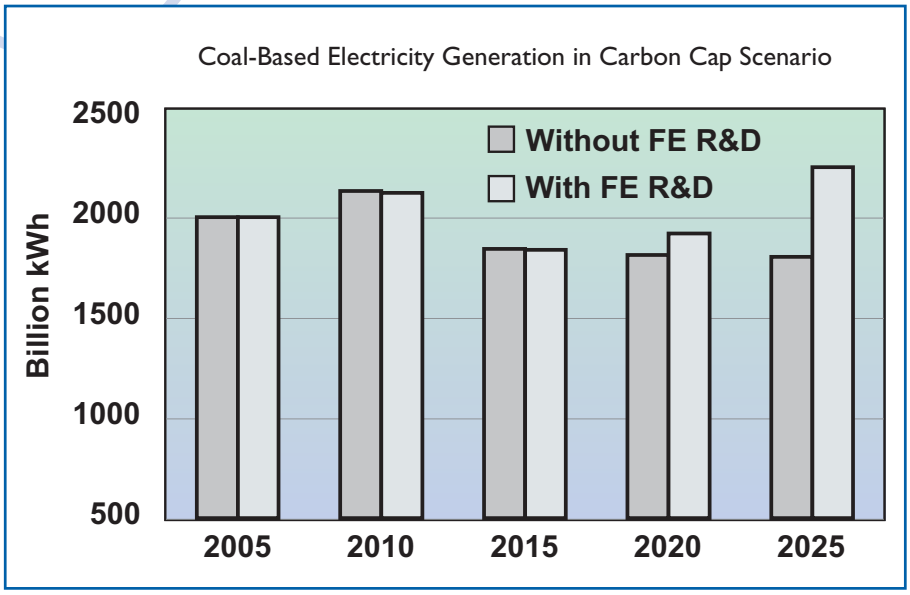
Clean Options for Future Energy Demand and Environmental Challenges

Fuel diversity is essential to providing affordable energy prices while meeting environmental restrictions and reducing U.S. reliance on imports.

FE R&D keeps coal competitive while reducing greenhouse gas emissions

Keeping Coal as a Viable Option

In the midst of growing domestic electricity demand and tightening environmental regulations, FE R&D is a key element in maintaining coal as a vital indigenous energy resource for meeting these challenges. Without FE R&D to provide clean, cost-effective technology options, coal-powered electric generation would decrease, and the nation would become more reliant on fewer fuel sources to meet growing demand. This would make the nation more vulnerable to supply disruptions and fuel price volatility. Advanced coal technology, including carbon sequestration technology, keeps coal competitively in the mix, resulting in an increased use of coal even in the face of strict environmental regulations.

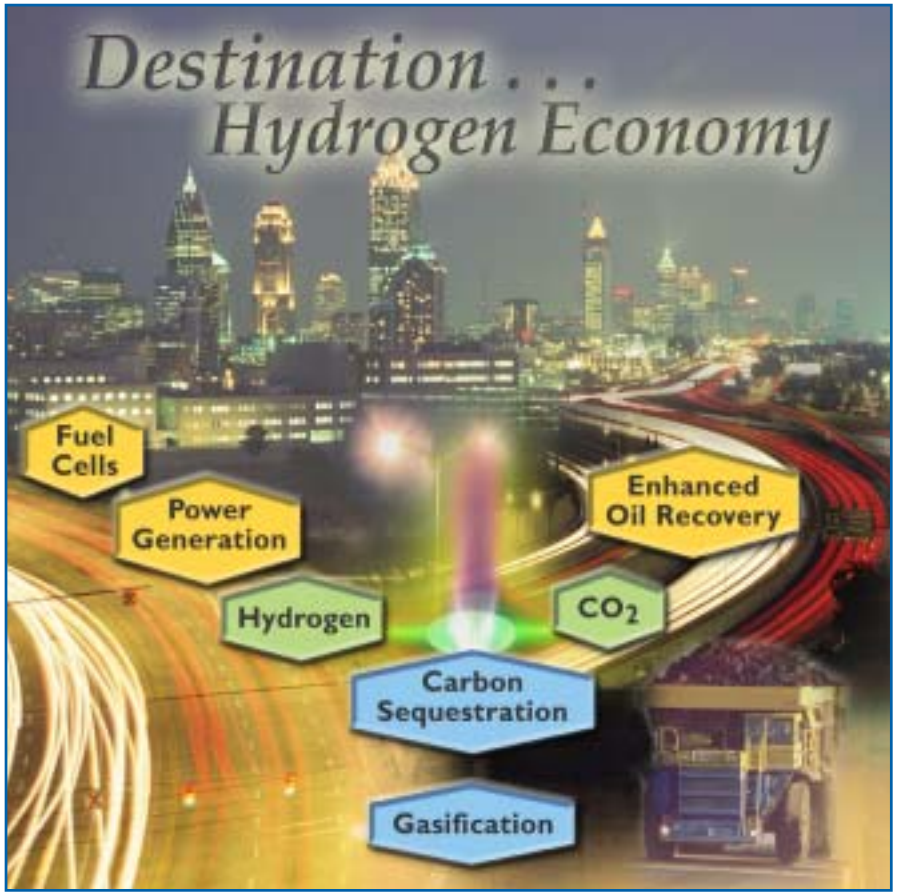


FE R&D provides an environmentally friendly option at a fossil fuel price. The high efficiency and low-cost electricity generation available from advanced power plants developed through the Clean Coal FE R&D Program, coupled with the technologies' superior environmental performance and low costs, result in the increased use of coal. In addition, the Clean Coal R&D Program technologies help to keep electricity prices down, furthering the nation's ability to maintain its diverse suite of fuel resources. Fuel diversity is essential to providing affordable energy prices while meeting environmental restrictions and reducing our reliance on imports.

All scenarios (except for the Business-As-Usual Scenario) met the same Clear Skies emission limits. Because it is the CSI regulation that forces emission reductions, in these scenarios, the benefits of the FE R&D Program generally cannot be measured in terms of avoided nitrogen oxides (NO_x), mercury, and sulfur oxides (SO_x) emissions. However, when FE's advanced technologies are deployed to meet the emission limits, reductions in energy costs are claimed as a benefit of the R&D program.

Transitioning to a Hydrogen Economy

Hydrogen R&D conducted by FE is engaging in early efforts to transition to a hydrogen economy by developing advanced and novel technologies that will facilitate the use of the nation's abundant coal resources to produce, store, deliver, and utilize affordable hydrogen. Using hydrogen can reduce environmental concerns associated with energy use in automotive and stationary power applications through the clean production of hydrogen from coal in parallel with carbon sequestration. Recent experience has shown that gasification has the potential to produce clean synthesis gas from coal with virtually zero pollutant emissions. Research in carbon sequestration is leading to technologies that will cost-effectively use concentrated CO_2 streams in other energy sector applications, such as enhanced oil recovery. Using coal-derived hydrogen in fuel cells provides efficient, emission-free power in both automotive and stationary applications. The pathway to a hydrogen economy requires that R&D be focused on reducing the cost of coal-based hydrogen-production technologies. In the interim, natural gas will serve as a transition fuel for producing hydrogen. The additional supply of natural gas to meet this need will be eased by the FE Gas Supply and Delivery R&D Program that is developing technology to economically recover additional natural gas resources.



