OFFICE OF FOSSIL ENERGY PROGRAMS:

INPUTS FOR

FY 2008 BENEFITS ESTIMATES

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INTRODUCTION

This report describes the ongoing effort within the U.S. Department of Energy (DOE) Office of Fossil Energy (FE) to quantify the significant economic and energy sector benefits that are attributable to its research and development (R&D) portfolio.

Calculation of these R&D benefits relies heavily on use of the National Energy Modeling System (NEMS) which was developed by the DOE Energy Information Administration (EIA). NEMS is an integrated, bottom up LP model used to produce forecasts of future energy use and pollutant and greenhouse gas emissions in the United States. NEMS captures the interactions between technology development, policy drivers, and market forces. It accounts for economic competition among different energy sources, different energy conversion technologies, and energy efficiency improvements.

The general methodology for calculating benefits is to:

1. Run NEMS with a set of technology cost and performance assumptions consistent with no further investment in FE R&D.
2. Run NEMS with technology cost and input assumptions consistent with the FE R&D program goals being achieved.
3. Derive benefits by analyzing the differences between the two cases.
4. Assess the sensitivity of the FE benefits by repeating steps 1-3 under different policy and world market scenarios.

Exercising the NEMS in this way provides a robust picture of what technologies developed by FE can achieve in the U.S. energy sector and the effects on the cost of electricity and other energy services. The benefits work is used to articulate the value of FE research and to help set funding priorities within the FE research portfolio. This report documents the benefits methodology. It sets forth the FE program goals that serve as the basis for the benefits analysis and defines the inputs into the NEMS model that are derived from the program goals.

FE R&D PROGRAM SUMMARY

The FE goal is to ensure the availability of ultra-clean ("zero" emissions), abundant, low-cost, domestic electricity and energy (including hydrogen) to fuel economic prosperity and strengthen energy security. The FE R&D efforts consist of the following two major programs: Clean Coal Program and Oil and Natural Gas.

The Clean Coal Program

The Clean Coal Program supports the President's top initiatives for energy security, clean air, climate change, and coal research. Accordingly, the Clean Coal Program focuses on the ultimate goal of developing "zero" emission, affordable energy from coal, by: 1) supporting the development of lower cost, more effective pollution control technologies embodied in the President's Coal Research Initiative, and helping to diversify the Nation's future sources of clean burning fossil fuels to meet the President's Clear Skies goals; 2) expanding the Nation's technology options for reducing greenhouse gases by increasing power plant efficiencies and by capturing and isolating these gases from the atmosphere as called for by the President's Global Climate Change Initiative; and 3) measurably adding to the Nation's energy security by providing longer-term alternatives to imported oil, such as hydrogen produced from coal.

A broad portfolio of technologies is being developed within the Clean Coal Program to accomplish these objectives. Ever increasing technological enhancements are in various stages of the research "pipeline," and multiple paths are being pursued to create a portfolio of promising technologies for development, demonstration, and eventual deployment. The Clean Coal program is organized into the following seven technology program areas:

- ***Innovations for Existing Plants*** – the development of pollution control options that will enable the current fleet of coal-fired power plants to comply with current and future environmental regulations without imposing major cost burdens on ratepayers, while also building the foundation for entirely new environmental control processes.

- ***Advanced Power Systems*** – the development of a new generation of electric power generating "platforms," employing advanced coal gasification, turbines capable of burning coal-derived syngas, and novel combustion concepts, that will form the core of the "zero" emission coal plant of the future.

- ***Carbon Sequestration*** – the development of a new suite of technologies that can safely and economically capture and store carbon dioxide from coal-based energy systems, permanently removing them as contributors to global climate change.

- ***Solid State Energy Conversion Alliance (SECA) Fuel Cells*** – the development of revolutionary new approaches to clean power generation using solid state technology to lower the cost and improve the performance of electrochemical-based fuel cells that can operate on coal-derived fuels.

- ***Hydrogen-From-Coal*** – the development of new, more affordable methods to extract commercial-grade hydrogen from coal and deliver it reliably to end-users, especially to the Nation's transportation sector.

- ***Clean Coal Power Initiative (CCPI)* –** a series of competitions conducted over a 10-year period (2002–2012) to encourage the Nation's energy industry to identify and cost-share the final stages of development for the best emerging new coal-based power-generating technologies.

- ***FutureGen* –** a culminating project to build the world's first integrated coal-based energy plant to generate electricity, produce hydrogen and sequester greenhouse gases, and serve as the proving ground for the advanced coal concepts.

The Oil and Natural Gas Program

The Oil and Natural Gas Program also contributes to the vital national goals of secure and reliable energy supplies and clean power generation. Oil and natural gas projects support focused research in the following three main areas:

- ***Advanced E&P technologies*** – more than two thirds of all the oil discovered to date in America still lies in the ground, economically unrecoverable by current technology. Of that total, more than half resides at depths shallower than 5,000 feet. This shallow, bypassed resource offers a huge target for recovery via application of advanced exploration and production (E&P) technologies. Similarly, advanced E&P technologies will provide the keys to unlock other conventional but difficult-to-recover oil and gas resources.

- ***Future Supply and Emerging Resources*** – as global competition accelerates for oil and gas supplies, America also will turn more towards its own emerging new hydrocarbon resources to meet its future energy needs. Chief among these are natural gas from methane hydrates and low-permeability ("tight") formations, coalbed natural gas, and deep gas found in reservoirs below 15000 feet.

- ***Transmission, Distribution, and Refining*** – also critical to meeting America's oil and natural gas supply needs is an improved domestic energy infrastructure. Our energy delivery systems are aging and falling short of meeting U.S. energy needs. NETL research investigates ways the Nation's energy transportation, storage, and refining systems can meet the challenge economically and with minimal impact to the environment.

The FY2008 target budget does not include funding for oil and gas research. Portions of the benefits from royalty-funded research provided by Section 999 of the Energy Policy Act of 2005, however, are included in the baseline (no FE R&D) case. It is assumed that benefits of this research will take place regardless of FE oversight and participation. Although not reported as part of the FY2006 benefits, NEMS analysis was conducted to determine the benefits attributable to the royalty-funded oil and gas program. Results of this analysis are included in a separate FE benefits report. It should be noted that NEMS is not currently setup to handle methane hydrates, and therefore, even when the oil and gas program benefits are determined, FE has been unable to determine benefits for methane hydrates within the standard NEMS framework. Benefits of this program must be developed separately.

In the Clean Coal Program benefit estimates for FY2008, the following Program Areas were addressed in the National Energy Modeling System (NEMS):

- Innovations for Existing Plants
- Advanced Power Systems (including advanced turbines and coal-based SECA fuel cells)
- Carbon Sequestration (only the capture portion of this program area)
- SECA fuel cells
- CCPI

- FutureGen

Current limitations in the NEMS model prevent inclusion of Hydrogen-from-Coal Program and some areas of the Sequestration Program (sequestration/storage, monitoring, mitigation, and verification, and non-CO2 greenhouse gases) in the benefits analysis.

Two demonstration initiatives, CCPI and FutureGen, are major factors in determining the projected commercial deployment dates of the technologies listed in Table 5. Because of their role in providing the opportunity to prove the design and operation of coal-based power plants using advanced technologies developed through FE R&D, the benefits of these programs can be viewed as the cumulative value from all of the individual technologies that would be required to create the desired future coal-fired plant.

Figure 1 provides an overview of the FE R&D portfolio in a hierarchical format, illustrating its associated programs, program areas, technologies, and R&D pathways.

Figure 1. Fossil Energy R&D Portfolio - FY06 Benefits Analysis

CLEAN COAL AND NATURAL GAS POWER SYSTEMS PROGRAM:

Technology	R&D Pathways
INNOVATIONS FOR EXISTING PLANTS	
Mercury Emissions Control	Advanced Control Technologies – Sorbent injection Advanced Control Technologies – Oxidation processes Emissions Characterization Development of Measurement Methods
Advanced NO_x Control	Advanced in-Furnace NOx Technologies
Particulate Matter / Acid Gas Emissions Control	Primary Fine Particulates Acid Gases
By-Product Utilization	Mercury Sequestration Trace Element Characterization
Power Plant Water Management	Advanced Cooling Technology Impaired Water Usage Advanced Water Recovery and Reuse Technology Advanced Treatment and Detection Technology
ADVANCED POWER SYSTEMS	
Advanced Gasification (IGCC Power Generation Plants)	Syngas Cleanup Syngas Membrane Separation Advanced Gasifier Concepts Low-Cost Air Separation
Advanced Syngas and Hydrogen Turbines	Combustors for High Hydrogen Fuels Advanced Thermal Barrier Coating Materials Enhanced Cooling Techniques for Nozzles and Airfoils Enhanced Aerodynamics/Mechanics for Turbine Airfoils Improve Rotor Torque Limitations Compressor and Air Separation Unit (ASU) Integration
Coal-Based SECA Fuel Cells	Core Technology Program Industry/Academia/Government Partnerships “Mass Customization” Approach Enhanced Technology Transfer
Advanced Natural Gas Combined Cycles	Improved Combustion Technology for NOx Control Durable Catalysts for Combustion Advanced Thermal Barrier Coating Materials Enhanced Cooling Techniques for Nozzles and Airfoils Enhanced Aerodynamics/Mechanics for Turbine Airfoils Increase Rotor Torque Limitations
CARBON SEQUESTRATION	
CO_2 Capture	Membranes Advanced Scrubbers CO_2 Hydrates Oxy-fuel Combustion
Sequestration/Storage	Evaluation of Hydrocarbon-bearing Geologic Formations Tree Plantings, Agricultural Practices, and Soil Reclamation Increased Ocean Uptake
Monitoring, Mitigation, and Verification	Advanced Soil Carbon Measurement Remote Sensing of Above-Ground CO_2 Storage and Leaks Detection and Measurement of CO_2 in Geologic Formations Fate and Transport Models for CO_2 in Geologic Formations
Breakthrough Concepts	Advanced CO_2 Capture, Advanced Subsurface Technologies, Advanced Geochemical Sequestration, Novel Niches
Non-CO_2 Greenhouse Gas	Waste Methane Capture

CLEAN COAL AND NATURAL GAS POWER SYSTEMS PROGRAM:

Technology	R&D Pathways
SECA FUEL CELLS	
🟩 Utility-scale Fuel Cells (10-20 MW)	Seals, Interconnects, and Cathode Materials
🟩 Utility Distributed Generation (1-2 MW)	Low-Cost Manufacturing Processes with High Yields
🟩 Residential and Commercial (kW-scale)	High-Temp Heat Exchangers and Blowers for Balance of Plant
🟧 Auxiliary Power Units for Transportation Sector	Computer-Based Design Criteria to Ensure Reliability Impact of Pressure on Reliability and Integration as well as on Scalability of Cells and Modules for Coal-Based Systems
HYDROGEN FROM COAL	
🟧 Central Production (Decentralized Locations)	Water Gas Shift Advanced Separation Process Intensification
🟧 Alternative Production (Decentralized Locations)	Synthetic Natural Gas (SNG) Conversion Coal-to-Liquids
🟧 Delivery	Utilize/Modify Existing Distribution Networks
🟧 Storage	Transportation and Stationary Applications
🟧 Utilization	Engine Systems Modification/Optimization
CCPI & FUTUREGEN	
🟩 Clean Coal Power Initiative (CCPI)	Combination of R&D Pathways from the Power Systems Program
🟩 FutureGen	

OIL AND NATURAL GAS PROGRAM:

Technology	R&D Pathways
🟧 Methane Hydrates	Hydrate Fundamental Properties Reservoir Characterization/Assessment Demonstrate Production
🟦 Core Oil and Natural Gas Programs	Reservoir Remediation Wellbore Cleanup Surface Optimization Improved CO_2 Supply Low-Cost Injectors (Conformance Control) Cost Effective, Hi-Res Imaging for Real Time Monitoring Environmental Solutions
🟦 EPAct Section 999	Consortium Produced Annual Plans Ultimate Recovery Production Enhancement Reduced Capital and Operational Expenses Geology/Environmental Implications Increased Recovery Reduced Finding Costs Low-Cost Technologies Regional Solutions

🟨 Program
⬜ Program Area
🟩 Modeled in NEMS for FE Benefits Analyses
🟧 Not Modeled in NEMS for FE Benefits Analyses
🟦 Portions Modeled in NEMS Baseline

SIGNIFICANT CHANGES FROM PREVIOUS ANALYSIS

The evolution of the FE benefits analysis effort from 2005 to the present is described below. Major changes from the 2005 analysis are:

- Analysis period extended from 2025 to 2030; consistent with AEO
- ESE NEMS run used a the baseline scenario instead of the AEO reference case
- Number of policy scenarios reduced from four to three
- The subtractive method for estimating benefits under the FE-only scenario has been replaced with the additive method
- The discount rate used to estimate cumulative benefits was reduced from five percent to three percent

Benefits Analyses Prior to FY2003

Prior to FY2003, attempts at quantifying FE benefits lacked a coordinated effort and consistent methodology across FE offices/programs. In many cases, individual programs determined specific benefits by using a variety of methodologies, models, and tools.

The Oil and Natural Gas programs each had its own, separate modeling system to evaluate their respective benefits. These systems were the Total Oil Recovery Information System (TORIS) for oil and the Gas System Analysis Model (GSAM) for gas. A later model named Comprehensive Oil and Gas Analysis Model (COGAM) was developed by both combining and enhancing the earlier models in order to capture the interdependency and synergies between the oil and gas sectors.

TORIS was developed in 1984 as an engineering-based modeling system designed to evaluate potential recovery from Enhanced Oil Recovery (EOR) activities in the United States. It predicted technically recoverable and economically recoverable reserves, as well as an expected value of production. A follow-on model system – the Oil Program Research Assessment (OPRA) – was used to input the timing of new technology and market penetration, as well as probabilities of project/technology implementation and R&D success. OPRA enabled project/technology managers to convert R&D funding into benefit streams for oil and gas production/reserves as well as capital/operations cost savings. OPRA and TORIS interacted with each other to generate a fully risked R&D benefit stream in the form of incremental oil and gas production. Over the years, additional components such as primary recovery, secondary recovery, infill drilling, exploration, and horizontal wells were added to the TORIS system to ensure that most of the oil research carried out by DOE could be modeled.

GSAM, fully developed by 1998, is a comprehensive model of the North American natural gas market. It models both conventional and unconventional natural gas. Like TORIS, the model calculates an expected value of production. GSAM captured program benefits in two ways. One approach was to run the model using a fixed price track and calculate incremental gas production. A second method involved generating a combination of incremental gas production and product price reductions by using a feature of the model which balanced supply and demand factors. GSAM was used to model most of the DOE gas program; however, parts of the program (gas hydrates, high-deliverability/alternative storage, and gas-to-liquids) are beyond GSAM's capability.

TORIS and GSAM were later integrated to create COGAM. Like its predecessors, COGAM generates fully risked benefits in the form of incremental oil and gas production over time. The model was extensively peer-reviewed during its development and incorporates features of both previous models.

FY2003 Benefits Analyses (GPRA05)

During FY2003, DOE FE developed estimates of benefits for each R&D program using a consistent methodology that was specifically designed to improve the quality and credibility of its R&D benefits forecasts. This was the first time that all parts of the FE portfolio were assessed together and with the same methodology. This methodology included:

- Use of the NEMS model to forecast market penetration, impacts, and benefits of FE technologies as they compete against all other similar technologies;
- Development of future scenarios to represent the most important and likely domestic futures;
- Explicit modeling by technology to estimate the impact of R&D funding on cost and performance goals;
- The use of both an "additive" method to estimate technology-level benefits (that is, to add one technology incrementally to the baseline to estimate its specific impact) and the "subtractive" method which includes all advanced technologies with one technology removed at a time to determine its individual impact.

The FY2003 effort established the details of the methodology used and verified that the methodologies developed would provide valid, credible, and useful results.

During this year extensive work was performed in order to represent oil and natural gas R&D program metrics in the NEMS modeling system. The approach used was to rely on the most recent metrics exercises using TORIS and GSAM. Parameters from these models were mapped into corresponding parameters in the Oil and Gas Supply Model (OGSM) of NEMS. These parameters were fine-tuned to ensure that an equivalent representation was achieved for the impact of DOE R&D on domestic oil and gas production. One significant difference between the coal and oil/gas data was consideration of risk. Risk had already been included in the oil and gas data before being inputted into NEMS.

FY2004 Benefits Analyses (GPRA06)

In FY2004, FE continued to develop, test, and evaluate the framework for benefits analyses. Through a peer review of experts, FE subjected its R&D benefits analyses to a technical critique. The reviewers, some of whom were arguably the top energy modelers in the country, provided valuable and insightful feedback for improving FE benefits analyses. The peer reviewers commented that the FY2003 analysis provided a good, solid start to quantifying research benefits for FE and that the methodology served as a strong basis for continuing development. The reviewers acknowledged that R&D benefits estimation is a complex and challenging undertaking and, accordingly, they recommended a variety of improvements that would enhance the capability to estimate future FE benefits and increase the credibility of estimates with a variety of stakeholders [Klara, 2004]. FE responded by implementing several improvements in the FY2004 benefits analyses, including:

- The inclusion of additional detail regarding technology goals and the rationale for setting and achieving those goals.
- The addition of a "current regulatory scenario" baseline that is similar to the EIA Annual Energy Outlook (AEO) reference case.
- The use of only the more conservative "subtractive method" for determining benefits, compared to the "subtractive" and "additive" methods that were both used in the FY2003 report.
- The adoption of discounting future benefits to a present value for more appropriate comparison.