Key Benefits of Hydrogen from Coal

A well-to-wheel analysis was performed outside the NEMS framework, which assumed that in 2025, 20 percent of all hydrogen (H_2) for fuel cell vehicle (FCV) hydrogen use demand in the United States will be produced from coal. This analysis estimated that the benefits of producing hydrogen from coal and utilizing the H_2 in FCVs will:

- save 370 thousand barrels per day of imported oil
- save 150 billion cubic feet of imported natural gas per year
- reduce the cost of U.S. fossil fuel consumption by almost $4 billion per year
- reduce NO_x emissions by 20 thousand metric tons per year
- reduce SO_x emissions by 5.3 thousand metric tons per year

Environmentally Sound Coal-Based Power

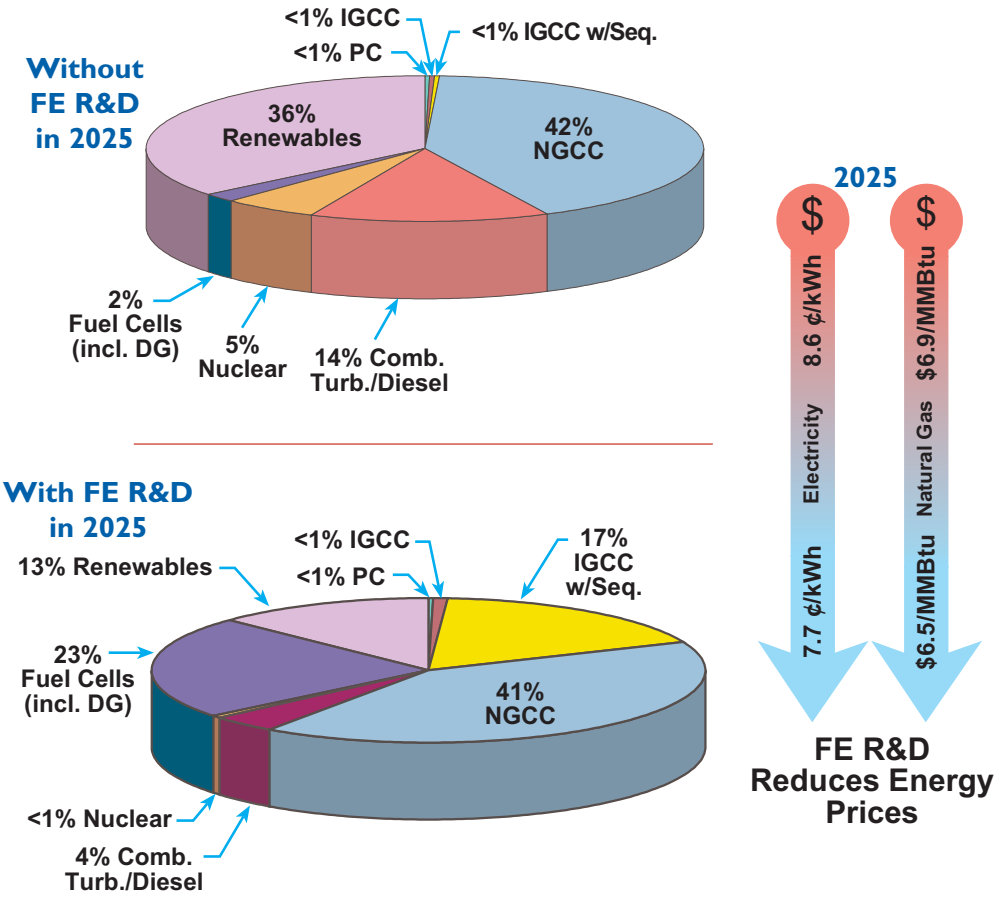
Addressing Environmental Challenges with Coal

Without FE R&D, regulatory pressure to reduce CO_2 emissions would limit pulverized coal plant capacity additions to only about 1 gigawatt (GW), and IGCC plants to less than 1 GW by 2025. No natural gas plants with carbon sequestration would be built because they are not economically competitive. Builds of renewables would increase and new nuclear plants would come on-line. The average price of electricity would be 8.6 ¢/kWh in 2025, and natural gas prices would hit nearly $7/MMBtu.

The picture changes significantly with FE R&D, where coal continues to play a key role in generating power, even with a carbon cap. Coal-based power systems grow to nearly 70 GW by 2025 (95 percent of which are IGCC plants with carbon sequestration), and fuel cell capacity grows to 87 GW. Renewables maintain a significant market share at 48 GW, but nuclear plants are edged out by FE's advanced power systems. The end result is that FE's advanced technologies meet the environmental requirements while reducing fuel and electric prices. With FE R&D, in 2025 the average price of electricity drops 0.9 ¢/kWh, and the natural gas price falls $0.4/MMBtu.

The electricity cost benefits in all four scenarios surpass $70 billion (discounted) after 2020, where cumulative electric cost savings begin to grow at a faster pace compared to the 2010 to 2020 timeframe (see bar chart on the next page). By 2025, in all scenarios, FE R&D provides more than $95 billion, (discounted) in electric cost savings. Discounted cumulative electricity energy savings by 2025 reach $96 billion in the Business-As-Usual Scenario, and exceed $127 billion in the High Fuel Prices Scenario.

Cost-Effective and Environmentally Sound New Capacity in a Carbon Constrained Future