Another new feature of the FY2004 benefits assessment was the use of FEBEN2, a newly-developed automation tool. This tool takes output data from the NEMS runs that both includes and excludes FE/NETL program goals relating to cost and performance and, using EXCEL, compares the results of the two cases. By comparing a case that includes the FE R&D program to a baseline case that does not, any differences can be attributed to the effects or influence from the R&D program. This same process was used in the FY2003 analysis; however, it involved the manual transfer of NEMS data into an EXCEL spreadsheet. FEBEN2 expedites this process and reduces potential errors that can occur when data is manually transferred.

For FY2004, oil and gas benefits were determined using the same approach used in FY2003. Benefits from environmental, methane hydrates, or storage and transmission were not calculated in FY2004. Additional work was performed to generate guidelines for adjustment of NEMS input parameters.

FY2005 Benefits Analyses (GPRA07)

In 2001, the National Research Council (NRC) issued a retrospective analysis of energy research at the DOE (NRC, 2001). Based on the methodology undertaken in this study, further discussions with the NRC committee, and the continuing goal of improving the benefit assessments, the following modifications and enhancements were incorporated in the FY2005 analyses:

- Use of two common scenarios for EERE/FE benefits analyses as a first step toward adopting a DOE-wide consistent methodology, resulting in a total of five scenarios
- Adjustment of the discount rate from five percent (used in the 2004 analysis) to three percent, which is consistent with NRC discount rate recommendations from its Phase I prospective study
- Use of the "additive" method to be consistent with EERE's methodology

Other recommendations of the NRC committee were explored, but not used to estimate benefits including:

- Investigation and development of a prototype probability function and decision tree that would rely on technical experts to assign risk to the benefits estimates
- Use of NEMS to generate consumer and producer surplus curves to better assess net economic benefits, whereas only consumer cost savings had been generated in previous DOE benefits assessments

The FY2007 target budget called for termination of the DOE Oil and Natural Gas programs. In addition, the budget sought to repeal the provisions in Section 999 of the Energy Policy Act of 2005, which specified that $50 million per year of oil and gas R&D be funded by oil and gas leases. For this reason, no attempt was made to calculate new benefit estimates from the Oil and Natural Gas programs. Nonetheless, the House and Senate have appropriated funding for the Oil and Natural Gas programs. A conference committee will determine the exact amount of funding to be appropriated in FY2007.

FY2006 Benefits Analyses (GPRA08)

This current report focuses on FE R&D benefits for FY2006 where three potential future scenarios are assessed: business as usual (the current regulatory scenario), high fuel prices (high world oil prices and restricted natural gas availability), and a carbon cap (emissions are capped at 2004 levels). In previous years, benefits were estimated through 2025, since this was the timeframe of the NEMS model. In 2006, EIA expanded NEMS projections by five years and thus the FY2006 analyses estimate benefits through 2030.

Similar to the circumstance which occurred in the FY2005 analysis, oil and gas benefits are not reported as part of this FE R&D benefits analysis. The reason is that the target FY2008 budget does not include funding for oil and gas research. Portions of the benefits from royalty-funded research provided by Section 999 of the Energy Policy Act of 2005, however, are included in the baseline (no FE R&D) case. It is assumed that benefits of this research will take place regardless of FE oversight and participation. Although not reported as part of the FY2006 benefits, NEMS analysis was conducted to determine the benefits attributable to the royalty-funded oil and gas program. Results of this analysis are included in a separate FE benefits report.

Levels of Benefits Calculations

Figure 2 illustrates the terminology used at different levels in this benefits determination process from the top FE R&D Portfolio level to the lowest R&D pathway (research area) level. Benefits are calculated at three levels in this portfolio hierarchy. First, benefits are calculated at the very top “portfolio” level or “as a whole” to include both the Power Systems Program and the Oil and Natural Gas Program. Second, benefits are calculated at the next lower “program” level for the Oil and Natural Gas Program and the Power Systems Program through separate NEMS runs. Finally, benefits calculations are done at the next lower “program area” level such as Innovations for Existing Plants, Advanced Power Systems, Carbon Sequestration, Advanced Natural Gas Turbines, Distributed Generation, etc. No benefits were individually calculated for the next lower “technology” level such as mercury emissions control, advanced NOx control, and advanced materials even though these technologies were modeled in NEMS and their benefits included in higher-level aggregate portfolio analyses. Likewise, no benefits calculations were performed at the next lower “R&D pathway” level.

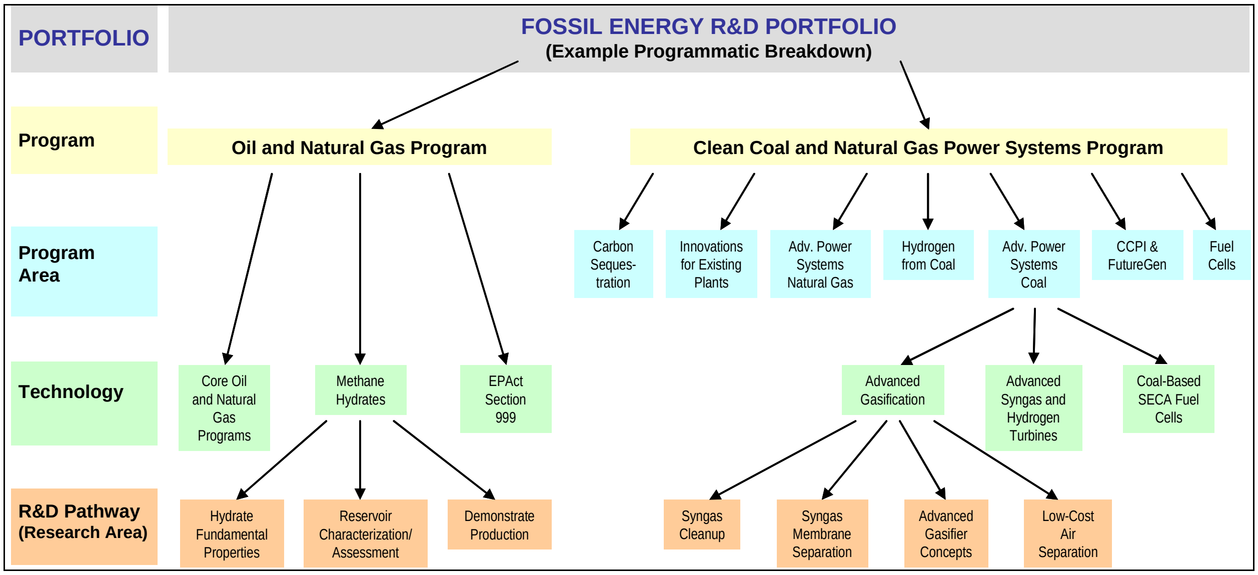

Figure 2. Fossil Energy R&D Portfolio - Example Programmatic Breakdown

THE BASELINE

Target Market Description

The primary market for technologies developed in the FE portfolio is mid to base load power. The near to mid term focus is on traditional central station power plants. Fuel cells and other advanced fuel conversion concepts migrate down the distribution line and integrate poly-products (e.g., hydrogen, diesel fuel, commodity CO_2) with power generation.

Baseload power plants are capital-intensive, long-lived assets. Reliability, defined here as the percent of hours in a given year that a unit is available to dispatch at full load, is a key performance criteria with 80-85% often set forth as a minimum requirement.

Power plant purchase decisions are made on the basis of expected net income and the expected cost of electricity, taking into account capital cost recovery and uncertainty in future fuel prices and environmental regulations. Many electricity supply companies, for example, incorporate an expected cost of CO_2 emissions into current investment decisions. The discounting of cash flows is an important factor – estimated permitting and construction delays have a significant effect on the economics of one technology versus another. Many utility companies employ portfolio techniques to manage risk and seek to utilize a mix of fuels and technologies. These considerations can impact individual power plant decisions. Regional considerations, for example the availability of coal of a certain type or the availability of a large source of water, can impact specific base load power plant economics.

Some regions of the country have restructured their electricity supply industry, others are still operate under conventional a cost of service or rate-base framework. The dispatch of baseload generation is likely to be similar under either market regime as grid operators follow economic dispatch principles. However, in restructured markets the expected revenues to the plant are uncertain. Uncertainty in the revenue stream implies uncertainty of net income and thus of return to capital, making investors more cautious. In most restructured markets the price of gas-fired generation clears the market. When gas prices are low (eg <$4.50/mmBtu), gas combined cycle units may displace older coal units as well as reduce overall revenues; when gas prices are high, coal-fired units run at high load factors, potentially making relatively large profits, especially when gas combined cycle plants run below capacity and the price of SO_2 allowances are not high enough to overcome the fuel price disadvantage of gas combined cycle. Since the risk of investment is primarily borne by investors in restructured markets, rather than by ratepayers as in cost-of service markets, investors in the power plant and purchasers of that plant's power must have an appreciation for the factors affecting the effective costs of the competing resources.

There are currently about 400 GW of base load power plants in the United States (300 GW coal, 100 nuclear). Many of these existing assets are aging. Some analyses predict that a large portion of them will need to be re-powered or replaced over the next two decades in order to comply with environmental regulations. Some existing nuclear power plants may be retired if metal failure is detected in fundamental components. Older and inefficient coal-fired power plants would become uneconomic under most CO_2 emissions reduction regimes. NO_x, SO_x, and Hg emissions caps may cause coal-fired power plant retirements as well.

Strong growth in demand for electricity is forecast over the next two decades. This, combined with the likely retirement of aging baseload power plants, is likely to create a window for a deployment of new base load assets. FE R&D can have a significant and enduring impact if its technologies are market-ready in time for the opportunity.

Baseline Adjustments to the AEO2006 Reference Case

Before benefits can be calculated and NEMS can be utilized, an appropriate baseline must be determined against which to compare the R&D program. Several options were considered.

One option for the baseline is the alternative EIA case described in AEO2006 in which it is assumed that no further learning occurs beyond what is available today. This is what EIA calls the low-fossil case since it assumes that the fossil technology performance remains unchanged from 2005 performance levels. This option was not selected since it is likely that industry would continue to incrementally improve the technologies, but at a slower pace than that which would occur with an active government-sponsored R&D program.

Another option for consideration is the AEO2006 reference case. The inputs and results for this case are well documented by EIA. The assumption that R&D will continue at historical levels was retained for this reference case despite data suggesting that industry oil and natural gas R&D is declining. The Oil and Natural Gas Program previously developed a baseline using offline models such as GSAM and TORIS to determine how to adjust the baseline so the possibility exists for modifying the reference case to “factor out” the impact of past and current government-sponsored R&D. However, since no tools currently exist to assist in making such an adjustment for the Power Systems Program, a different method for projecting a future without the benefit of government-sponsored R&D is required.

Therefore, for the Power Systems Program, the preferred option involves polling industry experts to get their opinions on what technology would look like in the future with and without FE R&D programs. A recent NETL-sponsored study, performed by Booz Allen Hamilton [BAH, 2004], did just that. The study polled technology vendors, users, coal companies, utilities, and architect and engineering firms during a series of four workshops from June 2003 to January 2004. The BAH study included projections for a moderate progression case, which was defined as “the natural evolution of all technologies based on cost and efficiency improvements that are gradual and consistent with historical trends.” This industry consensus was viewed as an acceptable method of adjusting the baseline. Using capital costs, heat rates, and operating and maintenance costs projected by the experts and cited in the BAH report, a new baseline for what would occur without government-sponsored R&D was developed. It should be noted that the BAH projections did not include the IEP R&D Program or the Hydrogen from Coal R&D Program. In the absence of this information, no adjustments to the baseline were made to reflect the technologies in these R&D programs. Tables 1-3 list the industry survey projections in the BAH report for the moderate progression case for current costs and estimates for costs in 2025.

For simplicity, the year-by-year baseline was established by straight-line interpolation between the 2005 and 2025 values and by further extrapolating the straight line to 2030. These data were assumed to represent the year the commercial technology would be on line. Capital costs do not include contingency.

Table 1. BAH Industry Expert for Baseline Capital Costs ($/kW using $2004)

Online Year	IGCC	IGCC with Sequestration	Advanced NGCC	Fuel Cells	DG - Baseload
2005	1,543	2,123	595	2,379	865
2025	1,212	1,655	541	2,379	865

Table 2. BAH Industry Expert Estimates for Baseline Heat Rates (Btu/kWh) / Efficiencies (%)

Online Year	IGCC	IGCC with Sequestration	Advanced NGCC	Fuel Cells	DG - Baseload
2005	8,427 (40.5%)	9,939 (34.3%)	6,700 (50.9%)	7,500 (45.5%)	10,500 (32.5%)
2025	7,400 (46.1%)	8,507 (40.1%)	6,300 (54.2%)	7,500 (45.5%)	10,500 (32.5%)

Table 3. BAH Industry Expert Estimates for Baseline O&M Costs ($2004)

Online Year	IGCC	IGCC with Sequestration	Advanced NGCC	Fuel Cells	DG - Baseload
Fixed O&M ($/kW)					
2005	34.8	40.9	11.6	7.7	14.8
2025	34.8	40.3	8.2	7.7	14.8
Variable O&M (mills/kWh)					
2005	4.1	4.7	1.3	21.9	6.6
2025	3.7	3.3	1.1	21.9	6.6

Representation of Program-Relevant Technologies in the AEO Reference Case

The NEMS Electricity Market Module (EMM) contains more than 20 electric generating technologies that compete for the Nation's increasing electricity market [EIA EMM, 2002]. Most of the electricity generating technologies under development by the FE Power Systems Program are explicitly represented in the EMM. Table 4 shows the EMM technologies that correspond to FE Power Systems Program technologies.

To represent FE technologies, the cost and performance specifications for the EMM technologies in column two are set to meet Power Systems Program goals for the technologies in column one. The cost and performance goals for Power Systems Program technologies are exogenous, year-by-year, input that is used instead of allowing the EMM to predict the cost and performance via learning curves. The learning equation assumes that the cost of a technology decreases exponentially with market penetration [Kydes, 1999]. In addition to the EMM, the NEMS

Commercial and Residential Modules are used to model SECA fuel cells in non-utility, distributed generation (DG) applications.

Table 4. EMM Technologies Used to Represent Clean Coal Program Advanced Technologies

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

1. Benefits for these technologies were not calculated in this study.
2. 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.

An advantage of using the NEMS EMM is that market penetration forecasts take into account the fact that many Power Systems Program 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 are captured from new electricity generating technologies on other energy markets, on the entire U.S. economy, and on energy costs to consumers.

Isolating Effects of Program Activities

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:

1. The “Business as Usual” Baseline (BAU) Scenario
2. High Fuel Prices (HFP) Scenario
3. Carbon Cap-and-Trade (CCT) Scenario

As previously stated, NEMS is the model used by EIA to forecast energy consumption and costs that are reported in the AEO. The NEMS model is also used to evaluate the impacts of FE R&D. To complete this evaluation, EIA modifies the NEMS code to represent the economic and regulatory policies that guide each scenario and provides these modified code sets to FE for use in its Benefits Analyses. Each of the three NEMS scenarios listed above was run with and without FE R&D goals. This produced six NEMS “cases.” Each NEMS case was assigned either the letter “A” or “B,” respectively, to indicate whether the case represents a future without or with government R&D goals being attained. The “A” and “B” cases are described below:

“A” Cases (The baseline case….No DOE FE R&D)

“A” cases represent what would happen without the support of the FE 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 government R&D caused technologies to be introduced into the marketplace earlier than without government 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 commercial availability of FE technologies in the baseline was set on a case-by-case basis, according to the industry expert projections cited in the BAH report. Future performance projected by these industry experts lags behind the performance assumed for the “B” cases.

“B” Cases (The case with all DOE FE R&D goals met)

“B” cases represent the cost and performance of FE technologies that will be achieved with government-sponsored R&D funding. In this analysis, FE R&D funding levels are assumed to continue as planned at sufficient levels such that all FE future cost and performance goals are achieved. This assumption applies to the Power Systems Program only and any changes in budget would be reflected by adjusting the level of risk involved. Cost and performance data were entered on a year-by-year basis to reflect successful achievement of FE R&D goals (cost and/or efficiency).

The overall benefits of the FE 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). FEBEN2, an automated tool, was used once again to process the output results from NEMS to determine differences between the two cases.

The difference between the results of these cases is assumed to be a direct consequence of the FE R&D program as stated in the following equation:

$$\textbf{Case B} - \textbf{Case A} = \textbf{Benefit of FE R\&D Program} \qquad \textbf{(1)}$$

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

$$\textbf{Impact of FE R\&D on V} = V_{\text{Case B}} - V_{\text{Case A}} \qquad (2)$$

Example: Let the variable P represent the annual, national average price paid for electricity by U.S. consumers. The change in electricity prices as a result of FE R&D is simply

$$\textbf{Impact of FE R\&D on electricity price} = P_{B,y} - P_{A,y} \qquad (3)$$

where y represents the year. Variables evaluated in this study include greenhouse gas (GHG) and criteria pollutant emissions, GHG intensity, fossil fuel use, natural gas prices to various sectors, cost of electricity, new electricity generating plant capacity, etc.