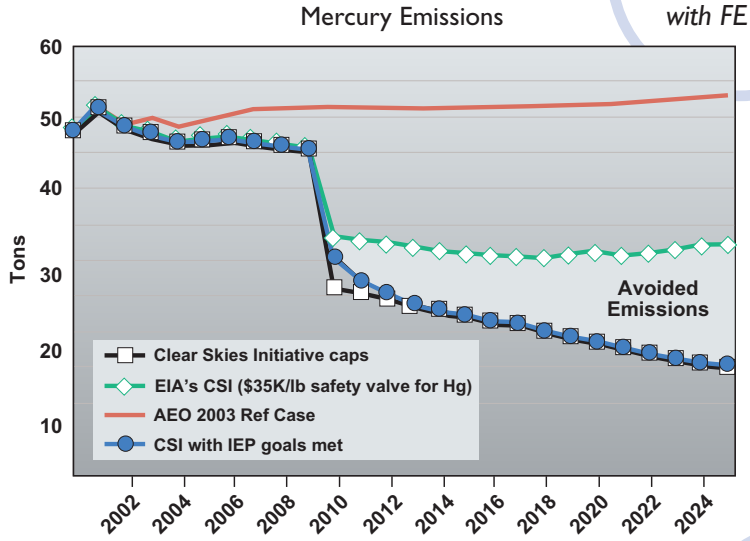


Mercury Emissions Reductions

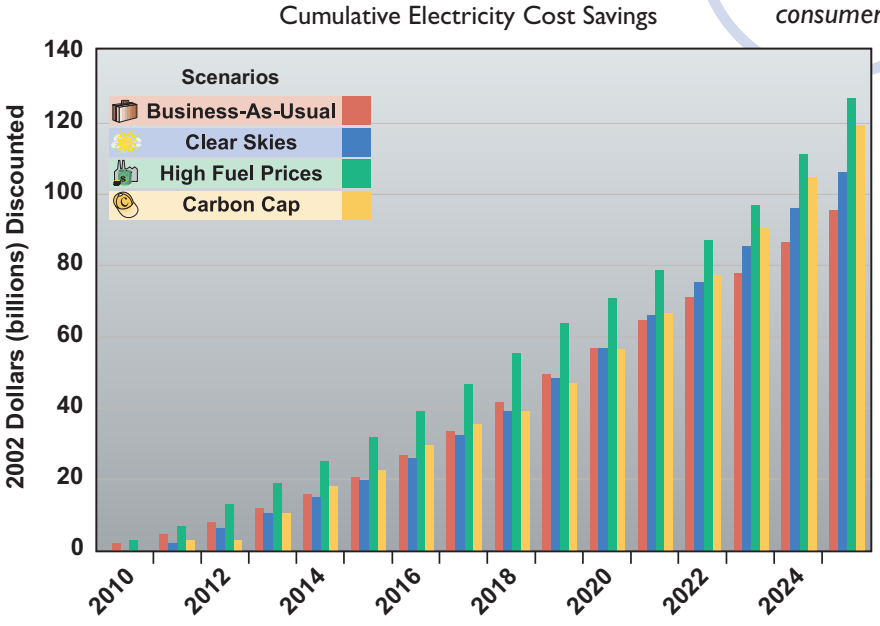
One area in which FE R&D environmental benefits can be measured directly in terms of avoided emissions is capture of mercury (Hg) from existing power plants. NEMS forecasts indicate that, using EIA cost and performance numbers for Hg control technologies, the United States will not be able to meet the actual 26 ton (in 2010) and 15 ton (in 2018) Hg caps of the CSI using existing technologies. NEMS forecasts that the U.S. will be able to lower its Hg emissions only to about 30 tons per year (green line with diamond symbols) — twice the level sought by the CSI. This is the result of a provision in the CSI that relaxes the mercury cap once a trading price of $35,000 per pound of mercury is reached.

However, with the reduced cost of Hg control provided by FE's technologies, it is possible to meet the 15 ton/year goal of CSI without exceeding the $35,000 per pound trading price. With FE's advanced technologies, national Hg emissions are 30 tons in 2010, slightly above the 26 ton CSI cap. After 2013, CSI caps (with banking) are met exactly (blue line with circles). Therefore, environmental benefits are realized in terms of additional Hg emissions avoided. The environmental benefit (167 aggregate tons of Hg emissions avoided between 2010 and 2025) is represented by the shaded area between the curves.

National Hg emissions are achieved only with FE R&D

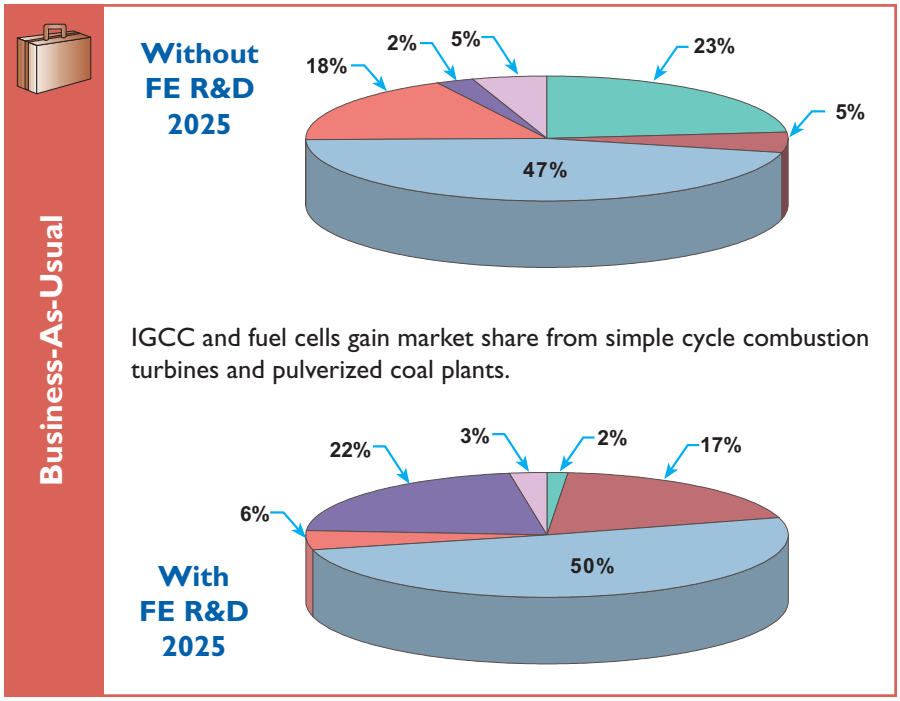


FE R&D results in significant electricity cost savings to consumers



Providing A Diverse Power Generating Fleet

Power Generation New Plant Capacity

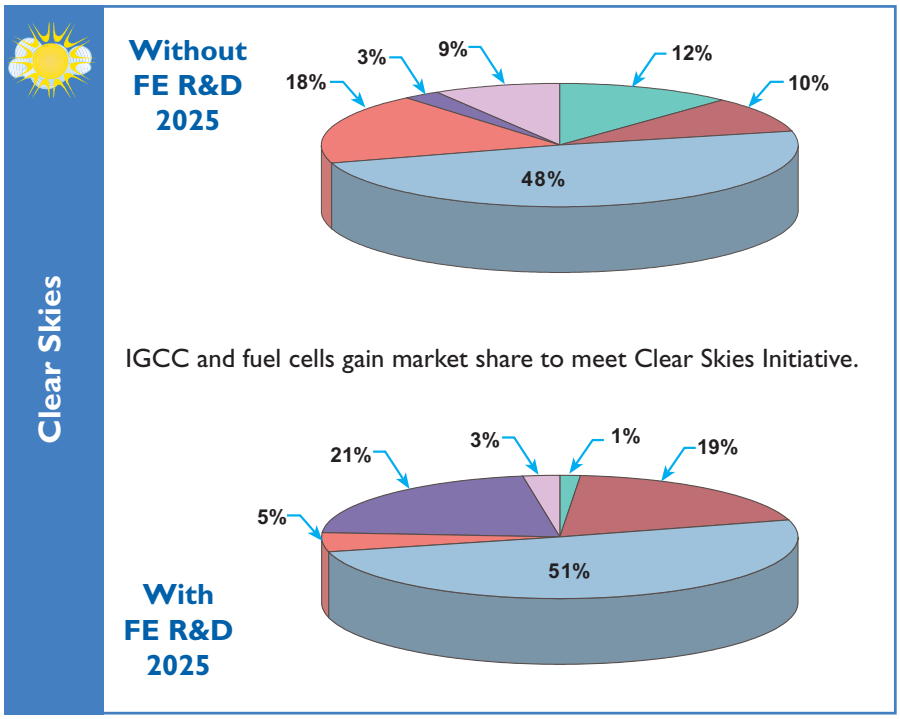


FE R&D contributes to the development of highly efficient, environmentally friendly fossil fuel-based power generation technologies. Commercial deployment of these technologies is linked to affordability and increased reliability. The following pie charts detail the impact that FE R&D has on new power generation technologies in 2025. These charts illustrate that in all scenarios, FE R&D provides a more diverse power generating fleet. Advanced coal technologies, like IGCC, meet the scenario-driven environmental

Legend

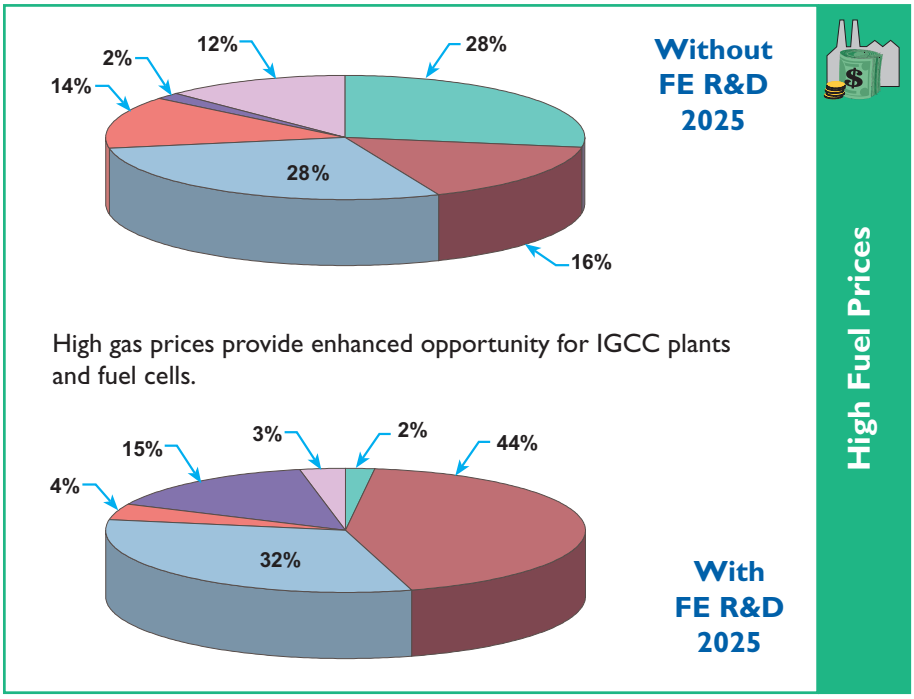
- NGCC
- IGCC w/Seq.
- IGCC
- Renewables
- Fuel Cells (including DG)
- Comb. Turb./Diesel
- Nuclear
- Pulverized Coal (PC)

Power Generation New Plant Capacity

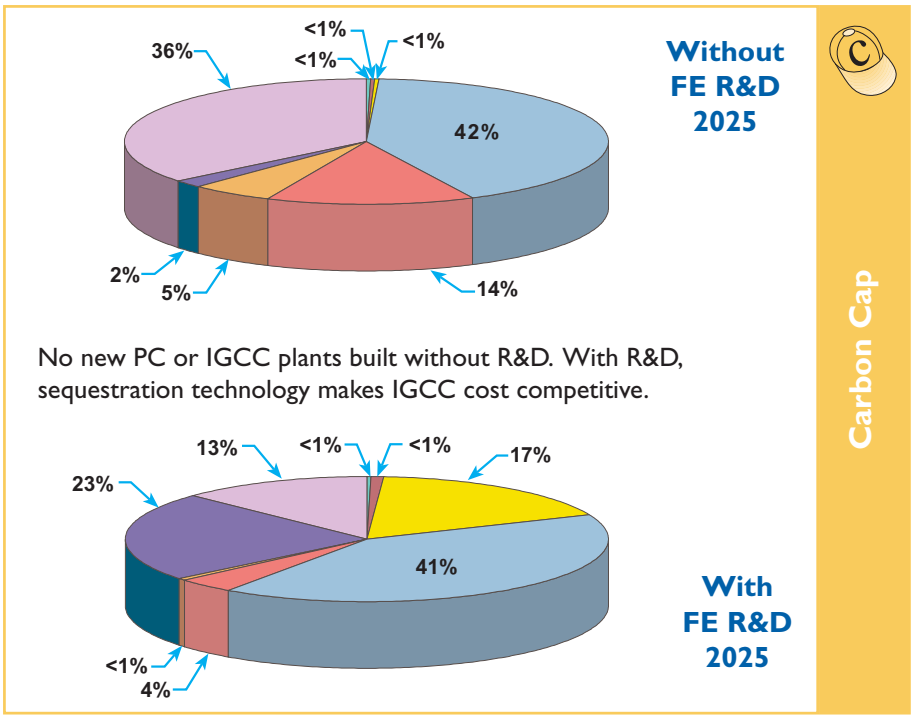


restrictions, while maintaining coal's importance to affordable power generation. In addition, FE R&D accelerates development of affordable and reliable advanced power generation technologies which enter service sooner than would have otherwise occurred without FE R&D. The result is a public benefit of billions of dollars in reduced energy costs. Moreover, these new capacity additions utilize domestic fuels, making the United States more energy secure by reducing its dependence on foreign fuel sources.

Power Generation New Plant Capacity



Power Generation New Plant Capacity



Legend

- NGCC
- IGCC w/Seq.
- IGCC
- Renewables
- Fuel Cells (including DG)
- Comb. Turb./Diesel
- Nuclear
- Pulverized Coal (PC)

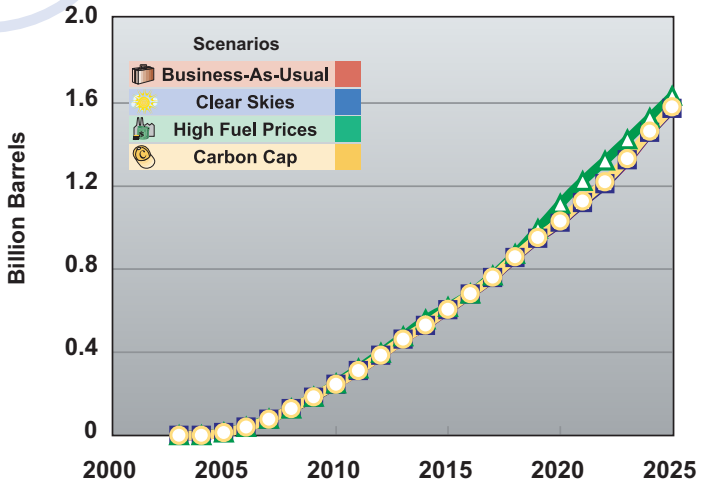
Options to Diversify Oil Supply and Ensure Energy Security

Developing Domestic Oil Resources to Diversify Supply

FE's oil R&D program addresses all facets of the oil supply industry, and development of a broad range of technologies. National energy security and declining private R&D are the main drivers behind federal R&D that targets new potential resources beyond industry's current capabilities. The Oil R&D programs seek development of domestic oil resources in an environmentally sound manner, thereby ensuring greater diversity of global oil supplies and offsetting increasing oil imports.