When comparing Case A with Case B using equation (2), a reduction (or negative value) will result in a "benefit" (e.g., cost of electricity (COE) reduction, emissions reduction), while in other cases an increase (positive value) also results in a benefit (e.g., crude oil or natural gas production increase). In FEBEN2, "benefits" are defined as "positive outcomes" and the benefits calculation formulas are set up accordingly. However, in equation (3) above, a negative outcome signifies a "benefit" (P_{By} must be lower than P_{Ay} to yield a benefit – and a negative value results if this is the case). Therefore, in FEBEN2, formula (3) is reversed to give:

$$\textbf{Reduction in electricity price resulting from FE R\&D} = P_{A,y} - P_{B,y},$$

which results in a positive value for the outcome – and hence a benefit. A negative value would signify a negative outcome or negative benefit. On the other hand, since an increase in crude production is a benefit, the equation is set up in FEBEN2 as:

$$\textbf{Impact of FE R\&D on domestic crude oil production} = P_{B,y} - P_{A,y},$$

which results in a positive value for the outcome and hence a benefit. In other words, FEBEN2 benefit calculations are performed to ensure that a positive change is always defined as a benefit and a negative change as the opposite ("negative benefit").

Whereas *portfolio-level* benefits are determined by comparing Cases A and B, determining *program-level* benefits (the portion of portfolio benefits "as a whole" that can be attributed to an individual program) requires that additional NEMS cases be run to isolate the impact of each program. Likewise, *program area-level* benefits (a program area represents the components of a program and includes a suite of related technologies as shown in Figure 2) require that additional NEMS cases be run to isolate the impact of each program area-level. Benefits for an individual program are calculated by comparing the output from Case A with the output from Case A with the cost and performance goals for one program added (i.e. Oil and Natural Gas Program or Power Systems Program). The same procedure would be applied to determine program area-level benefits (advanced power, sequestration, IEP, etc.). This "additive method" used to arrive at individual program-level and program area-level benefits is described below in greater detail.

Additive Method – The additive method compares one NEMS case that assumes FE R&D for a single program is successful with another NEMS case that assumes no FE R&D is implemented (Case A). The difference between the two cases isolates the impacts and benefits of the particular program that was "added." Specific costs and performance goals are used as NEMS inputs for the one program for which individual benefits are being calculated. All other inputs and assumptions are identical to Case A. The individual runs result in a case representing a future with the isolated program only. Similarly, separate runs are conducted for each program area within a given program. The results of the runs are then compared individually to the results of the Case A run, where none of the program areas are successful. The difference between the runs is solely attributable to the program area "added" to the individual run. The calculation used to determine program area benefits can be expressed by:

(Case A with Program Area 1) – Case A = Benefit of Program Area 1

The impact of FE R&D for one particular program area, for example, advanced power systems, is estimated as

$$\textbf{Impact of Advanced Power Systems R\&D on } V = V_{\text{Case A with Advanced Power Systems}} - V_{\text{Case A}}$$

"Advanced Power Systems" is one of the program areas directly modeled in NEMS. The only difference between Case A $_{\text{with Advanced Power Systems}}$ and Case A is that the cost and performance inputs for advanced power systems are set to match the GPRA goals of FE's "advanced power systems" program area whereas the Case A (without R&D) values exclude these goals. Therefore, the difference between these NEMS cases, one in which goals for advanced power systems are met and one in which those goals are not met, can be attributed directly to FE's Advanced Power Systems R&D Program Area.

Other Program-Relevant Adjustments to AEO Reference Case

The target FY2008 budget does not include appropriated funding for oil and natural gas research. However, portions of the benefits from non-appropriated royalty-funded research provided by Section 999 of the Energy Policy Act of 2005 are included in the baseline (no FE R&D) case. These benefits are assumed to be similar to past benefits from federally-sponsored oil and natural gas research and are thus reflected in the AEO Reference Case technology progress trends. Hence, the net effect is that no oil and natural gas program related adjustments were made to the AEO Reference Case, except for minimal adjustments related to expected environmental compliance costs that are not in the AEO Reference Case because they relate to possibly more stringent environmental regulations.

Since this benefits report deals only with benefits from appropriated funding, FE does not include them in their totals. NEMS analysis was conducted to determine the benefits attributable to the Oil and Natural Gas program, but those results are included in a separate FE benefits report.

PROGRAM OUTPUTS

Assumed Budget Projections

Achieving the R&D goals assumed in this analysis requires that programs are funded at adequate levels. Technological break through, unanticipated roadblocks, changes is policy, and numerous other factors can impact out-year budget requirements in unpredictable ways. However, our current best forecast is documented in the President's FY2007 budget proposal. For the advanced coal based technologies to meet the performance levels projected in this benefits analysis, funding is assumed to be at the base out-year funding level.

Table 5 summarizes the technologies modeled in NEMS, applicable program area objectives and goals, and projected commercial deployment dates. Oil and natural gas milestones and benefits are discussed in the FE Benefits Report.

Table 5. Program Areas/Technologies Explicitly Modeled in NEMS

Technology	**Technology Goal**	**Target Date**	**Commercial Deployment Date**
IEP Hg	***Cost of Hg removal is reduced by 50% as compared to cost of Activated Carbon Injection (ACI) , and removal efficiency is 70% in 2007 and >90% in 2010***	***2007 ,2010***	***2012, 2015***
IEP NO_X	***Cost of NOx removal is reduced by 25% on a $/ton basis compared to Selective Catalytic Reduction (SCR) and removal efficiency is <.15lb/MMBtu in 2007, 0.1 lb/MMBtu in 2010, and .01 lb/MMBtu by 2020,***	***2007, 2010, 2020***	***2009, 2015, 2025***
Advanced Power Systems	***50% HHV efficiency, $1000/kW ($2002)***	***2010***	***2018***
•Gasification	***60% HHV efficiency***	***2015***	***2023***
•Syngas and H2 Turbines			
•Fuel Cells and Hybrids			
•Combined Cycles	***Turbine efficiency targets were assumed: 60% HHV efficiency, 2ppm NOx***	***2012***	***2020***
Carbon Sequestration	***10% increase in COE compared to baseline IGCC without sequestration***		
SECA Fuel Cells			
•Utility Hybrids	***59% HHV efficiency, $400/kW*** (65% LHV)	***2012***	***2017***
•Utility DG	***50% HHV efficiency, $400/kW*** (55% LHV)	***2012***	***2017***
•Building Sector DG	***50% HHV efficiency, $400/kW*** *Waste heat recovery 55-60% for CHP mode*	2012	***2017***

Figures 3 and 4 provide a graphical presentation of the capital costs and efficiencies used as EMM input for Power Systems Program technologies in this analysis. Each set of curves represents a particular technology both with and without the R&D program (see legend). The difference between the A and B curves for each technology reflects the date by which technologies enter the market place with and without the support of R&D funding.

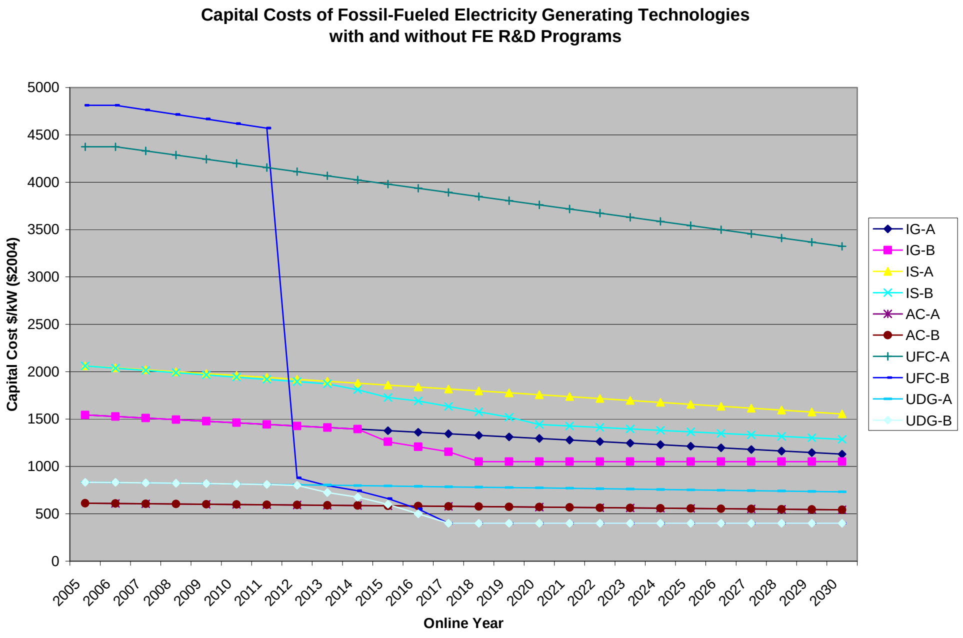

Figure 3. NEMS EMM Input Assumptions for Power Systems Program Capital Costs

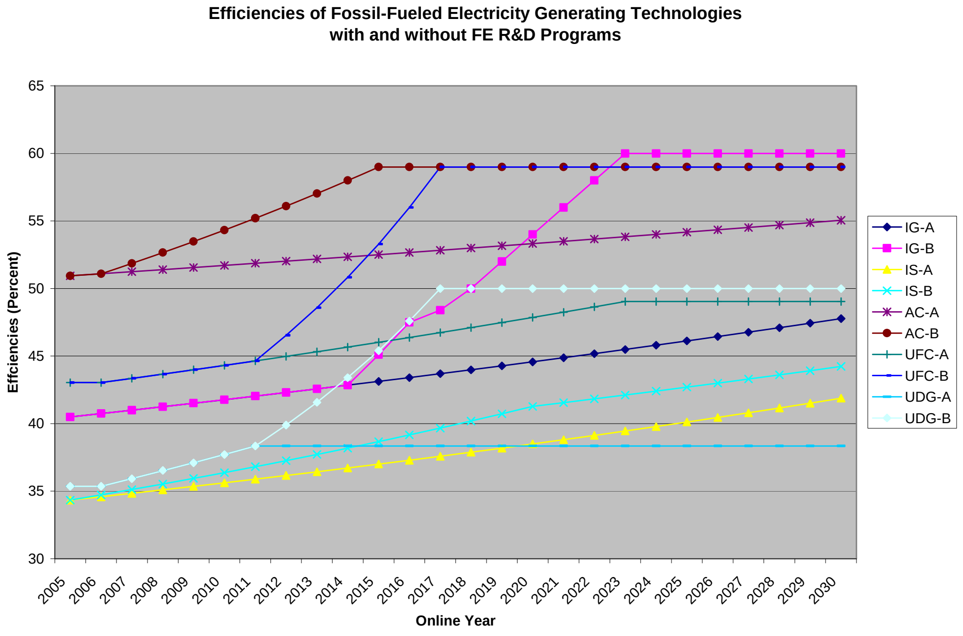

Figure 4. NEMS EMM Input Assumptions for Power Systems Program Efficiencies

KEY:

A – No FE R&D (baseline) Case	B – FE R&D Case	IG – Advanced Power Systems
IS – Carbon Sequestration	AC – Advanced Turbines (Natural Gas)	UFC– Utility Fuel Cells
UDG – Utility Distributed Generation		

The research goals and associated NEMS inputs for the following program areas are described below:

1. Innovations for Existing Plants
2. Advanced Power Systems (Coal)
3. Carbon Sequestration
4. Advanced Turbines
5. Fuel Cells, Hybrids, and Distributed Generation

To understand how each program contributes toward the overall mission of FE as well as how the R&D goals of each technology in the program can be used in NEMS to determine R&D benefits, the program outputs are set up with the following sub-sections for each technology:

GPRA Goals The R&D goals cited in this report are the technological goals that have been set in each of the program areas in compliance with the Government Performance and Results Act (GPRA). Typically, the GPRA goals are explicitly cited for each program area in the GPRA plan. However, in some cases, the R&D goals for a technology are included within a higher level program area goal. For example, advanced syngas turbine R&D goals are included in the overall goal for the Advanced Power Systems program area. Furthermore, R&D goals for some program areas are dependent on the outcome of other program areas. An example is the R&D goal for the Carbon Sequestration program area for electric power generation costs, which is dependent on the outcome of some technologies within the Advanced Power Systems program area. Whether a strict GPRA goal or not, all program area and technology goals that are useful in setting up the input for the NEMS benefits analyses are noted in the following sub-sections.

Pathways R&D pathways describe the technological means that are required in order to progress from an existing technology to the desired advanced technology. A pathway can be thought of as a research area with its associated technological approach and timeline. It outlines the R&D that needs to be accomplished to achieve the goal. Pathway descriptions are included to indicate that the goals have been determined based on test data and analyses that provide verification and validation that these paths are an achievable approach to meeting the ultimate R&D goal.

Input Assumptions The performance of a program area or one of its supporting technologies and the year that this new technological capability is assumed to come online in the marketplace are the primary data required as input to NEMS for determining the benefits of FE R&D. NEMS input assumptions (costs and efficiency) are directly derived from GPRA goals and the corresponding technology roadmaps. For this analysis, it is assumed that the commercial technology will operate as the R&D goals state; however, the GPRA goal timelines are adjusted to reflect when the technology will be considered commercial. The GPRA goal dates are viewed as the date that R&D is completed, yet demonstration at larger scale and construction time must be factored into the timeline to determine a reasonable on-line year for NEMS input. The amount of time added to the R&D date varies depending on the maturity of the technology and the availability of suitable demonstration sites. The rationale for adding time to each R&D goal is described in the following section.

1. Innovations for Existing Plants Program Area

The Innovations for Existing Plants (IEP) program area, within the Clean Coal and Natural Gas Power Systems Program supports both the Clean Air Interstate Rule (CAIR) and the Clean Air Mercury Rule (CAMR). It achieves this by developing technologies for all coals that will be ready for commercial demonstration by 2007 with the potential to reduce mercury by 50-70 percent at 75 percent of the 2003 reference removal cost of $50,000-$70,000/lb of mercury and NOx to less than 0.15 lb/MMBtu at three-quarters of the cost of selective catalytic reactors (SCR), currently at $80-$100/kW. By 2010, these technologies are to be ready for commercial demonstration that achieve 90 percent or greater mercury capture at 75 percent of the 2003 reference removal cost of $50,000-$70,000/lb of mercury. Accordingly, the major focus of the IEP Roadmap is the development of knowledge and technology to support multi-pollutant, multi-media solutions for the affordable and acceptable continued use of coal.

IEP GPRA Goals

The specific targets of the IEP program area that were developed in compliance with GPRA are given in Table 6. These targets address mercury removal technology only.

Table 6. GPRA Mercury R&D Performance Targets – Innovations for Existing Plants

Performance Targets	**Year**	**Mercury Removal Efficiency**		**Removal Cost**
		Target	**Actual**	
Mercury (Hg) Removal Cost and Efficiency Have >90% Hg capture technology (at <75% conventional technology cost) ready for full-scale commercial demonstration. 2005: Perform pilot-scale slipstream field tests of promising technologies (50-75% removal) 2006: Initiate pilot-scale slipstream field tests (>90% removal) 2007: Complete field tests of technologies deployable at 75% of conventional cost (50-75% removal) 2009: Complete field testing (>90% removal) 2010: Technology ready for full scale demo (>90%removal)	2003		50-70%	$50K-70K/lb (Reference Cost)
	2005	50-75%	50-75%	At reference cost
	2006	>90%		At reference cost
	2007	50-70%		<75% of reference cost
	2008	>90%		<90% of reference cost
	2009	>90%		<75% of reference cost
	2010	>90%		<75% of reference cost

A recent validation study performed for this R&D area revealed that the IEP mercury technology pathway is on target with Phase II field tests proving at least 90% removal of mercury from low-rank coals. Work is continuing to address issues posed by bituminous coals.

Although not cited specifically in the 2006 GPRA plan, the IEP program area also has R&D targets for the reduced cost and improved performance of NO_x control technologies. These goals are reported in Table 7.

Table 7. NOx R&D Performance Targets - Innovations for Existing Plants

NOx Performance Targets		
Year	**NOx emissions**	**Cost**
2007	.15 lb/MMBtu	75% of SCR cost in $/ton of NO_x removed
2010	0.1 lb/MMBtu	75% of SCR cost in $/ton of NO_x removed
2020	.01 lb/MMBtu	75% of SCR cost in $/ton of NO_x removed

IEP Pathways

In addition to existing traditional air-quality concerns, the following factors are also key drivers in the IEP program area roadmap:

- National emissions caps, similar to the current SO_2 and NOx caps, under CAIR;
- Control of mercury and other hazardous air pollutants under Title III of the Clean Air Act Amendments and CAMR;
- Water-quality and use issues associated with power production, including air pollutant loading to surface water, constraints in water availability, and cooling water intake structure regulations; and
- Solid residue and by-product issues, including increased volumes and related impacts associated with more stringent regulatory requirements.

Whatever regulatory requirements are ultimately enacted, the products of IEP will provide necessary components for effective compliance: an improved scientific understanding that can support well-grounded decisions and the technology solutions that can support cost-effective, timely implementation.

Retrofit emissions controls are currently available but are expensive and inadequate for some applications such as mercury removal. The IEP program area plans to significantly reduce the cost of these systems for compliance in the near-term (by 2010). Therefore, the IEP program area is assumed to accelerate development of technologies to reduce emissions of NOx and Hg from existing coal-fired power plants to directly support CAIR and CAMR.

This program area has two major products: knowledge (high-quality scientific data and analysis for use in policy and regulatory determinations) and technology (advanced environmental control systems for coal-based power plants). Working collaboratively with technology developers, users, regulators, and others, the IEP program area seeks market-based technology solutions to environmental challenges. In the United States, over 300 GW of coal-fired, air combustion power plants are currently in operation. They are the baseload power supply—stable and affordable—that has fueled the nation's economic growth and prosperity for the past several decades. The majority of these power plants were designed and built well before current air emission requirements became law. According to the National Academy of Sciences, nearly $60 billion in benefits have been gained from DOE research in NO_x and SO_2 control technology. The emissions from U.S. coal plants have been dramatically reduced while coal use has increased.