FE R&D increases domestic crude oil production by 1.6 billion barrels

Cumulative Increase in Domestic Crude Oil & Lease Condensate Production (excludes natural gas plant liquids)



Impacting Oil Consumption, Production, and Imports

Considerable oil-related impacts are associated with FE programs, regardless of the scenario. Incremental cumulative crude oil production over the 2003 to 2025 time period amounts to 1.6 billion barrels. Without exception, the increase in domestic production offsets crude oil imports (excluding imports of petroleum products). Crude oil imports, however, due to some fuel switching capacity in the stationary power generation sector, are reduced above and beyond the increase in domestic production. The combined impact of increased domestic production and reduced crude oil consumption results in a reduction in crude oil imports of as much as 2.1 billion barrels. Notably, these reductions translate into savings in oil import payments, approaching $35 billion, in proportion to world oil prices.

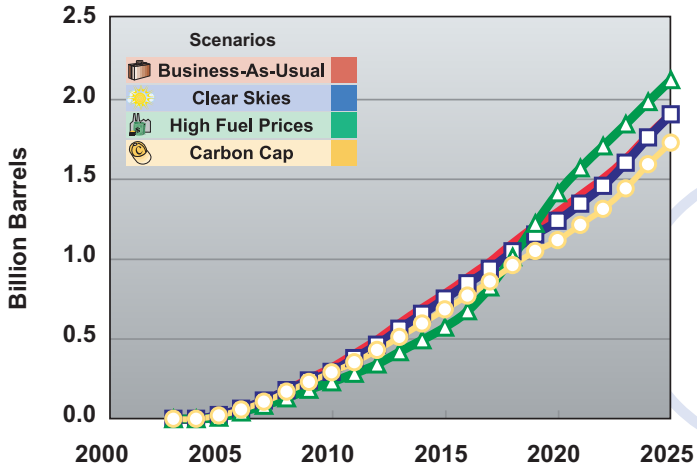
An interesting outcome to note is that FE's natural gas technologies program can impact future expenditures for crude oil imports. Higher natural gas prices result in fuel switching from gas to distillate, subsequently increasing demand for oil, much of which must be imported. Consequently, the combined impact of FE's natural gas and oil program technologies can be substantial in reducing the costs of importing crude oil.

Leveraging Oil and Gas Program Benefits

Not all components of the oil R&D program could be adequately analyzed in this study. Of the more direct benefits that were analyzed, such as the extension of domestic crude oil production and its impact on imports, the expected economic benefits exceed the R&D investment by a wide margin. Benefits to be analyzed in a subsequent study include the impact of the oil and gas environmental program, with special reference to its impact on access to federal lands, and a more comprehensive evaluation of CO_2-based oil and gas recovery processes. In a sense, what remains to be evaluated are options to develop the nation's substantial, but challenging resources (remaining unrecovered crude oil in marginal or abandoned reservoirs, oil and gas on federal lands, etc.). It is believed that, under plausible scenarios, the benefits of pursuing these opportunities are truly substantial.

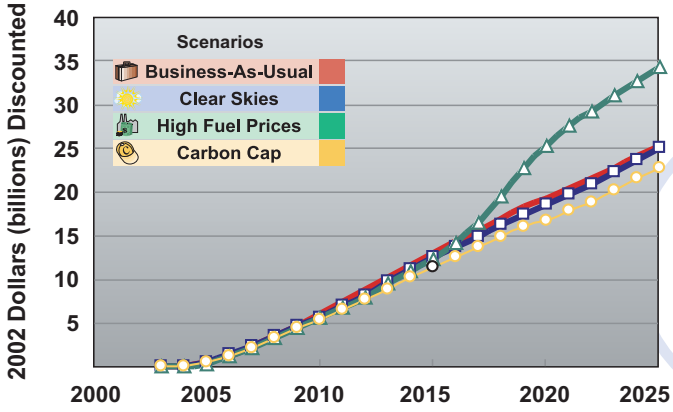
For all scenarios considered, the greatest annual economic benefits attributable to the oil and natural gas R&D programs are realized in the 2010 to 2020 time period. The size and duration of these impacts relate to the availability of and accessibility to alternative sources of non-Lower-48 natural gas supplies (i.e., supplies from Alaska, Canada, and Mexico, and supplies of liquefied natural gas (LNG)). Availability of these alternative supplies at significant scale cannot be expected with reasonable certainty in this time frame. Important contingencies include U.S. policies with respect to construction of an Alaska natural gas pipeline and construction of new or expanded LNG import facilities.

Cumulative Reduction in Crude Oil Imports
(excludes petroleum products)



FE R&D reduces oil imports by as much as 2.1 billion barrels

Cumulative Savings in Crude Oil Import Bill
(excludes petroleum products)

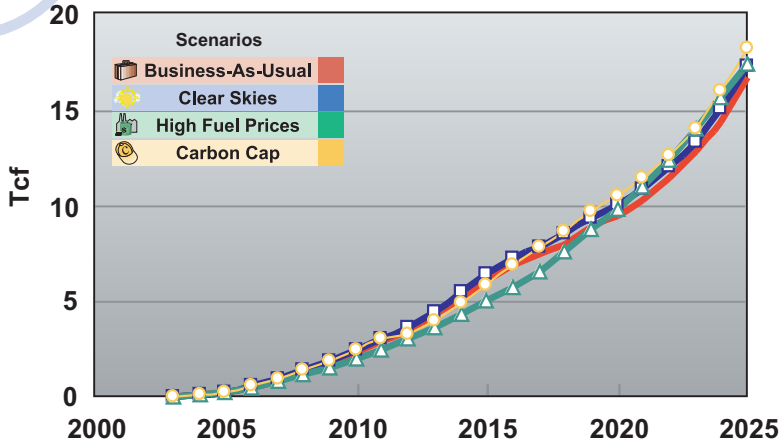


FE R&D reduces the national bill for crude oil imports with the amount proportional to world oil prices

Options to Increase Natural Gas Production and Ensure Energy Security

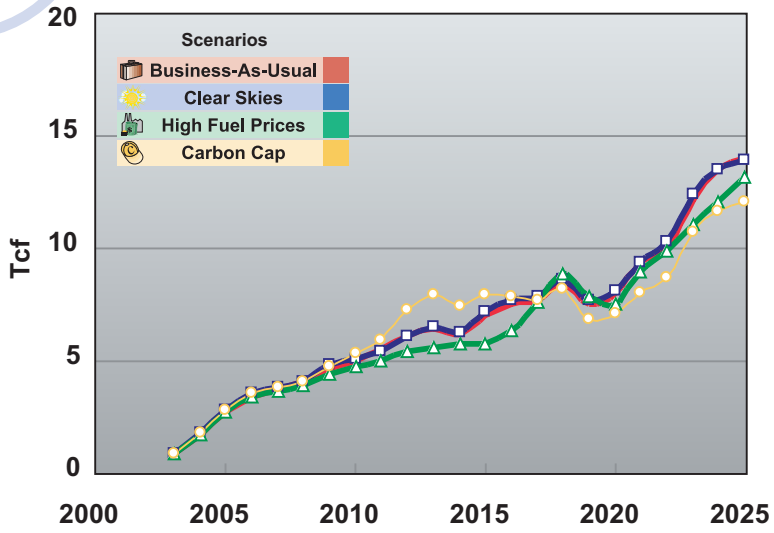
FE R&D increases cumulative domestic natural gas production by 17.5 Tcf