As research progresses, some pathways may not be viable due to environmental, economic, technical, or other reasons. Particularly in multi-pollutant approaches, new concepts may open new pathways. Through the process of roadmap development, these new pathways can be identified and explored.

Tables 8, 9, and 10 outline the pathways identified in the IEP program area that lead from barriers and issues to objectives in the reduction of NOx and mercury emissions.

Table 8. IEP Program Area Roadmap

Drivers	R&D Pathways		Outcomes
• Demand for low-cost power as a foundation of economic strength • Increasing scope and complexity of environmental regulations • Need to increase the efficiency of generation by minimizing parasitic load of environ-mental controls • Enhance the synergies in multi-media interrelation-ships while mitigating negative effects	**Mercury Emissions Control**	• Advanced control technologies • Emissions characterization • Development of measurement methods	• Reduced cost of compliance with environ-mental requirements • Integrated control systems with high efficiency and low cost • Continued reliance on low-cost domestic resources • Improved regional, national, and international environmental quality
	Advanced NOx Control	• Advanced combustion control • Post-combustion control • New SCR catalysts	
	Particulate-Matter and Acid-Gas Emissions Control	• Primary fine particulates • Gaseous precursors • Acid gases	

Table 9. Mercury Emissions Control Technology Pathway

Pathway	Barriers and Issues	Technology Approaches	Technology Objectives
Control Technologies *Develop cost-effective options for new and retrofit applications*	• Different coal ranks produce different forms (species) of mercury • Elemental and oxidized forms of mercury behave differently • Flue gas contains very dilute concentrations of mercury making capture difficult and expensive	• Develop comprehensive cost and performance data • Field testing of most promising control concepts • Continued pilot and bench-scale development of novel technologies	Commercial demonstration of technologies to achieve: • 50-70% reduction by 2007 for all coal ranks • +90% capture by 2010 • <3/4 or less the cost of baseline estimates
Emissions Characterization *Develop methods and data to support control system needs*	• Variability in the forms of mercury found in flue gas • Variability in the amount of mercury in different coal feedstocks • Variability in the speciation of mercury in coal flue gas	• Apply best available measurement methods to characterize mercury emissions • Focus on impact of conventional APCD such as Selective Catalytic Reduction on mercury	• Reliable data on emissions and control from coal-based power systems

Pathway	Barriers and Issues	Technology Approaches	Technology Objectives
Development of Measurement Methods *Develop standard methodology for mercury speciation in flue gas*	- Understanding of mercury behavior in flue gas is limited	- Evaluate and develop advanced mercury CEM technology as part of field testing program	- Provide for a reliable, inexpensive method for continuous measurement of total and speciated mercury

Table 10. NOx Emissions Control Technology Pathway

Pathway	Barriers and Issues	Technology Approaches	Technology Objectives
In-Furnace Control *Reduce NOx formation in the combustion process*	- Multi-pollutant regulations will require deeper cuts in NOx emissions - Current low- NOx burners increase unburned carbon in fly ash	- Ultra-low NOx burners - Pre-combustion modifications - Oxygen-enhanced combustion - Combustion catalysts	- Demonstration of advanced combustion NOx control technology to provide cost and performance validation - Achieve 0.15 lb/MMBtu at <¾ cost of SCR by 2007 - Achieve 0.10 lb/MMBtu at <¾ cost of SCR by 2010
Post-Combustion Control *Convert NOx to N_2 after combustion*	- SCR systems have high capital and operating costs - SCR systems can create balance-of-plant issues - Small, older plants may not be retrofitted with SCR	- Assess alternative reducing agents - Develop low-temperature SCR catalysts - Integrate advanced combustion NOx control with SNCR and SCR	- Demonstration of advanced combustion/SCR technology to provide cost and performance validation - Achieve 0.01 lb/MMBtu at <¾ cost of current methods by 2020

IEP Input Assumptions

As mentioned in the introductory section, the GPRA goals represent targets for the R&D program. The NEMS code deals with commercially available technologies and requires that the online year and plant performance be provided for power generating technologies. Therefore, using NEMS to estimate benefits for a specific program area requires that the R&D goals cited in the GPRA plan be translated into a schedule for commercial deployment. It is the penetration of a new technology in the marketplace that provides a means to assess its benefit. As the technology is deployed, its use may reduce consumer costs or provide other public benefits such as energy security and reduced emissions. The following describes how the R&D program roadmap (technology target and timeline) are modified to represent a reasonable graduation from GPRA R&D scale targets, through demonstration, to first commercial plant deployment.

For the IEP program area, the timeline for the GPRA R&D goals is moved by two to five years into the future to account for the time period required to demonstrate the technology on a larger scale and be considered commercially available by the marketplace. Online years for the various components of the IEP program area are listed in Tables 11 and 12.

Not all technologies within the IEP program area however, have benefits estimated using NEMS as the tool. For example, in addition to mercury and NOx control, IEP R&D is also developing technologies for particulate matter control, to increase by-product utilization, and to address water quality and use issues. Benefits resulting from these components of the program area are calculated separately in analyses external to the NEMS code. Therefore, the following description of NEMS assumptions focuses only on the IEP R&D goals for mercury and NOx.

Table 11. Mercury Control Modeling Assumptions

Mercury
Benefits Analysis Assumptions for IEP Program Area

- The following timeline is assumed for commercial deployment:
    - 2012 70% removal efficiency 50% of the cost of ACI*
    - 2015 90% removal efficiency 50% of the cost of ACI*
- The cost reduction is applied only to the cost of activated carbon since the cost of activated carbon is the bulk of the control technology cost. Although ACI cost is an input to NEMS and can be changed from one NEMS run to the next, it cannot be changed year by year within one NEMS run.
- NEMS assumes ACI technology is commercially available when required—no timing constraints are applied.
- 5 years are added to the GPRA R&D goals to allow time for commercial demonstration and adoption by the marketplace.

*GPRA goals cite <75% of the cost of ACI (a reduction of 25%). In the benefits assessment, it is assumed that the removal cost is reduced beyond 25% to half of current ACI costs. Current ACI costs are assumed to be $50K-70K/lb.

Table 12. NOx Control Modeling Assumptions

NOx
Benefits Analysis Assumptions for IEP Program Area

- The following timeline is assumed for commercial deployment:
    - 2009 .15lb/MMBtu NOx 75% of SCR cost in $/ton of NOx removed
    - 2015 .10lb/MMBtu NOx 75% of SCR cost in $/ton of NOx removed
    - 2025 .01lb/MMBtu NOx 75% of SCR cost in $/ton of NOx removed
- As the NOx removal level is increased, costs will increase although they will still be below that of an SCR.
- 2 years are added to the 2007 GPRA R&D initial target to allow time for commercial demonstration and adoption by the marketplace.
- 5 years are added to the more aggressive 2010 and 2020 GPRA R&D targets to allow time for commercial demonstration and adoption by the marketplace.

2. Advanced Power Systems (Coal) Program Area

The Advanced Power Systems (Coal) program area consists of unique combinations of gasification, gas cleanup, gas turbine, fuel cells, and synthesis gas conversion technologies for converting carbon-based feedstocks to synthesis gas, electricity, fuels, chemicals, and steam.

These systems offer alternative approaches to existing technologies for providing clean, affordable energy products to meet future market and environmental requirements.

By 2010, the Advanced Power Systems (Coal) program area – part of the Clean Coal and Natural Gas Power Systems Program – will complete R&D for advanced gasification combined cycle technology. This technology can produce electricity from coal at 45-50% efficiency (HHV) at a capital cost of $1,000 per kilowatt ($2002) or less. By 2015, this program area will demonstrate future integrated coal-based energy plants that offer zero emissions (including CO_2 capture and sequestration) and multiple products, including electricity and hydrogen.

These goals are written for Advanced Coal-Based Power Systems and are designed to support administration priorities. These goals have two time horizons, 2010 and 2015, where efficiency, costs, and emissions are significantly improved. The 2010 goals are addressed by the efforts of the FE Gasification and Turbine Programs. By 2015, coal-based power systems will take advantage of contributions from the Advanced Syngas and Hydrogen Turbines, Advanced Gasification, and SECA Fuel Cell technologies to further minimize emissions and achieve higher efficiency at lower costs. The ability to meet these goals is based on the success of all programs. These goals are referenced in the *Office of Clean Coal Strategic Plan*[1].

The Advanced Power Systems (Coal) program area is comprised of these technologies:

- Advanced Gasification (IGCC Power Generation Plants). The few IGCC plants operating today do not rely on the advanced components being developed in the Coal Technology IGCC R&D (including advanced materials, gas cleaning, membranes, etc.). These components will significantly improve efficiency and reduce cost and will provide carbon sequestration-ready concentrated gas streams. Coal-based IGCC is not a mature technology (only two plants are operating in the United States and both are being subsidized) and FE R&D is expected to successfully develop and integrate key technology components to improve IGCC commercial competitiveness.

- Advanced Syngas and Hydrogen Turbines. Turbines for gas-fired combined cycle power generation are considered 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. Current FE turbine R&D focuses on the development of turbines that will allow IGCC and other related processes to reach established performance goals [NETL, 2006]. To achieve the ultra high efficiency goals of the Advanced Power Systems program area as well as the near-zero emissions goal for the longer term, advanced turbines – which may be integrated with fuel cells in what is termed a hybrid system – are required.

- Coal-Based SECA Fuel Cells. Fuel cells have long had the potential to radically change electricity generation and use. Despite offering superior environmental and operational performance, fuel cells have been relegated to niche applications because of their high cost. The DOE has forged a unique alliance between government, industry, and the

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[1] The *Office of Clean Coal Strategic Plan* has not yet been released. When available, it may be found at http://www.netl.doe.gov/publications/brochures/brochure_toc.html

scientific community – the Solid State Energy Conversion Alliance (SECA)[2] – to develop a solid-oxide fuel cell (SOFC) 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 for vehicles.

Advanced Power Systems (Coal) GPRA Goals

The specific targets of the advanced gasification, advanced turbines, and SECA fuel cells developed in compliance with GPRA are given in Tables 13 and 14. An annual validation analysis is performed to determine progress against the GPRA targets. Recent tests have proven successful performance of both a dry-feed pump to replace the slurry feed system and a warm gas cleanup system to replace the conventional Selexol unit for acid gas removal. Based on the performance of these tests, a systems analysis of an advanced IGCC system was performed. The projected performance of that IGCC was a system efficiency of 43% HHV and a reduction in capital cost of $50/kW. This predicted performance exceeds the 2006 GPRA target for efficiency and shows that with additional work on the warm gas cleanup system, the cost reduction target for 2007 is likely to be achieved.

Table 13. GPRA R&D Performance Targets - Advanced Power Systems

Performance Targets	Year	Target	Actual
Efficiency of Advanced Coal-Based Energy Plant. Department develops advanced coal-based power systems capable of achieving 45-50% thermal efficiency at a capital cost of $1,000 per kilowatt ($2002) or less. **(**Efficiency is the percent of fuel energy converted to electricity). Target values are demonstrated at pilot or pre-commercial scale which validates feasibility of targets. 2005: Gas cleanup synthesis gas slipstream tests 2007: Proof-of-concept tests of advanced materials & instrumentation in commercial-scale gasifiers 2009: Air separation pilot-scale tests 2010: Tests of turbine combustors operating on syngas and pilot-scale tests of advanced gasifiers. Target efficiency point improvements are associated with gas cleanup (1-2%), air separation (1-3%), and gasifier/turbine (3-5%).	2003		40%
	2005	41%	41%
	2006	42%	
	2007	42%	
	2008	43%	
	2009	44%	
	2010	45-50%	
Capital Cost of Advanced Coal-based Energy Plants. Target values are demonstrated at pilot or pre-commercial scale which validates feasibility of targets. Gas cleaning (~10% of plant cost) can be reduced by $60 to 120/kW, air separation (12-15% of plant cost) can be reduced by $75 to 100/kW, and turbine systems (~30% of plant cost) can be reduced by $60 to 100/kW. Costs are reported in $2002.	2003		$1,300/kW
	2007	$1,200/kW	
	2008	$1,150/kW	
	2009	$1,100/kW	
	2010	$1,000/kW	

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[2] The SECA Program is carried out under the auspices of the DOE Office of Fossil Energy. The DOE National Energy Technology Laboratory (NETL) and its sister Laboratory, the Pacific Northwest National Laboratory, are responsible for program development. NETL is the DOE program office responsible for managing program implementation. Activities are coordinated with NETL's Strategic Center for Coal.

Table 14. GPRA R&D Performance Targets - SECA Fuel Cells

Performance Target	Year	Target	Actual
Capital Cost of Fuel Cell Stacks. Ultimate objective of this target is reduction of 3-10 kilowatt solid oxide fuel cell (SOFC) stack costs to $100/kilowatt. SECA R&D plans are designed with a specific cost goal that will create economically competitive, free market deployment of fuel cell systems. This annual measure validates progress in reducing the cost of the fuel cell stack, the critical, high risk component of the system, and is based upon stack tests conducted annually. The program goal is $400/kW (as measured in year 2000 dollars) for entire SECA fuel cell system at the end of SECA Phase III which will occur in the 2010-2012 timeframe, depending on the individual start dates of the six SECA industry teams. The completion dates for the major phases of the SECA program are: 2005 SECA Phase I ends for first industry teams 2008 SECA Phase II ends for first industry teams 2010 SECA Phase III ends for first industry teams 2015 Large Scale SECA/hybrids subprogram ends The same $400/kW cost goal may apply to the large SECA fuel cell/turbine hybrid systems that will be developed under a new subprogram and initiated in FY2006 (binding performance measures TBD following awards to competitive solicitations).	2000		$5,500/kW*
	2005	$350/kW	<$300/kW
	2006	$300/kW	
	2007	$250/kW	
	2008	$225/kW	
	2009	$165/kW	
	2010	$100/kW	
	2011	$100/kW**	
	2012	$100/kW**	
	2015	TBD	

* *Approximate 2000 price for comparison of commercially available fuel cells (not SECA fuel cells). SECA fuel cell technology did not exist in 2000.*

** *Applies to remaining SECA teams that complete Phase III in 2011-2012*

Advanced Syngas/H_2 Turbines technologies contribute to efficiency, emissions, and cost improvements for Advanced Power Systems (Coal) program area goals. The contributions to these goals are presented below:

Table 15. R&D Performance Targets - Advanced Syngas/H_2 Turbines

Contributions of Advanced Syngas/H_2Turbines Technology

Toward 2010 Advanced Power Systems (Coal) Goal:

- Efficiency: Demonstrate 2-3% points improvement in combined cycle (CC) performance (fuel to busbar efficiency compared to the "without R&D" IGCC performance).

- Cost: Demonstrate a 20-30% reduction in combined cycle (CC) overnight capital cost plus enhanced value for lower COE. (Compared to the "without R&D" IGCC performance).

- Emissions: Demonstrate combustor emissions with 2 ppm NOx (@15% O_2) in simple cycle exhaust.

Toward 2015 Advanced Power Systems (Coal) Goal:

- Efficiency
  - Hydrogen turbine CC with 3-5 % points (total) improvement above "without R&D IGCC baseline
  - Oxy-fuel turbine based IGCC system >50% efficiency with CO_2 capture

- Cost
  - Competitive COE for near zero emissions and CO_2 capture

- Emissions
  - H_2 Turbine based IGCC demonstrate with 2 ppm NOx (@15% O_2)
  - Oxy-fuel turbine based IGCC with zero emissions (100% turbine exhaust captured and sequestered- zero criteria pollutants and CO_2)

- Multi Products
  - H_2 turbine based IGCC with higher capacity gasification
  - Oxy-fuel turbine based IGCC with multi-product production

Advanced Power Systems (Coal) Pathways

Advanced GasificationTechnology

Numerous market opportunities for advanced power systems are expected to develop in the next decade for new baseload power and other commodity products in both developed and undeveloped nations. To address these needs, first generation IGCC and co-generation facilities have been successfully operated in the United States and elsewhere. Although these plants have confirmed the benefits of gasification-based technologies, significant reductions in capital and operating costs as well as improvements in reliability and thermal efficiency are required to make gasification the technology of choice for advanced power systems. These activities are described more fully in the Technology Roadmap and Program Plans available on the FE/NETL website: http://www.netl.doe.gov/technologies/coalpower/cctc/technology_roadmap.html

The Advanced Gasification technology area consists of the following R&D pathways:

Synthesis Gas Cleanup - Industry would like to have technologies that are capable of achieving the performance of a Rectisol unit but at equal or lower cost than an amine system. Several technologies currently under development have potential for achieving just that [Gardner, 2002; Gupta, 2003; Newby, 2003; Srinivas, 2003]. A novel sorbent-based technology utilizing a transport reactor is currently being commissioned in conjunction with a coal gasifier that can achieve sulfur levels as low as 1-5 parts per million (ppm) in the synthesis gas stream while operating at moderate process conditions (i.e., 500-700^{o}F). Such temperatures are consistent with downstream process applications and obviate the need for cooling and reheating which impart an efficiency penalty on the system. Integrated operations are necessary to demonstrate the impact of trace contaminants in the coal-derived synthesis gas on the performance and longevity of the sorbent and its regenerability, and to evaluate attrition resistance.

Selective catalytic oxidation technologies being developed have the potential for achieving sulfur levels well below 1 ppm while operating at moderate process temperatures. In this approach, a small quantity of oxygen is injected into the synthesis gas stream where it reacts with H_2S over a catalyst to directly form elemental sulfur. To achieve the desired performance, either the COS in the raw gas stream must be hydrolyzed to H_2S or a new catalyst must be developed to directly convert COS to elemental sulfur.

Preliminary engineering analyses of these two technologies have shown significant improvements over current commercial technologies. While achieving greater than an order of magnitude reduction in sulfur over amine-based systems and comparable performance to Rectisol, the capital cost of the technology could be reduced by at least $60-80/kWe compared to amine-based technologies. In addition to the capital cost reduction, there is a concomitant increase in thermal efficiency of 1-2 efficiency points.

For the above two approaches to be commercially attractive at moderate process temperatures, technologies are needed that can remove other trace contaminants at similar process conditions. Technologies for mercury, ammonia, and chloride removal are currently being developed and testing in conjunction with a coal gasifier is expected within the next year or two.

Separation of Hydrogen and Carbon Dioxide- Another priority of gas separation is the need to separate hydrogen and carbon dioxide (CO_2). Most current technologies provide one gas or the other but not both. Cost and efficiency improvements can be achieved with lower temperature operation and delivery of the gases at high pressures. There are some applications that are better suited for lower pressure gas delivery and this necessitates the need for a portfolio of membrane-based separation technologies to address multiple applications.

The bulk of the DOE R&D for hydrogen separation is focused on inorganic membranes (organic membranes appear to have limited applications for coal-based hydrogen because of their extreme sensitivity to process conditions and trace contaminants). Inorganic membranes can be further classified as either porous or dense and the latter can be further subdivided into metallic or solid electrolytes (ceramic).

Of the porous membranes being developed, the most promising appears to be one developed by Oak Ridge National Laboratory (ORNL). Because of the manufacturing process employed in producing this membrane, the pore size and distribution can be precisely controlled to allow primarily hydrogen to diffuse through the pores, thereby achieving very high separation factors. Although classified by the U.S. government for many years, the membrane technology was recently declassified for hydrogen separation applications; the manufacturing process, however, still remains classified. DOE and ORNL are initiating an effort to move this lab-scale success to the next phase by developing a prototype module for performance testing on coal-derived shifted synthesis gas.

Considerable effort has also been devoted to metallic membranes, most of which are based on Palladium (Pd). Although initially thought to be promising, these membranes have been found to be susceptible to degradation from the presence of both sulfur and CO. However, Eltron Research has recently reported metal alloys that have shown very high hydrogen fluxes at temperatures around 400°C [Roark, 2002]. The composition of the alloy has not been disclosed pending the filing of a patent application; however, the materials used are not expensive. Again, the stability of these membranes in the presence of trace contaminants from coal must be determined.

Dense ceramic solid electrolyte membranes have also been under intense investigation; however, the required operating temperature of the membrane is much too high for applications to coal-based hydrogen production, and hydrogen fluxes have not achieved the level of commercial significance.

Although considerable effort is being devoted to membranes, there needs to be a more diversified approach to hydrogen separation technology development that does not rely solely on the use of membranes. Other novel concepts, for instance, employ chemical solvents and solid sorbents. One of the more promising approaches is the CO_2 hydrate process being developed jointly by Nexant, Inc., Simteche, and Los Alamos National Laboratory [Spencer, 2003]. In this approach, the shifted synthesis gas is contacted with cold water containing a promoter to form a hydrate which captures CO_2. The CO_2 is released from the hydrate by the application of heat or reducing pressure. Unlike membrane-based technologies, this approach results in both high pressure H_2 and CO_2 streams.

Advanced Gasifier Concepts - The gasifier technologies being deployed today are based on 30-year-old concepts. Only incremental improvements have been made to the overall technology. Radically new approaches will be needed to produce significant improvements. The next generation of gasification-based processes will require new process configurations that in addition to generating electricity are also capable of competitively producing methane, hydrogen, chemicals for industrial feedstocks, and alternative liquid fuels. These new approaches have the potential to significantly improve the Nation's energy security by producing from the abundant low-cost U.S. coal resource an alternate source of chemicals and gaseous fuels, superior liquid transportation fuels, and hydrogen to step us toward a hydrogen-based economy and reduce our reliance on imported oil.

The transport gasifier being pioneered by Southern Company has shown significant promise for a variety of feedstocks and works especially well on low-rank coals and lignites. The chemical looping concepts being developed by Alstom, GE Global Research [Rizeq, 2002], and the Zero Emission Coal Alliance (ZECA) [Ziock, 2003] offer a new direct route to the production of hydrogen and the capture of CO_2 through the use of solid sorbents. In these concepts, air and coal are fed to the system and pure streams of H_2 and CO_2 are produced. Multiple reactors are employed with transfer of solids between the beds. For instance, air is fed to one of the reactors where the oxygen is absorbed on an oxygen transport material. This material is transferred to a second bed where the oxygen desorbs and reacts to generate heat for the gasification reactions. These technologies are in the very early stages of development and more research is necessary to address the issues associated with the transfer of hot solids between the vessels; however, preliminary studies have shown the potential for significant capital cost reductions and efficiency improvements if the performance goals can be achieved.

Air Separation - The current cost of oxygen from cryogenic technology amounts to nearly 15 percent of the capital cost of IGCC plants and can consume upwards of 10 percent of the gross power output of the plant. Since cryogenic technology is technically mature, a new air separation technology will likely be necessary to realize significant cost reductions. Toward this end, research is being conducted to develop ceramic membranes for air separation.

Advanced dense ceramic membranes possessing both ionic and electronic conductance are being developed as a high temperature approach for air separation [Armstrong, 2002; Prasad, 2003]. Preliminary engineering analyses have shown that such approaches have the potential for reducing the capital cost of an IGCC plant by $75-100/kWe with a corresponding 1-2 point gain in thermal efficiency. Although many challenges exist in material composition and processing to produce defect-free chemically and thermally stable membranes with commercially relevant fluxes, significant progress has been made over the past few years. Since ceramic membranes operate at high temperature, they are well suited for thermal integration with the gas turbine, which enhances IGCC system efficiency.

The first commercial offering of these membrane-based technologies is not expected to occur until near the end of this decade. Currently, only small-scale membrane modules are being produced. These membrane modules must be scaled-up to meet gasification plant needs and new manufacturing processes are required to obtain improved system performance, manufacturing reliability, and cost. The results of DOE lab-scale research feeds into the prototype testing phase of the program to bridge the gap from small-scale development to that required for commercial-scale, advanced ultra-clean power plants.

Figure 5 shows an outline of how these R&D pathways for the Advanced Power Systems (Coal) program area will move from the current technology to advanced technologies.

Challenges

Optimization of Coal Use with:

- *Zero emissions*

High efficiency

- *Low cost plants for production of*
  - *Electric power*
  - *Fuels*
  - *Chemical*
  - *Hydrogen*

Reduction of Power Plant Pollutants (NOx, SOx, Hg, As, Cd, Se, PM)

Reduction of CO_2 Emissions

Maintain Low Cost of Electricity to the Public through diversified mix of indigenous fuels

R&D Pathways

By 2010

Advanced Gasification

- Advanced Gasifiers
  - Transport/Compact gasifiers
  - Advanced materials & instrumentation
  - Dry feed pump
  - 85% capacity factor
  - 98% carbon conversion
- Syngas Cleanup
  - Warm gas cleaning (all contaminants including Hg)
- Air Separation
  - ITM oxygen

Advanced Syngas Turbines

- Advanced combustors, materials, aerodynamics/ mechanics

By 2015

All of 2010 improvements, plus:

Advanced Gasification

- Advanced Gasifiers
  - Chemical looping gasifiers
  - 90% capacity

Hydrogen Gas Turbines

- Advanced combustors, materials, aerodynamics/ mechanics

Coal-Based SECA Fuel Cell

- High-tech materials
- Advanced electrochemical technologies

Targets

By 2010

- Efficiency 45-50% (HHV)
- Capital $1000/kW ($2002)

By 2015

- Efficiency 50-60% (HHV)
- Capital $1000/kW ($2002)
- Targets for plants w/o carbon capture
- Near-zero emissions

Figure 5. Advanced Power Systems Program Area Roadmap

Advanced Syngas and Hydrogen Turbines Technology

The FE Advanced Turbines technology area is focused on key technologies needed to develop advanced turbines that will operate cleanly and efficiently when fueled with coal-derived synthesis gas and hydrogen fuels. The Advanced Turbines R&D program is an investment in secure U.S. electric power production that is clean, efficient, affordable, and fuel-flexible and will make possible the continued use of coal, our nation's largest domestic fossil energy resource. Developing advanced turbine technology is critical to the development of power generation technologies that will minimize the emissions of criteria pollutants and carbon dioxide. The implementation of the Advanced Turbines R&D is driven by high-level FE Advanced Power System program area goals with 2010, 2012, and 2015 time horizons. Outlined in Table 16 is how the turbine R&D will address these goals and the expected contributions.

FE Advanced Turbines R&D is designed to provide low cost technological solutions to administration priorities and high-level DOE goals. These include the Climate Change, Clean Air Rules, Hydrogen and FutureGen Initiatives.

The R&D pathways presented in this section include the expected contributions from the Advanced Turbines R&D towards the 2010 and 2015 goals of the Advanced Power Systems program area.

A generalized approach to the technical issues and benefits associated with the 2010 technology goals are listed in Table 16. 2015 goals are addressed by further advances in hydrogen turbines and by oxy-fuel turbines for coal gasification systems. The technologies also support R&D in MW-scale (1-100 MW) hydrogen fueled turbines and the efficient and low cost compression of large volumes of CO_2. As part of the hydrogen turbine initiative, MW-scale machines capable of clean and efficient hydrogen use are being developed for industrial and auxiliary loads. The emissions goal for MW-scale hydrogen combustion is two ppm with good efficiency. Hydrogen-based systems are not currently modeled in NEMS and, therefore, benefits of these systems must be determined in a separate analysis.

Coal-Based SECA Fuel Cells Technology

Fuel cells have long offered a lot of potential, but cost considerations have precluded their widespread implementation. The current focus within FE is on the development of 3-10 kilowatt solid oxide fuel cell (SOFC) modules having a capital cost of $400/kilowatt (a 10-fold cost reduction from 2003) by 2010. By 2015, the objective is to demonstrate MW-class fuel cell/turbine hybrids, using aggregated SOFC modules adaptable to coal and having a capital cost of $400/kilowatt. SECA can be divided into two subprograms:

- <u>Distributed Generation</u>. The initial focus of SECA is to produce 3-10 kW SOFC modules at a capital cost of no more than $400/kW by 2010 and to also have the power densities, reliability, and operating characteristics compatible with commercial service in both stationary and transportation power applications. Immediate markets that are identified include distributed generation applications (such as residential or commercial power uses), long-haul truck and recreational vehicle auxiliary power units, and corollary military applications.

Table 16. Approach of Advanced Syngas/H_2 Turbines R&D

Technical issue to pursue	Benefit to gas turbine or power plant
Combustor for 2 ppm NOx	Eliminates SCR and other penalties (NH_4 slip, cost back pressure)
More durable catalysis for in combustor NOx formation prevention	Reduced O&M, makes catalytic combustion possible
H_2 Premixing without flash back	Enables low NOx combustion and related robust combustion techniques
Higher turbine inlet temperatures (TIT) (~2100°F)	Approximately 1% pt. improvement to simple cycle per each ~70°F increase
Better thermal barrier coating materials	Higher TIT, less air extraction, reduced RAM* overall improvement in efficiency
Enhanced cooling techniques	Higher TIT and less air extraction
Increase rotor torque limitation	Higher power output with reduced capital cost (~20%)
Compressor and air separation unit integration	0.5-1.0% points efficiency improvement, but with higher capital cost
Ceramic parts	Higher TIT
Enhanced aerodynamics	Higher throughput & specific power
* RAM: Reliability, Availability and Maintainability	

- Coal-Based Applications. A longer-term goal is to integrate SOFC modules into advanced power plant concepts by 2015 that transcend the immediate distributed generation market for SECA modules and move them into coal-, biomass-, or solid waste-fueled applications. Ultimately, SECA fuel cells will play a role in, and have application to, systems supporting a national hydrogen economy. In the utility sector, SOFCs can be used as components of central power sources or strategically located to provide utility grid support to offset transmission, distribution, and new generating capacity investments. SOFCs are an essential element in meeting long-term, 2015 Clean Coal and Natural Gas Power Systems Program efficiency goals of 60 percent on coal and 75 percent on natural gas.

In order to attain the aggressive objective of reducing solid-state fuel cell costs to $400/kW (about one-tenth the cost of today's fuel cells), four basic R&D pathways aligned to technology strategies were adopted:

- A "Mass Customization" approach resolves the market entry dilemma — initial costs are too high to sell a large number of units, while high volume production is needed to bring the cost down. Mass customization is best defined as a delivery process through which mass-market goods are produced to satisfy a range of specific customer needs, with minimum individual customization at an affordable price. SECA applies this concept by mass producing a majority of components and requiring little special packaging for application-specific units. This approach serves as the ultimate combination of "custom-made" and "mass production" and it is rapidly emerging as the organizing business principle of the 21st century.[3]

- Industry/Academia/Government Partnerships leverage the skills of each entity by placing them in appropriate roles. By mobilizing the forces of industry with the research community and accelerating investment in expertise to develop commercially higher-risk SOFC technology, SECA is in the unique position of being able to substantially speed the development of an economical, high-power-density SOFC for multiple market applications.

- A Core Technology Program available to all industrial teams eliminates redundancy. This alliance of U.S. industry, universities, and other research organizations represents a new model for joint government and private industry technology development. It also provides for effective use of SECA funding resources, which is critical to the success of SECA. The coordination of "Industry Teams" with a "Core Technology Program" is designed to solve difficult technical issues faster without redundancy of effort, while assuring that the SECA alliance members and end-users benefit.

- Enhanced Technology Transfer enables all industry participants to benefit from breakthroughs by the scientific participants, thereby enhancing technology transfer. Participants perform work subject to what is termed an "exceptional circumstance" to the Bayh-Dole Act and any intellectual property is offered to all Industry Teams as a non-exclusive license. The Core Technology is regularly peer-reviewed by independent organizations and industry teams.

The development of fuel cell technology has been broken down into three phases. The timing and requirements of these phases are detailed in Tables 17 and 18. The FY2006 GPRA goals require an interim cost target of $300/kW or less for the SOFC power system stack in the 3-10 kW range. Two of the SECA industry teams have met the interim target of $300/kW for the stack, projecting a stack cost of $245/kW. Further, a third party audit of the stack cost validated these claims and verified that progress toward GPRA goals is on target.

Advanced Power Systems (Coal) Program Area Input Assumptions

Based on the goals and strategies listed above, the modeling assumptions listed in Table 19 were made for the Advanced Power Systems R&D program area. Since the R&D goals reflect the timing for the development of technologies within the R&D program area, they must be adjusted to reflect the timing and performance of operating commercial plants. NEMS requires that the input be representative of the year the technology is first deployed commercially. Thus, a commercialization period from development of a technology until full implementation as an operating plant must be taken into account.

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[3] During the last 15 years, choice has become an important ingredient of consumer purchasing decisions. For instance, during that period the number of automobile models has increased from 140 to 260, and computers can now be custom-designed to meet a specific user's needs, with a minimum amount of repackaging of the basic system.

Table 17. SECA Milestones

Key Roadmap Milestones
(SECA - SECA/Fuel Cell Coal-Based Systems – FutureGen – Central Generation)

- 2005 – Phase I SECA prototypes
- 2005 – Select Fuel Cell Coal-Based System Teams
- 2008 – SECA Phase II prototype testing
- 2008 – Modular fuel cell stack test on coal gas
- 2010 – Phase III SECA $400/kW modules
- 2010 – MW-class (250-kW) aggregated, $400/kW fuel cell module test on coal gas
- 2012-2015 – MW-class scaleable fuel cell coal based system at FutureGen
- 2015-2020 – Test MW-class fuel cell coal based system on coal producing 60% efficiency plant efficiency
- 2020 – 100 MW-class fuel cell systems

Table 18. SECA Minimum Technical Requirements

	Phase I 2005	**Phase II 2008**	**Phase III 2010**
Power Rating	3-10 kW	3-10 kW	3-10 kW
Cost Capable of Being Achieved	$800/kW	$600/kW	$400/kW
Efficiency, Mobile	25-45%	30-50%	30-50%
Efficiency, Stationary	35-55%	40-60%	40-60%
Steady State Hours	1,500	1,500	1,500
Steady State Availability	80%	85%	95%
Degradation per 500 hours	≤ 2.0%	≤ 1.0%	≤ 0.1%

Table 19. Advanced Power Systems Modeling Assumptions

Advanced Power Systems Program Area
Benefit Analysis Assumptions for
Gasification, Syngas/H_2 Turbines, SECA Fuel Cell Technologies

- Booz Allen Hamilton is used as the baseline. Refer to Tables 1, 2 and 3 for specific values.
- The GPRA goal date is increased by a total of 8 years to allow time for the technology to be demonstrated at a larger scale and for the first commercial plant to be constructed. It is assumed that with FutureGen, CCPI and other industry plant additions, the technology will reach demonstrate performance during that four-year demonstration period. An additional 4 years is added for construction of the commercial plant. Therefore, the 2010 GPRA goal is reflected in 2018 as the online year for NEMS input (defined as the date that the plant with given performance is operating).
- Advanced turbine developments improve combined cycle efficiency by 2-3% points and reduce cost by 20-30% by 2010 and are deployed in the 2015+ plants.
- The following online profile is assumed for IGCC (costs are in 2002$):
  2015 45.1% HHV, $1200/kW*
  2016 47.5% HHV, $1150/kW*
  2017 48.4% HHV, $1100/kW*
  2018 50% HHV, $1000/kW (2010 goal)
  2023 60% HHV, $1000/kW (2015 goal)
- The 2015 goal (online in 2023) is to develop technologies for zero-emission coal plants (without carbon capture) that are fuel-flexible and capable of multi-product output and efficiencies over 60 percent. In NEMS, the IGCC generates power only (no co-production) and the 60% HHV efficiency applies to electrical efficiency (without sequestration) and assumes integration with a $400/kW SECA SOFC - turbine hybrid. This advanced system is known as IGFC.
- $400/kW SECA SOFCs that can run on syngas in the hundred MW class are available by 2015 and deployed in the 2023 IGFC plant.
- Advanced turbine developments provide 3-5% improvement in combined cycle efficiency and reduce NOx emissions to 2 ppm (@ 15% O_2).