Cumulative Increase in Domestic Natural Gas Production



FE R&D increases domestic natural gas proved reserves in 2025 by 12.5 Tcf

Net Cumulative Increase in Domestic Natural Gas Reserves



Targeting Secure Supplies & New Resources

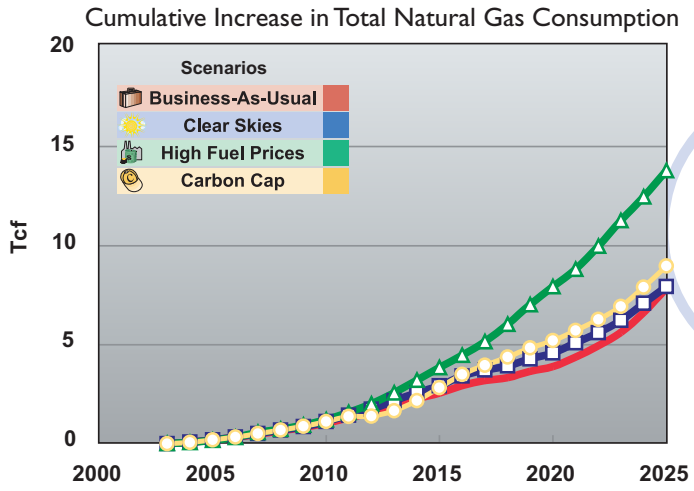
FE's natural gas R&D program encompasses aspects of the natural gas industry from exploration and production to processing and storage. In addition, FE is engaged in developing unconventional or alternative natural gas resources such as ultra-deep gas and methane hydrates. Given that energy security is a national priority, demand for natural gas is forecast to increase, and private R&D is declining, federal R&D is targeting resources beyond industry's current capabilities. This creates public benefits through investment in long-term, high-risk research with potentially high payoffs such as a cleaner environment, more secure and stable supplies, and new potential resources.

Stimulating Domestic Gas Production

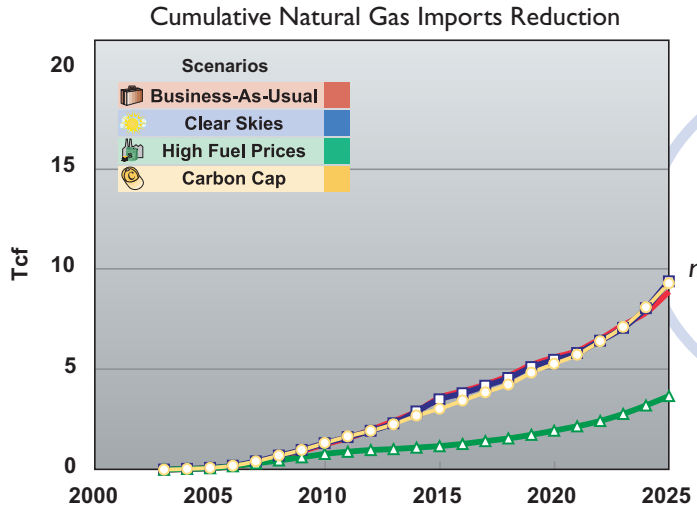
Economic benefits to consumers, in the form of reduced gas and electricity expenditures, have already been tabulated on pages 4 and 7. FE's natural gas R&D program also diversifies sources of supply of natural gas. Over the 2003 to 2025 time frame, the United States will produce about 17.5 Tcf more domestic natural gas in the Lower 48 due to FE R&D programs. By 2025, the domestic natural gas proved reserves base will increase by about 12.5 Tcf, resulting in a 30 Tcf increase in combined

production and proved reserves. This would more than fulfill the 2025 demand for natural gas, based on EIA projections. Increased domestic production (not to be confused with the Government Performance Results Act (GPRA) metric, defined as the increase in economically recoverable resources), is a key indicator of how demand and associated E&P activity is stimulated in consequence of cost reductions arising out of the R&D program.

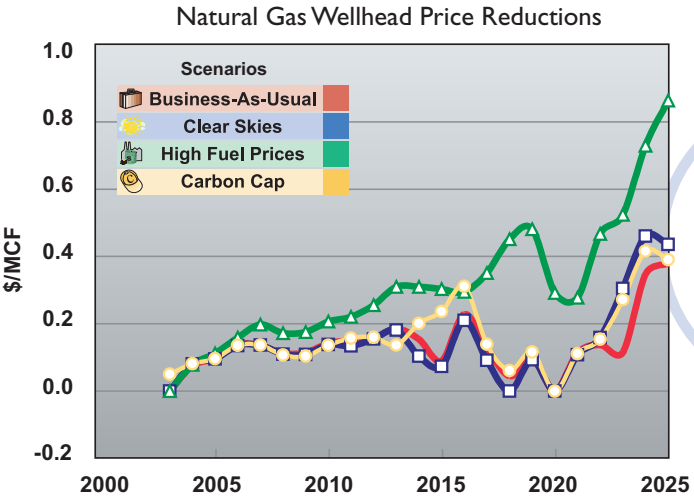
With the exception of the High Fuel Prices Scenario, roughly half of the increased domestic production offsets imports, while the other half helps to meet increased consumption due to fuel switching and demand stimulation. Impacts under the High Fuel Prices Scenario are different in several respects. Reductions in average wellhead natural gas prices are considerably greater and less erratic over time due to the absence of large sources of alternative supplies (e.g., LNG, and Alaska). Moreover, while incremental production is similar under all scenarios, a much greater proportion of the production is used to meet new demand stimulated by lower prices, as opposed to offsetting imports.



FE R&D keeps gas prices affordable, increasing natural gas consumption



For High Fuel Prices Scenario, increased gas production is used more to meet growing demand than offset gas imports



FE R&D reduces wellhead prices more significantly in the High Fuel Prices Scenario

Pioneering a Revolution in Natural Gas Supplies – Methane Hydrates

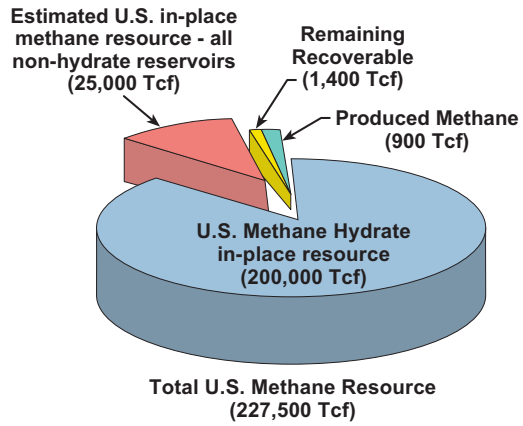
Methane hydrates have been detected worldwide around most continental margins. In the United States, large deposits have been identified and studied in Alaska, along the west coast from California to Washington, along the east coast, including the Blake Ridge offshore of the Carolinas, and in the Gulf of Mexico.

U.S. Geological Survey (USGS) assessments in 1995 and 1997 suggest an in-place gas hydrates resource for the United States of about 200,000 Tcf, dwarfing the Nation's estimated 1,400 Tcf of conventional gas resources and reserves. Worldwide estimates of the methane hydrates resource approach 400,000,000 Tcf — a staggering figure compared to the 5,000 Tcf that make up the world's currently known gas reserves.

Key Benefits of Natural Gas from Methane Hydrates

Inherent limits exist to using a mid-term energy market forecasting tool like NEMS to assess the benefits of the Hydrates Program. Economic, environmental, and security benefits resulting from increased energy supplies from methane hydrates are substantially beyond the 20 to 25 year time scale of a typical NEMS forecast. Estimation of these benefits requires a separate analysis. Knowledge benefits, another class of benefits identified as an important consideration by the National Academy of Sciences in their review of DOE R&D program benefits, will almost certainly accrue over the next 25 years in geosciences, climate science, and climate change technology, but intangible benefits like these also require a separate analysis.

Roughly 88% of the Total U.S. Methane Resource Resides in Methane Hydrates



http://www.netl.doe.gov/scngo/naturalgas/hydrates/index.html

It is reasonably certain that the United States will consume increasing volumes of natural gas well into the 21st century, just to meet traditional demands in the residential, commercial, industrial, and electricity sectors. Widespread use of natural gas in the transportation sector, as envisioned by some for the longer term, would represent a significant new demand that will be severely moderated by unavailable supplies from conventional sources. These envisioned uses of natural gas include its direct use as a transportation fuel, source of alternative liquid fuels (gas-to-liquids conversion), and source of hydrogen in the infrastructure transition phase and subsequent phases of a hydrogen economy.

The view of the National Petroleum Council regarding the likely future course of hydrates production calls for production to start in 2015, building to 1 Tcf/year by 2020 and rapidly escalating thereafter, but is contingent on a robust federal R&D program. With no immediate payoff, the private sector is not vigorously pursuing research that could make methane hydrates technically and economically viable. Therefore, federal R&D is the primary way the United States can begin exploring the future viability of a high-risk resource whose long-range possibilities might one day dramatically change our energy portfolio. Mid-term (2010) goals of the hydrates program are to develop and field-test technologies for characterizing Alaskan hydrate deposits, comprehensively study hydrate environmental implications, and increase the safety of offshore oil and gas operations near hydrate deposits in the Gulf of Mexico.

FE R&D Technology Contributions to Public Benefits

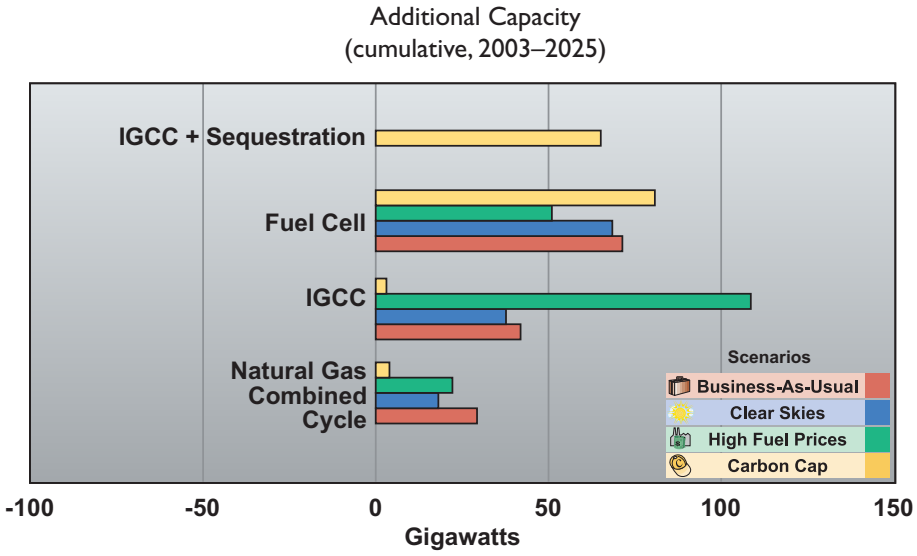
This report is primarily focused on benefits at the programmatic level and reports total benefits for the entire portfolio of FE's research. These benefits estimates are the result of individual technologies, each of which contribute to total program benefits. The table below reports the distinctive contributions of each subprogram element of FE's R&D program.

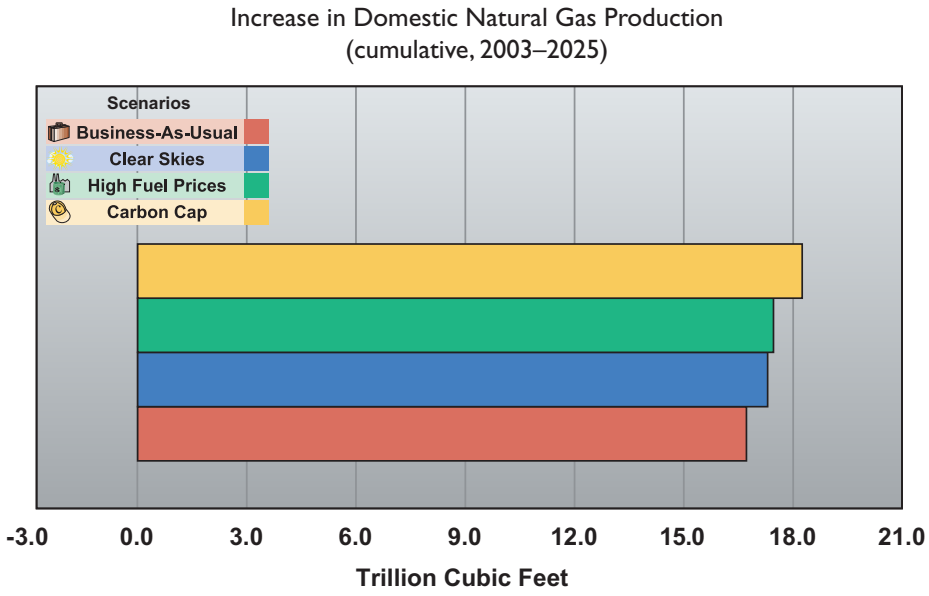
Key FE R&D Program Benefits by Program Element*

Program Element	Benefits (2002 dollars, discounted at 5 percent)
IGCC	• Up to $104 billion in cumulative energy savings to U.S. consumers by 2025 • Up to 164 GW of IGCC plants built by 2025
Carbon Sequestration	• Up to 70 GW of IGCC with sequestration plants built by 2025 • More than $20 billion in cumulative energy savings to U.S. consumers by 2025
Distributed Generation/Fuel Cells	• Up to 87 GW of operational fuel cells by 2025 • Up to $11 billion electricity costs savings by 2025
Innovations for Existing Plants	• $11.5 billion cost reduction for Hg control • $2.6 billion cost reduction for NO_x control • Meets CSI cap without triggering safety valve
Hydrogen *(Hydrogen benefits were determined in a well-to-wheel analysis that was performed outside of the NEMS framework)*	Producing hydrogen from coal and utilizing it in fuel cell vehicles (FCVs) will: • save 370 thousand barrels per day of imported oil • save 150 billion cubic feet of imported natural gas per year • reduce the cost of U.S. fossil fuel consumption by almost $4 billion per year • reduce NO_x emissions by 20 thousand metric tons per year • reduce SO_x emissions by 5.3 thousand metric tons per year
Oil Supply & Delivery R&D	• Over 325,000 bbl/day increase in crude production by 2025 • Increased production will offset up to 2 billion barrels of crude oil imports by 2025 • Up to $35 billion savings on oil product imports by 2025
Oil and Natural Gas R&D Environmental Benefits *(The benefits were calculated in a separate analysis based on NEMS results for wells drilled, natural gas consumption, oil imports, etc.)*	• Up to 46 million barrels in reduced oil spills by 2025 • 250 million barrels in reduced drilling waste volumes by 2025 • 23,000 fewer surface acres impacted by 2025 • Up to 21,000 tons reduced CO, NO_x, SO_x, and hydrocarbon emissions by 2025 • 4 million tons reduced CO_2 emissions by 2025 in oil and gas operations
Natural Gas Supply & Delivery R&D	• More than 2 Tcf/year increase in production by 2025 • 12.5 Tcf increase in proved reserves base by 2025 • About one-half of increased production will offset imports • Lower prices result in reduced demand for oil products • Up to $100 billion savings realized from reduced average consumer prices by 2025
Methane Hydrates *(Benefits were based on the National Petroleum Council 1999 Gas Supply Study)*	• If only 1 percent of the U.S. methane hydrates resource could be made technically and economically recoverable, the U.S. could more than double its domestic natural gas resource base • Projections are for 1 Tcf/year hydrates production by 2020