*These efficiency targets were determined by interpolation using the BAH study projections. These values are higher than those listed in the GPRA table for Advanced Power Systems (Table 13).

3. Carbon Sequestration Program Area

The goal of the Carbon Sequestration R&D program area is to develop technologies to the point of commercial development by 2012 for direct capture and geologic sequestration of CO_2 from fossil-fuel conversion processes that protect human and ecosystem health and that result in less than a 10 percent increase in the cost of electricity (COE), as compared to an IGCC using today's off-the-shelf technology.

The DOE Carbon Sequestration program area can be divided into two major segments: (1) Core R&D and (2) Infrastructure Development. Also implied is the integration of technologies. In addition, FE/NETL is funding and participating in some crosscutting activities that begin to develop the infrastructure for sequestration (Regional Carbon Sequestration Partnerships) and that integrate sequestration with energy production (FutureGen). Figure 6 illustrates the elements of the Carbon Sequestration program area.

These activities are also described more fully in the Carbon Sequestration Technology Roadmap and Program Plan available on FE/NETL's website:
http://www.netl.doe.gov/publications/carbon_seq/2006%20Sequestration%20Roadmap%20FINAL.pdf

Core R&D efforts are aimed at developing carbon sequestration technologies. The area is split into five sub-areas: (1) CO_2 Capture, (2) Sequestration/Storage, (3) Monitoring, Mitigation, & Verification (MM&V), (4) Breakthrough Concepts, and (5) Non-CO_2 Greenhouse Gas. Infrastructure Development is occurring through seven Regional Carbon Sequestration Partnerships – groups funded to evaluate regional CO_2 emissions sources and sequestration options.

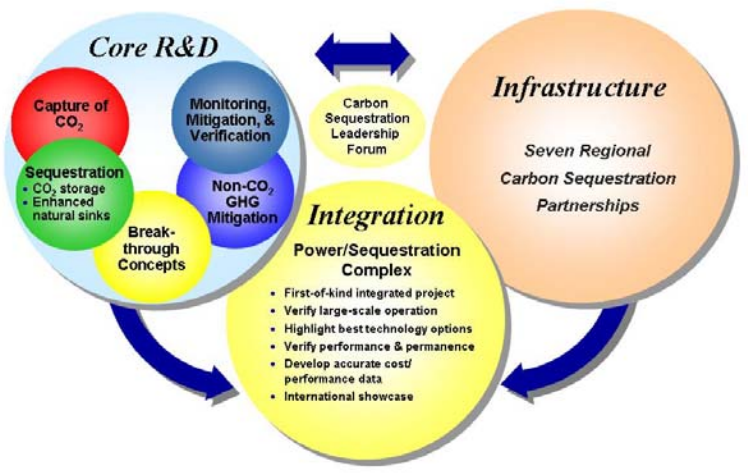

Figure 6. Carbon Sequestration Technology Development Efforts

Carbon Sequestration GPRA Goals

GPRA performance targets for the Carbon Sequestration program area are shown in Table 20. Based on analysis of pilot and bench scale tests, system analyses show that the COE for an IGCC system incorporating recent technology advances coupled with a MEA unit for CO_2 separation and capture is estimated to be less than a 20% increase over an analogous system with CO_2 capture, hence validating that the FY2006 GPRA target has been met and that progress is on track.

Table 20. GPRA Performance Targets – Carbon Sequestration

Performance Targets	Year	Increase in COE	
		Target	Actual
Carbon Capture & Sequestration Cost. Develop to the point of commercial development technologies for direct capture and geologic sequestration of CO_2 from fossil-fuel conversion processes that protect human and ecosystem health and that result in less than 10% increase in the COE. In 2003 the cost impact of state-of-the-art technology increased the cost of electricity (COE) by 30% for new plants, as compared to non-sequestered counterparts. Measure is based on analysis of laboratory and pilot scale tests of 90% carbon capture technologies. 2005: Perform initial pilot-scale capture tests 2007: Perform comprehensive pilot-scale capture tests 2009: Conduct field demonstrations of geologic sequestration 2012: Complete regional field validation tests	2003		30%
	2005	25%	25%
	2006	23%	
	2007	20%	
	2008	19%	
	2009	17%	
	2010	15%	
	2011	13%	
	2012	10%	

Carbon Sequestration Pathways

The Carbon Sequestration program area R&D efforts are aimed at developing carbon sequestration technologies in the following five areas:

- CO_2 Capture Technology – when a carbon-based fuel (coal, oil, natural gas) is burned to produce electricity, CO_2 is produced. This CO_2 is part of the flue gas which also contains nitrogen, water vapor, and criteria pollutants (mercury, particulate matter, sulfur dioxide, and nitrous oxides). Depending on which electricity generating process is used, the CO_2 concentration in this stream is from 3-18 percent of the total gas. The processes involved in separating the CO_2 from the rest of the gas and preparing it for reuse or sequestration/storage is called CO_2 Capture.

  Capture represents about 75 percent of the incremental cost of the total sequestration process. The issue is that a new, sequestration-ready power plant today costs 30–50 percent more than a traditional coal-fired power plant. The lower end of this cost range is a new IGCC with a Selexol or Rectisol scrubber, while the upper end is an oxy-fuel combustion process, with a pulverized coal power plant with state-of-the-art scrubbing in midrange. Specific R&D pathways that will lower the capital cost and energy penalty associated with capturing CO_2 from large point sources include: membranes, advanced scrubbers, CO_2 hydrates, and oxy-fuel combustion.

- Sequestration/Storage Technology – offers a promising set of technologies through which captured CO_2 and potentially other GHGs and criteria pollutants are stored for long periods of time in geologic formations. Scientists are studying various aspects of these technologies and beginning to test them on a small scale in order to determine how carbon sequestration can provide a safe, effective, and efficient means of preventing CO_2 from entering the atmosphere. Although the methods for evaluating and mitigating any health, safety, or environmental risks are a high priority, the regulatory framework for

CO_2 storage has not been developed and it won't be until the issues are better understood. However, the issues won't be fully understood unless there are field tests.

Of the utmost importance is ensuring (and verifying at a large scale) that storage methods are permanent. Also needed are methods to evaluate a reservoir's capacity. How do we determine the maximum amount of CO_2 that can be safely stored? Are there cap rocks? Fracture faults? The infrastructure to transport CO_2 to storage sites needs to be developed, as well as societal agreement on protocols for identifying storage sites.

Some of the specific R&D pathways that will lead to an improved understanding of the factors affecting CO_2 storage permanence and capacity in geologic formations, terrestrial ecosystems, and potentially the deep oceans are: evaluation of hydrocarbon-bearing geologic formations and saline formations; tree plantings, agricultural practices, and soil reclamation; and increased ocean uptake.

- Monitoring, Mitigation, and Verification (MM&V) Technologies – are essential to ensuring safe, permanent storage of CO_2. Monitoring takes place prior to, during, and after any injection into a geologic formation. A mitigation plan is established to ensure that technologies are available to mitigate any leaks, in the unlikely event they should occur. Verification is needed over the long-term to ensure that sequestered CO_2 remains in storage.

  Tools are needed to monitor the land surface over large areas for small leaks to ensure safety and to detect even low levels of environmental risk. It is difficult to detect a 500 ppm concentration of CO_2 that might indicate a slow leak against a background measurement of 370 ppm. Further, effective remediation methodologies need to be ready for implementation in the event of CO_2 leaks from any of the repositories.

  The petroleum industry has tools for subsurface monitoring, but improved resolution is needed – lower cost 4-D seismic. Still needed are protocols for accounting and certifying CO_2 storage. How often must measurements be taken? How accurate do measurements have to be? How often do reservoir models have to be rerun?

  Specific R&D pathways that will lead to achieving program goals include: advanced soil carbon measurement, remote sensing of above-ground CO_2 storage and leaks, detection and measurement of CO_2 in geologic formations, and fate and transport models for CO_2 in geologic formations.

- Breakthrough Concept Technologies – New ideas are needed to make significant reductions in atmospheric concentrations of GHGs. These "breakthrough concepts" are revolutionary approaches with potential for low cost, high permanence, and large global capacity. These revolutionary approaches to CO_2 capture and storage will have the potential to address the level of reductions in greenhouse gas emissions consistent with long-term atmospheric stabilization.

Specific R&D pathways that will accomplish this goal include: advanced CO_2 capture, advanced subsurface technologies, advanced geochemical sequestration, and novel niches.

- Non-CO_2 GHG Technologies – In the United States, although roughly 80 percent of anthropogenic GHG emissions come from burning fossil fuels and are in the form of CO_2, it is not the most potent GHG. Core Sequestration R&D also includes several non-CO_2 GHG reduction projects that focus on capturing waste methane, which has a much higher global warming potential (GWP) value than CO_2, from landfills or coalmines and reusing it to generate onsite electricity.

  Emissions sources are widely dispersed and in many sectors. They include fugitive methane emissions from landfills, wastewater treatment, and pipelines. In some cases, there is uncertainty regarding the ownership of the resource and the applicable environmental regulations.

- Infrastructure – Finally, CO_2 capture and sequestration may not occur in the same place. A transportation infrastructure needs to be developed to move the CO_2 from one geographic area to another. Also, state and federal regulations, background geologic information, education programs, and medium and long-term MM&V plans must be developed. All of these items comprise the infrastructure necessary to define the sequestration environment. Each regional sequestration partnership will assess the area within its territory to determine potential for both terrestrial and geologic sequestration, to identify priority sites for additional field validation tests, and to develop the research agenda for each site. In the Validation Phase (Phase II) of the partnerships initiative, specific areas will be selected for proof-of-concept-scale research. As part of this effort, each partnership will identify the potential regulatory and infrastructure requirements that a region would need should climate science dictate that sequestration be deployed on a wide scale in the future.

Carbon Sequestration Program Area Input Assumptions

Not all aspects of the Carbon Sequestration program area can be represented in NEMS. In fact, the only part of the Carbon Sequestration R&D program area that is captured in the current analysis is the capture and sequestration of CO_2 from power generation plants.

Table 21 lists the modeling assumptions made for the Carbon Sequestration R&D program area to take the GPRA goals for R&D and translate them into commercial deployment.

Table 21. Carbon Sequestration Program Area Modeling Assumption

Carbon Sequestration Program Area
Benefit Analysis Assumptions

- Booz Allen Hamilton (BAH) report is used as the baseline for an IGCC without sequestration. Refer to Tables 13, 14, and 15 for specific values.
- The capital costs and efficiencies of a baseline IGCC plant without sequestration in the same given year is used to compare COE to determine the percent increase in COE for an identical plant with sequestration. Capital cost and plant efficiency of the sequestered plant are incrementally reduced until a targeted COE is reached. The BAH baseline used for comparison does provide some incremental improvement in conventional IGCC over time.
- Improvements in capital cost and efficiency for an IGCC with sequestration include not only the advances made by the sequestration R&D program, but also advancements gained in other Advanced Power Systems R&D such as advanced gasification, advanced turbines, and SECA fuel cells.
- Advanced gasification improvements include low-cost air separation, warm temperature gas cleaning, advanced gas membrane separation, and improved gasifier capacity, reliability, and carbon conversion. All technology developments achieved for IGCC will be adopted in the sequestered plant if technically feasible.
- Advanced turbine developments improve IGCC combined cycle efficiency by 2-3% points and reduce cost by 20-30% by 2010 and are deployed in the 2015+ plants. By 2015, R&D provides technologies that improve efficiency by 3-5% over baseline combined cycle efficiency and reduce NOx emissions to 2 ppm (@ 15% O_2). These technologies can be deployed in the 2020+ systems.
- Oxy-fuel turbine based IGCC systems provide an alternate pathway to >50% efficiency with CO_2 capture in the 2020 timeframe.
- $400/kW, hundred MW-class, SECA SOFCs that can run on syngas are available by 2015 and are deployed by 2023 in an IGFC plant
- The sequestration R&D program is expected to deliver technologies for demonstration as early as 2009. A total of 8 years is added to the GPRA R&D goal dates to determine online year (defined as the date that the plant with given performance is operating). This allows 4 years for the technology to be demonstrated at a larger scale and another 4 years construction time for the commercial-scale plant. Therefore, the ultimate goal of a 10% increase in COE over the baseline in 2012 is reflected in 2020 as the online year for NEMS input. The following online profile is assumed based on GPRA interim performance targets:

2013	25% increase in COE with sequestration compared to the baseline*
2014	23% increase in COE with sequestration compared to the baseline
2015	20% increase in COE with sequestration compared to the baseline
2016	19% increase in COE with sequestration compared to the baseline
2017	17% increase in COE with sequestration compared to the baseline
2018	15% increase in COE with sequestration compared to the baseline
2019	13% increase in COE with sequestration compared to the baseline
2020	10% increase in COE with sequestration compared to the baseline

- Costs include capture and sequestration assuming plants are built close to CO_2 sinks and therefore transport costs are minimal.

*The baseline used for determination of the cost penalty is an IGCC based on conventional technology.

4. Advanced Turbines (Natural Gas) Program Area

In addition to the contributions by the Advanced Syngas and Hydrogen Turbines technologies towards the 2010 and 2015 goals of the Advanced Power Systems program area, natural gas turbine power systems R&D is expected to generate additional benefits as the knowledge gained through development of coal-based R&D migrate or "spin-off" into other areas. In this section, the Advanced Power Systems (Natural Gas) program area is evaluated to determine areas in which new technologies developed for coal-based systems may improve gas-fired combined cycle turbines as well. These technological advances include:

- new barrier coatings and advanced materials to accommodate higher firing temperatures,
- improved cooling techniques to improve performance,
- advanced combustors that eliminate SCR and other penalties associated with NO_x control,
- durable catalysts for catalytic combustion,
- increased rotor torque limitation to increase power output, and
- enhanced aerodynamics for higher throughput and specific power.

Although turbines for gas-fired combined cycle power generation are considered a mature technology, it is anticipated that the technological advances listed above that are being pursued in the coal-based program will also provide an opportunity to improve the gas-based turbine systems. Any benefits resulting from application of these advanced technologies in gas-fired turbine combined cycles can be attributed to the FE R&D portfolio. Modeling assumptions for natural gas combined cycle (NGCC) Advanced Turbines are described in Table 22.

Table 22. Advanced Turbines NGCC Modeling Assumptions

Advanced NGCC
Benefit Analysis Assumptions for Advanced Power Systems (Natural Gas) Program Area

- Booz Allen Hamilton (BAH) report is used as the baseline for NGCC. Refer to Tables 1, 2, and 3 for specific values.
- Improvements in efficiency over the baseline for an NGCC are assumed to result from R&D migrating from the coal-based turbine program.
- No cost improvement over the baseline NGCC is assumed. Advanced turbine developments improve combined cycle efficiency to 60% HHV [or 66% LHV] and reduce NOx emissions to 2 ppm (@ 15% O_2) by 2010 and are deployed in 2015 plants.

5. Fuel Cells, Hybrids, and Distributed Generation Program Area

A major focus of Fuel Cells R&D is to increase the robustness of distributed generation and thereby lower vulnerability of the electricity grid by introducing prototypes of 3-10 kilowatt solid oxide fuel cell modules with 10-fold cost reduction to $400 per kilowatt (versus 2003 baseline of $4,500 per kilowatt), with 40-60 percent electrical efficiency. A longer-term goal is to adapt these modules to zero-emission coal systems. The integration of SOFC modules into advanced coal-based power plant concepts transcends the immediate distributed generation market for SECA modules and will move them into coal-, biomass-, or solid waste-fueled applications. However, in the nearer term, SOFCs can be used as components of central power sources or could be strategically located to provide utility grid support to offset transmission, distribution, and new generating capacity investments.

It is these immediate markets, including residential or commercial distributed generation applications (such as CHP uses), long-haul truck and recreational vehicle auxiliary power units, and corollary military applications that are the focus of this section. Most of these near-term applications will be fueled with natural gas, gasoline, or diesel fuel. Deploying these low-cost, highly efficient and clean power generators will provide benefits in the near term long before the coal-based systems are commercial.

SECA is evaluated to determine the benefits that would result from deployment of SOFC modules in near term applications such as:

- Utility-scale fuel cells (10-20 MW),
- Utility distributed generation (1-2 MW), and
- Residential and commercial distributed generation (kW-scale).