*The benefits described in this table represent a subset of the overall benefits of the FE R&D program. See box opposite table of contents page for more details.

Summary of Major FE R&D Impacts





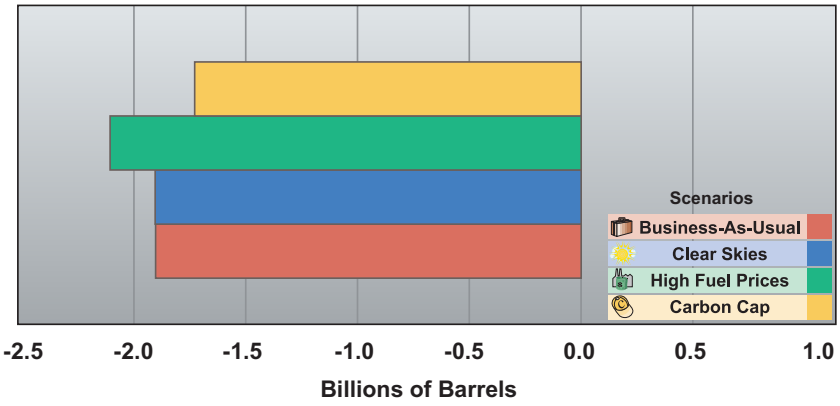
Summary of Major Impacts

The following graphs summarize the impacts of FE R&D on selected variables (e.g., technology, fuel, price, etc.) drawn from all variables featured in this report. The impact on each variable shown is the difference between the case with the benefit of FE R&D and the case without the benefit of FE R&D. These differences are cumulative over the time period from 2003 until 2025. Additionally, these impacts are provided for all four different scenarios (Business-As-Usual, Clear Skies, High Fuel Prices, and Carbon Cap).

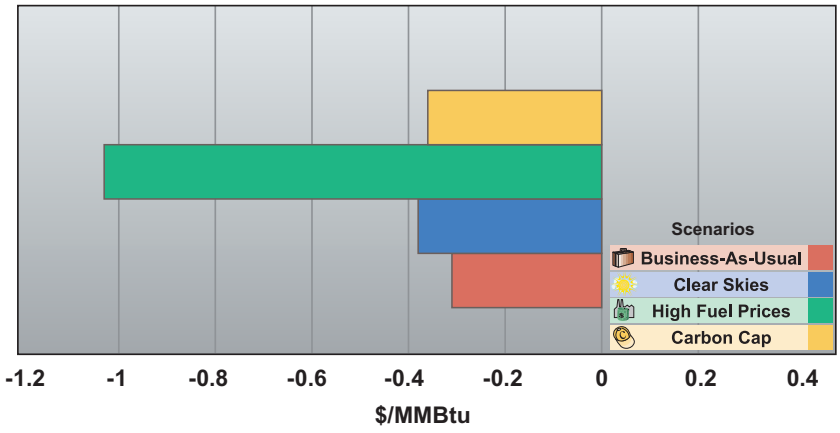
For example, in the "Additional Capacity" graph, fuel cells show a cumulative gain of over 50 GW of installed capacity, irrespective of the scenario in which they are examined. This same graph illustrates how IGCC plants equipped with sequestration technology penetrate the market with over 50 GW when a carbon constraint is imposed.

These gains in installed capacity, as well as changes in other measures as illustrated in this series of bar charts, are due to the impact of the FE R&D program on specific technologies over and above anything that would otherwise have occurred.

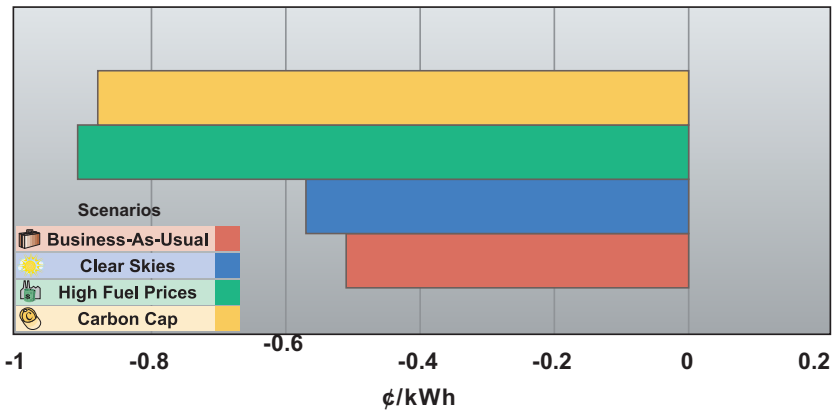
Crude Oil Imports Difference
(cumulative, 2003–2025)



Natural Gas Price Difference in 2025



Electricity Price Difference in 2025



Acronyms/Abbreviations

AEO ..... Annual Energy Outlook
Btu ..... British Thermal Unit
CO_2 ..... Carbon Dioxide
Comb. Turb/Diesel ..... Simple Cycle Combustion Turbine and/or Diesel Engines
CSI ..... Clear Skies Initiative
DG ..... Distributed Generation
DOE ..... U.S. Department of Energy
E&P ..... Exploration and Production
EIA ..... U.S. Energy Information Administration
FCV ..... Fuel Cell Vehicle
FE ..... Office of Fossil Energy
FY ..... Fiscal Year
GHG ..... Greenhouse Gas
GPRA ..... Government Performance Results Act
GW ..... Gigawatt
H_2 ..... Hydrogen
Hg ..... Mercury
IGCC ..... Integrated Gasification Combined-Cycle
kWh ..... Kilowatt Hour
LNG ..... Liquefied Natural Gas
MMBtu ..... Million Btu
NEMS ..... National Energy Modeling System
NGCC ..... Natural Gas Combined-Cycle
NO_x ..... Nitrogen Oxides
PC ..... Pulverized Coal Combustion
R&D ..... Research and Development
Seq. ..... Sequestration
SO_x ..... Sulfur Oxides
Tcf ..... Trillion Cubic Feet

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