These applications are assumed to be fueled with natural gas. Auxiliary power units for the transportation sector are not modeled in NEMS.

Table 23 lists the modeling assumptions for natural gas based SECA distributed generation. SECA fuel cells represent advanced, novel concepts that would replace current fuel cell technology; therefore, cost and performance goals are represented by a step change. Without government funding and facilitation of dialogue among the variety of organizations participating in this effort, it is assumed that it would take industry much longer to develop this technology, if it would be developed at all.

Table 20. Distributed Generation SECA Modeling Assumptions

Natural Gas Based SECA
Benefit Analysis Assumptions for Fuel Cells Program Area

- Natural gas-fueled markets under consideration include: Utility scale fuel cells (10-20 MW), Utility distributed generation (1-2 MW), residential and commercial distributed generation (kW-scale). All are assumed to be fueled with natural gas. Auxiliary power units for the transportation sector are not modeled in NEMS. Improvements in efficiency over the baseline for these fuel cell applications are assumed to result from early phases of the R&D program.

- The AEO2006 reference case is used as the baseline for SECA. Initial costs assumed are representative of MCFC costs and are >$4000/kW for utility applications and > $800/kW for small scale DG. O&M costs and heat rates also based on AEO2006.

- The SECA program will accelerate manufacturing to deliver gas-based SECA fuel cells to market by 2012.

- R&D Phase Targets:
  - 2005, $800/kW, 44-51% LHV efficiency for central station DG and Hybrids respectively
  - 2008, $600/kW, 51-59% LHV efficiency for central station DG and Hybrids respectively
  - 2010, $400/kW, 55% LHV for SECA central DG stationary applications, and 65% LHV for Hybrids

- Variable O&M costs for utility SECA "with R&D" case = 5 mills/kWh (Surdoval), Fixed O&M are unchanged from AEO2006.

- The following online profile is assumed for utility-scale central power natural gas-based SECA (hybrids) based on GPRA interim performance targets:

2012	$800/kW,	46.5% efficiency HHV
2015	$600/kW,	53.2% efficiency HHV
2016	$500/kW,	56% efficiency HHV
2017	$400/kW,	59% efficiency HHV

- The following online profile is assumed for utility-scale distributed natural gas-based SECA based on GPRA interim performance targets:

2012	$800/kW,	40% efficiency HHV
2015	$600/kW,	45.4% efficiency HHV
2016	$500/kW,	47.6% efficiency HHV
2017	$400/kW,	50% efficiency HHV

- The same online capital cost profile for utility-scale DG is assumed for residential and commercial natural gas-based SECA in CHP mode.
  - Electrical efficiency is assumed to be 50% HHV for these applications.
  - Waste heat recovery is assumed to be 60% and 55% for residential and commercial CHP applications, respectively.

TRANSLATING PROGRAM OUTPUTS TO MARKET OUTCOMES

Outputs from FE's R&D Portfolio are determined as a result of the activities contained within the program areas and R&D pathways described in previous sections. By contrast, marketplace developments and activities are normally not controllable by FE R&D. Table 24 links the outputs of FE program area activities, such as mercury emissions controls, NOx emissions controls, and new fossil-fired power plant technologies with immediate, interim, and ultimate outcomes for energy sector markets. Outcomes for oil and natural gas R&D are contained in the FE Benefits Report.

Table 21. Linkage of Outputs with Outcomes

Outputs	Associated Immediate Outcomes†	Associated with Interim Outcomes‡	Associated Ultimate Outcomes
Hg Control for Existing Power Plants	50% cost reduction of Hg removal compared to ACI	70% removal efficiency in 2007 and 90%+ removal efficiency in 2010	Commercial deployment of cost reduction and efficiency removal by 2015
NOx Control for Existing Power Plants	25% cost reduction ($/ton) of NOx removal compared to SCR	Removal efficiency of <15lb/MMBtu in 2007; 0.1lb/MMBtu in 2010; and 0.01lb/MMBtu in 2020	Commercial deployment of cost reduction and efficiency removal by 2025
Advanced Coal-Fired Power Plants	Capital cost reductions to compete with commercial coal-fired power systems and efficiency improvements	50% HHV efficiency and $1000/kW ($2002) in 2010; 60% HHV efficiency in 2015	Commercial deployment of cost reductions and efficiency improvements by 2023
Advanced Natural Gas-Fired Power Plants	Efficiency improvements over current NGCC power systems	60% HHV efficiency, 2ppm NOx in 2010	Commercial deployment of efficiency improvements by 2015
Carbon Sequestration to Reduce CO_2 Emissions	Reductions in energy penalty for power systems with sequestration	Reduce COE energy penalty to 10% increase compared to baseline IGCC without sequestration by 2010	Commercial deployment of power systems with sequestration and 10% COE energy penalty by 2020
Fuel Cells Development	Capital cost reductions and efficiency improvements	By 2012 • **Utility Hybrids** – 59% HHV efficiency, $400/kW • **Utility DG** – 50% HHV efficiency, $400/kW • **Building DG** – 50% HHV efficiency, $400/kW	Commercial deployment of capital costs reductions and efficiency improvements by 2017

†NEMS input is based on research and systems analysis studies.

‡NEMS algorithms were used without changes. Regulatory initiatives for emissions controls impact the integrated model. Also, EPACT 2005 reduced initial capital investments for IGCC and PC plants up to a specified GW limit.

Key Factors in Shaping Market Adoption of FE Technologies

Capital, O&M, and plant construction costs, of FE technologies are key price factors in shaping market adoption. Figures 7 and 8 illustrate the levelized costs of various FE technologies, with and without FE R&D. The graphs include nuclear and sample renewable technology curves for comparison. The A Case curves represent technology costs without FE R&D and the B curves represent the technology costs with FE R&D. The difference between the A and B curves for each technology represent the effects FE R&D has on the levelized costs for developing these technologies. For FE technologies, the curves indicate lower levelized costs with the R&D, which would in turn accelerate market adoption of these technologies.

Other key factors in shaping market adoption include consumer preferences/values, manufacturing factors, and policy factors. The utility sector, for example, tends to be risk adverse and reluctant to adopt more complex power generation technologies such as IGCC. In addition, the uncertainty surrounding CO_2 regulations adds to the utility sector's reluctance to make large investment decisions on advanced power generation technologies. To account for these anxieties, cost contingencies are incorporated into scenarios developed for the benefits analysis.

Fuel cell R&D offers an example of how a program area accounts for manufacturing factors. The Coal-Based SECA Fuel Cells Technology section in the Program Outputs section discusses a "Mass Customization" approach to SECA fuel cell market entry as a critical R&D pathway to obtaining the aggressive reductions in SECA fuel cell capital costs. As noted in this section, high volume production is needed to bring costs down but initial costs are too high sell a large number of units. SECA fuel cells manage this manufacturing dilemma by adopting a mass customization approach whereby most of the technology components will be mass produced but require little special packaging for application-specific units.

Finally, EPACT 2005 is the most influential policy factor effecting scenario development, benefits analyses, and market adoption. EPACT contains tax credits, for PCs and IGCC for example, which will reduce capital costs and accelerate market adoptions. In addition, future emissions regulations including possible CO_2 constraints will effect market adoption, all of which are taken into consideration by the NEMS code developed by EIA for each of the benefits analysis scenarios.

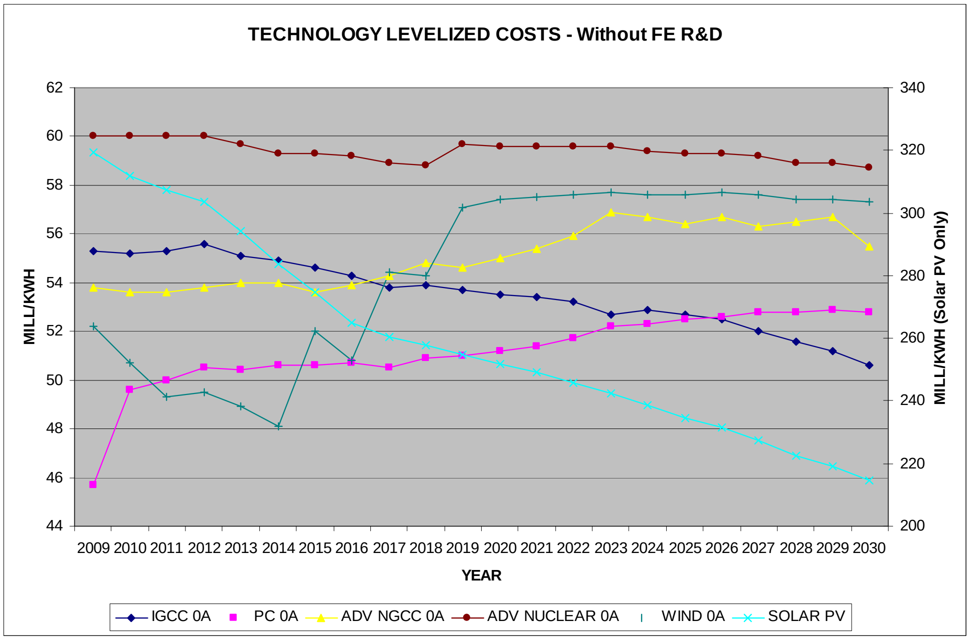

Figure 7. Levelized Costs Without FE R&D

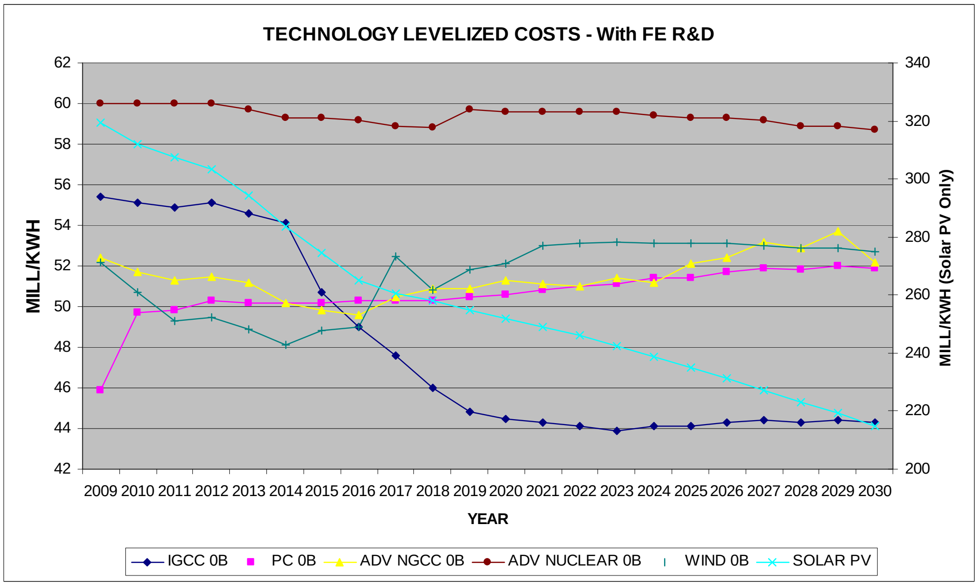

Figure 8. Levelized Costs With FE R&D

Immediate Outcomes

The success of FE's R&D portfolio hinges on the benefits to taxpayers from investments in FE programs and corresponding technologies with the ultimate goal of ensuring the highest value for the R&D. Two critical factors in calculating credible benefits and ensuring this ultimate goal is to set realistic goals and/or targets for FE programs, program areas, and technologies and choosing the appropriate R&D pathways to achieve these goals and targets. In developing program goals and pathways, FE relies on systems analysis research grounded in credible sources to set realistic goals and appropriate R&D pathways. Table 25 provides a sampling of reference documents used by FE to justify GPRA goals, baseline assessments, market analysis, performance targets for technologies, etc.

Table 22. Sampling of Systems Studies Supporting FE R&D Goals/Targets

Gasification

- 2006 Cost and performance Comparison of Fossil Energy Power Plants DOE/NETL-401/053106. Volume 1: Bituminous Coal and Natural Gas to Electricity. Draft Final Report May, 2006
- Systems Study for Improving Gas Turbine Performance for Coal/IGCC Application, Final Report to U.S. DOE, GE Energy, Cooperative Agreement DE-FC26-03NT41889, September 2005.
- Derek Aldred and Timothy Saunders, Development Program for Continuous Metered Injection of Coal into Gasification and PFBC System Operating Pressures, Presented at the EPRI Coal Fleet Conference, 2005.
- Jerry Schlather, Eastman Chemical and Brian Turk, Research Triangle Institute, Field Testing of a Warm Gas Desulfurization Process Using a Pilot Scale Transport Reactor System with Coal Based Syngas, to be presented at the 23rd Annual International Pittsburgh Coal Conference, September, 2006.
- Phil Armstrong, Ted Foster, Doug Bennett, and VanEric Stein, ITM Technology: Scaling up a low Cost Oxygen Supply Technology, Presented at the Gasification Technologies Conference, October 1-4, 2006.
- B. Baird, H. Karim, S. Etemad, S. Alavandi, W.C. Pfefferle, K.O. Smith and W. Nazeer, "Catalytic Combustion for Ultra-Low NOx Hydrogen Turbines", 23rd Annual International Pittsburgh Coal Conference, September, 2006.
- David Gray, Salvatore Salerno, and Glen Tomlinson, Current and Future IGCC Technologies: Bituminous Coal to Power, Mitretek Technical Report MTR-2004-05, and August, 2004.

Sequestration

- "Fuel Cell Energy Direct Fuel Cell for CO_2 Capture in Pulverized Coal Plant Applications," DOE/NETL-401/072706, July 27, 2006 (For NETL internal distribution only pending management approval)
- "Cost Goals for Carbon Sequestration R&D," DOE/NETL

- “Carbon Sequestration Systems Analysis”, presentation to the NRC Sequestration Panel, NETL, September 29, 2005

Turbines

- “Baseline Simple and Combined Cycle Turbine Performance in IGCC Applications,” DOE/NETL-402/021506, Draft Report May 2006 (For NETL internal distribution only pending management approval)
- “Advanced Power Plant Development and Analyses Methodologies: Semi-Annual Report,” DE-FC26-00NT40845, February 6, 2006(For NETL internal distribution only pending management approval)

Fuel Cells

- Thijssen, J., “Cost of SOFC Stacks and Systems”, Report Number R102-06-01D, Contract Number DE-AC26-04NT41817.313.01.05.036, 2006.
- Delphi Automotive Corporation, “Delphi Phase 1 Demonstration System A Test Report Revision 1”, August 16, 2006, Cooperative Agreement Number DE-FC26-02NT41246. (EPAct-protected report)
- FuelCell Energy, “SECA Phase I Prototype Comprehensive Test Report,” Document # ST-TR-06-001, September 6, 2006, Cooperative Agreement Number DE-FC26-04NT41837. (EPAct-protected report)
- General Electric, “Phase I Prototype System Final Test Report, Solid State Energy Conversion Alliance (SECA) Solid Oxide Fuel Cell Program”, November 2005, Cooperative Agreement Number DE-FC26-01NT41245. (EPAct-protected report)
- Pacific Northwest National Laboratory, “Quarterly Progress Report for SECA Core Technology Program, FY06 Third Quarter: April-June, 2006", July 2006, Field Work Proposal FWP40552.

IEP

- “Thermoelectric Freshwater Reductions Achievable With Advanced Water Technologies” -Draft- DOE/NETL-40403.01.05, July 2006 (For NETL internal distribution only pending management approval)
- “Estimating Freshwater Needs to Meet Future Thermoelectric Generation Requirements” DOE/NETL-2006/1235, August 2006
- “DOE/NETL’s Phase II Mercury Control Technology Field Testing Program: Preliminary Economic Analysis of Activated Carbon Injection” January 2006 Draft #4 – 1/18/2006

FutureGen

- “FutureGen: Candidate Advanced Technologies – Coal Conversion Plant” DOE/NETL-401/030306, Draft Revision 3– April 11, 2006, (For NETL internal distribution only

pending management approval)

- “Advanced C-Sequestration IGCC Plant: A Next-Step FutureGen Plant Concept” DOE/NETL 401/061506. June 15, 2006, (For NETL internal distribution only pending management approval)
- “Hydrogen Separation Membrane Technologies Technical and Economic Assessment” March 31, 2006, (For NETL internal distribution only pending management approval)

Figure 9 illustrates the planning and analysis process FE uses to develop its R&D. The figure depicts some of the critical questions that systems analysis research attempts to answer in developing program goals and pathways. In addition, systems analysis research assists in quantifying targets for R&D projects (what must the new concept beat?), identifying technology merit (does the concept show potential to improve system performance?), and assessing portfolio options (where should R&D best focus?).

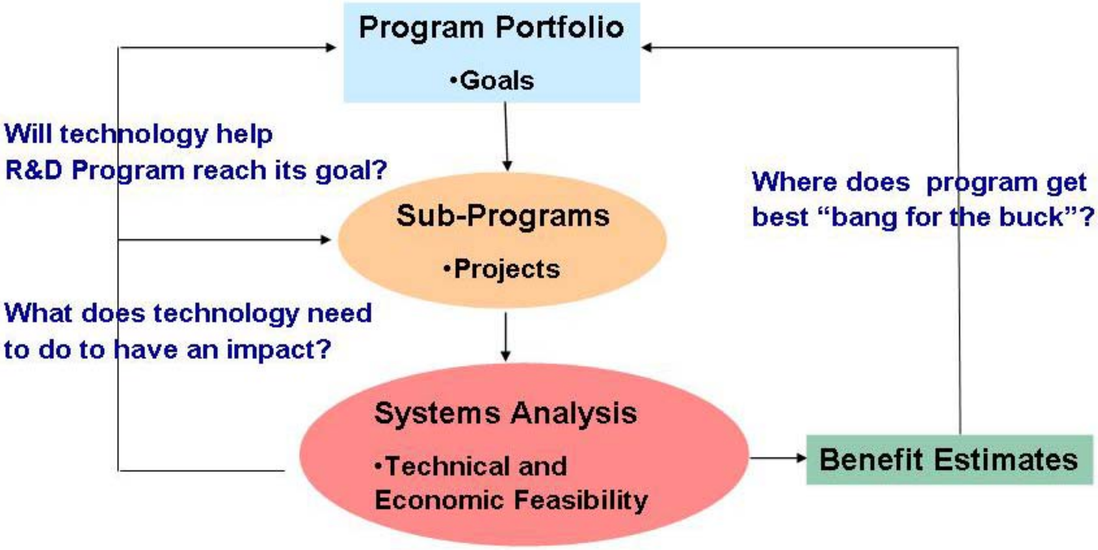

Figure 9. Planning and Analysis Process

This planning and analysis process for FE program goals also is an important element in the benefits analysis and the research into scenario development. Figure 10 illustrates how FE systems analysis forms an integral component of the FE R&D annual benefit analysis.

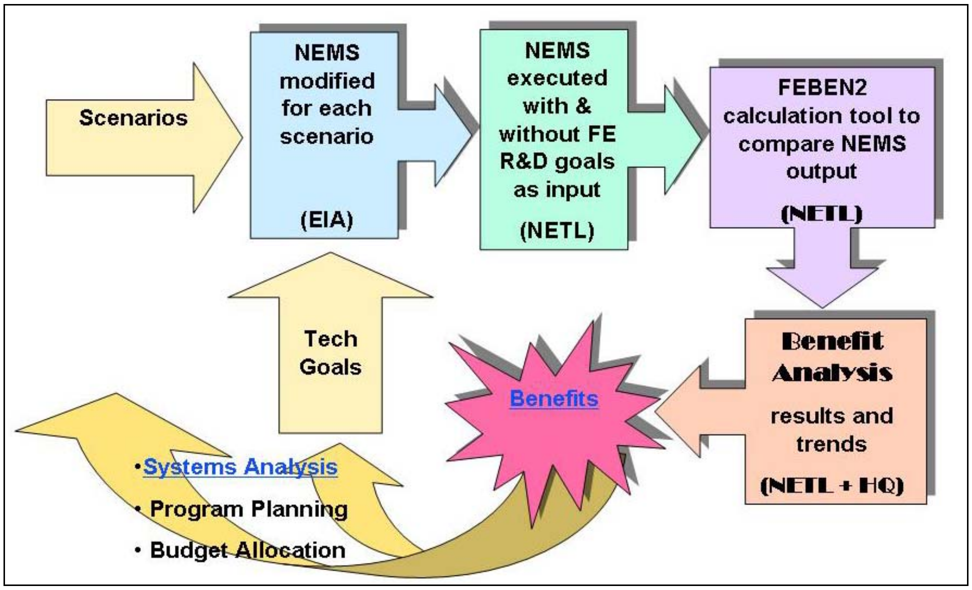

Figure 10. FE R&D Annual Benefit Analysis Process

Interim Outcomes

In predicting market penetration and deployment of technologies, FE benefits analyses do not make any assumptions; NEMS is used only to project the size of market penetration of FE technologies and price of energy commodities, such as electricity. The Program Outputs section provides market penetration and commercialization goals and targets for all of the program areas for which benefits are calculated. These goals/targets are repeated here for clarity.

The IEP program area is developing technologies to reduce (1) mercury emissions by 50-70 percent at 75 percent of the 2003 reference removal cost of $50,000-$70,000/lb of mercury and (2) NOx emissions to less than 0.15lb/MMBtu at three-quarters of the cost of SCR (i.e. $80-$100/kW). The technologies to meet these goals/targets are expected to be ready for commercial demonstration by 2007. In addition, IEP will advance commercial demonstration of mercury emissions reduction technologies to achieve 90 percent or greater control at 75 percent of the 2003 reference removal cost by 2010.

The Advanced Power Systems (Coal) program area has two time horizons, 2010 and 2015 for its goals/targets. By 2010, this program area will complete R&D for advanced gasification combined cycle technology, which will produce electricity from coal at 45-50 percent efficiency (HHV) at a capital cost of $1,000 per kilowatt ($2002) or less. By 2015, the program area will demonstrate future integrated coal-based energy plants that offer zero emissions (including CO_2 capture and sequestration) and multiple products, including electricity and hydrogen.

The goals/targets for the Advanced Power Systems (Natural Gas) program area are tied to coal-based R&D. Natural gas turbine power systems R&D is expected to generate additional benefits as the knowledge gained through development of coal-based R&D migrate or "spin-off" into other areas. The Advanced Power Systems (natural gas) program area is evaluated to determine areas in which new technologies developed for coal-based systems may improve gas-fired combined cycle turbines. It is anticipated that the technological advances being pursued in the coal-based program area will provide opportunities to improve natural gas-based turbine systems.

The Carbon Sequestration program area is divided into Core R&D and Infrastructure Development. The Core R&D is the technology development segment of the program area and is sub-divided into five areas: (1) CO_2 Capture, (2) Sequestration/Storage, (3) Monitoring, Mitigation, & Verification (MM&V), (4) Breakthrough Concepts, and (5) Non-CO_2 Greenhouse Gas. Infrastructure development is occurring through two major demonstration initiatives, the Regional Carbon Sequestration Partnerships and FutureGen. Both the Core R&D and Infrastructure Development work in concert such that commercial deployment of carbon sequestration, including direct capture and geologic sequestration of CO_2, occurs by 2012 with less than a 10 percent increase in the cost of electricity.

CCPI and FutureGen are demonstration initiatives that are major factors in determining the projected commercial deployment dates of Power Systems Program technologies such as IGCC, NOx controls, CO_2 capture and storage, and fuel cells. CCPI is developing new coal technologies that can help utilities meet requirements to cut sulfur, nitrogen and mercury emissions from power plants by nearly 70 percent by the year 2018. FutureGen will be a coal-fueled prototype plant that will co-produce electricity and hydrogen while preventing air pollutants and greenhouse gases from being released into the atmosphere. Benefits for these two demonstration projects are not calculated specifically in NEMS. However, the benefits for CCPI and FutureGen are viewed as the sum of all of the Power Systems Program benefits as well as individual technologies that make-up the various Power Systems program areas.

The major goal of the Fuel Cells program area is to increase the robustness of distributed generation by introducing 3-10kW SOFC prototype modules and decrease the vulnerability of the electricity grid. To achieve the goal, the program area sets a 10-fold target cost reduction to $400/kW (versus a 2003 baseline of $4,500/kW) with 40-60 percent electrical efficiency.

Final Outcomes (Benefits)

All benefits calculated for FE for the period of 2005 – 2030 are based on a comparison of NEMS results to compare Cases A and B for all scenarios. No other integrated energy market model(s) is used to determine benefits in the 2005 – 2030 timeframe. Currently, NEMS does not model coal to hydrogen so benefits in this program area were not calculated in this exercise. In addition, several technologies within the IEP, Carbon Sequestration, and Fuel Cells program areas are not modeled in NEMS for this FE benefits analysis. The specific areas not modeled in NEMS were described previously in this appendix.

Post-2030, the MARKAL model is used to extrapolate the benefits that accrue from after 2030, particularly those programs, such as Sequestration, that do not penetrate the market until close to the end of the NEMS timeframe. Very little has been done to this point to better represent the FE Program post-2030 in MARKAL. This is an area that will be addressed for the next round of benefit analyses.

SUMMARY OF INPUTS

The following tables provide a summary of NEMS input data developed for the IEP, Advanced Power Systems (Coal), Advanced Power Systems (Natural Gas), Carbon Sequestration, and Fuel Cells program areas. The data represent immediate outcomes which in the FE benefits analyses are referred to as “NEMS input.”

Table 23. NOx Control NEMS Input

Online Year	Removal Efficiency	Cost
2012	70%	50% of ACI
2015	90%	50% of ACI

Table 27. Hg Control NEMS Input

NOx Control Goals	With FE R&D*	Without FE R&D	
	Total/Avg.	**SNCR**	**SCR**
Online Year 2009	**Weight-Avg Advanced NOx**		
NOx reduction, %	64%	40%	90%
Minimum NOx rate, lb/MMBtu	0.12	0.20	0.05
Controlled NOx rate, lb/MMBtu	0.15		
Capital cost, $/kW	25	19	115
Fixed O&M, $/kW-yr	0.34	0.30	0.62
Variable O&M, mill/kWh	0.13	0.97	0.64
Online Year 2015	**Weight-Avg Advanced NOx**		
NOx reduction, %	76%	40%	90%
Minimum NOx rate, lb/MMBtu	0.08	0.20	0.05
Controlled NOx rate, lb/MMBtu	0.10		
Capital cost, $/kW	44	19	115
Fixed O&M, $/kW-yr	0.63	0.30	0.62
Variable O&M, mill/kWh	1.09	0.97	0.64
Online Year 2025	**Weight-Avg Advanced NOx**		
NOx reduction, %	98%	40%	90%
Minimum NOx rate, lb/MMBtu	0.01	0.20	0.05
Controlled NOx rate, lb/MMBtu	0.01		
Capital cost, $/kW	87	19	115
Fixed O&M, $/kW-yr	0.46	0.30	0.62
Variable O&M, mill/kWh	0.47	0.97	0.64

*The cost reduction is to be applied to the low-NOx burner technology option within NEMS so that it can be allowed to compete against SCR.

Assumptions:

1. Boiler type 2003 baseline emission rates per EPA emissions database.
2. Boiler type capacity per UDI database.
3. NOx reduction % calculated from 2003 baseline rate.
4. Minimum NOx rate equal to 80% of controlled NOx rate.
5. Controlled NOx rate per IEP goals statement.
6. All costs in 2004$
7. Costs for SNCR & SCR per EPA IPM assumptions.
8. Costs for 2007 per IEP advanced NOx combustion control estimates.
9. Costs for 2010 technologies based on costs being no greater than 2007 technologies coupled with SNCR.
10. 2020 technologies based on advanced ULNB and advanced low temperature SCR combination. Cost based on 75% of conventional SCR cost estimates.
11. Weight-average cost and performance calculated for a generic "Advanced NOx Control" technology for NEMS.
12. 2007 technologies will be online in 2009
13. 2010 technologies will be online in 2015
14. 2020 technologies will be online in 2025

Table 28. NEMS Input for Advanced Power Systems (Coal)

Advanced Power Systems NEMS Inputs 2006
(IGCC, Advanced Turbines, Coal-Based SECA Fuel Cells)

Assumptions

- R&D Goals:
  - 2010, 45-50% HHV and $1000/kW in 2002 dollars for IGCC ($1050/kW in 2004 dollars)
  - 2015, 60% HHV for zero emission IGFC plant without sequestration
- Online years:
  - 2010 goal: 8 years until online (4 years for demo, plus 4 years for construction of first commercial plant)
  - 2015 goal: 8 years until online (4 for demo, plus 4 for construction of first commercial plant)
- Baseline capital cost, O&M costs, and heat rates based on BAH study
- With FE R&D O&M costs based on BAH study for advanced technology case (with R&D)
- Capital costs include project contingency
- Typical unit size assumed to be 550 MW
- Interpolation used to smooth curve between baseline and FE R&D case when feasible (no step change)

Online Year	**Advanced Power Systems (NEMS Category = IG)**			
	Capital Cost $/kW ($2004)		**Heat Rate Btu/kWh**	
	Without FE R&D	**With FE R&D**	**Without FE R&D**	**With FE R&D**
2005	1543	1543	8427	8427
2006	1526	1526	8376	8376
2007	1510	1510	8324	8324
2008	1493	1493	8273	8273
2009	1477	1477	8222	8222
2010	1460	1460	8170	8170
2011	1444	1444	8119	8119
2012	1427	1427	8068	8068
2013	1411	1411	8016	8016
2014	1394	1394	7965	7965
2015	1378	1260	7914	7568
2016	1361	1207	7862	7185
2017	1345	1155	7811	7052
2018	1328	**1050**	7759	**6826**
2019	1311	1050	7708	6563
2020	1295	1050	7657	6320
2021	1278	1050	7605	6095
2022	1262	1050	7554	5884
2023	1245	1050	7503	**5688**
2024	1229	1050	7451	5688
2025	1212	1050	7400	5688
2026	1196	1050	7349	5688
2027	1179	1050	7297	5688
2028	1163	1050	7246	5688
2029	1146	1050	7195	5688
2030	1130	1050	7143	5688

Table 249. Carbon Sequestration Program Area NEMS Input Assumptions

Carbon Sequestration NEMS Inputs 2006
(IGCC with Carbon Capture and Sequestration)

Assumptions

- R&D Goals:
  - 2007, 20% increase in IGCC COE with sequestration added
  - 2012, 10% increase in IGCC COE with sequsetration added
- Online years:
  - 2007 goal: 8 years until online (4 years for demo, plus 4 years for construction of first commercial plant)
  - 2012 goal: 8 years until online (4 for demo, plus 4 for construction of first commercial plant)
- Baseline (without R&D) for capital cost, heat rates and O&M costs for "IGCC with Sequestration" is from BAH study
- To determine COE increase, IGCC w/ Sequestration w/ FE R&D is compared to IGCC w/o FE R&D in the same year
- With FE R&D O&M costs based on BAH study for advanced technology case (with R&D)
- Capital costs include project contingency
- Typical unit size assumed to be 380 MW
- Interpolation used to smooth curve between baseline and FE R&D case when feasible (no step change)

Online Year	Carbon Sequestration (NEMS Category = IS)			
	Capital Cost $/kW ($2004)		Heat Rate Btu/kWh	
	Without FE R&D	With FE R&D	Without FE R&D	With FE R&D
2005	2061	2061	9939	9939
2006	2041	2037	9867	9828
2007	2020	2013	9796	9716
2008	2000	1990	9724	9605
2009	1980	1966	9653	9494
2010	1960	1942	9581	9382
2011	1939	1918	9509	9271
2012	1919	1895	9438	9160
2013	1899	1871	9366	9048
2014	1878	1810	9295	8937
2015	1858	**1728**	9223	8826
2016	1838	1691	9151	8715
2017	1818	1633	9080	8603
2018	1797	1576	9008	8492
2019	1777	1520	8937	8381
2020	1757	**1443**	8865	**8269**
2021	1736	1427	8793	8214
2022	1716	1412	8722	8158
2023	1696	1396	8650	8103
2024	1676	1380	8579	8047
2025	1655	1365	8507	7992
2026	1635	1349	8435	7937
2027	1615	1333	8364	7881
2028	1595	1318	8292	7826
2029	1574	1302	8221	7770
2030	1554	1286	8149	7715

Table 30. Advanced Turbines NGCC NEMS Input

Advanced Turbines NEMS Inputs 2006
(Advanced Natural Gas Combined Cycles)

Assumptions

- R&D Goals:
  - 2010, 50% HHV efficiency for syngas combined cycles (IGCC). Assume coal-based improvements can be adopted in NGCC technology improving NGCC efficiency to 65% LHV (59% HHV) by 2015.
- Online years:
  - 2010 goal: 5 years until online in gas systems (2 years for demo, plus 3 years for construction of first commercial plant)
- Baseline (without R&D) capital cost, O&M costs, and heat rates based on BAH study
- O&M costs for "with R&D" case based on BAH study for advanced technology case
- Capital costs include project contingency
- Typical unit size assumed to be 400 MW
- Interpolation used to smooth curve between baseline and FE R&D case when feasible (no step change)
- NOx emissions are 2 ppm in "with R&D" case

Online Year	Advanced NGCC (NEMS Category = AC)			
	Capital Cost $/kW ($2004)		Heat Rate Btu/kWh	
	Without FE R&D	With FE R&D	Without FE R&D	With FE R&D
2005	612	612	6700	6700
2006	609	609	6680	6680
2007	606	606	6660	6581
2008	603	603	6640	6481
2009	601	601	6620	6382
2010	598	598	6600	6282
2011	595	595	6580	6183
2012	592	592	6560	6083
2013	590	590	6540	5984
2014	587	587	6520	5884
2015	584	584	6500	**5785**
2016	581	581	6480	5785
2017	578	578	6460	5785
2018	576	576	6440	5785
2019	573	573	6420	5785
2020	570	570	6400	5785
2021	567	567	6380	5785
2022	565	565	6360	5785
2023	562	562	6340	5785
2024	559	559	6320	5785
2025	556	556	6300	5785
2026	553	553	6280	5785
2027	551	551	6260	5785
2028	548	548	6240	5785
2029	545	545	6220	5785
2030	542	542	6200	5785

Table 251. Utility FC and Utility DG NEMS Inputs

SECA NEMS Inputs 2006
(Utility FC and Utility DG)

Assumptions

- R&D Phase Targets:
  - 2005, $800/kW, 44-51% LHV efficiency for central station DG and Hybrids respectively
  - 2008, $600/kW, 51-59% LHV efficiency for central station DG and Hybrids respectively
  - 2010, $400/kW, 55% LHV for SECA central DG stationary applications, and 65% LHV for Hybrids
- Online years:
  - For Utility DG, assume manufacturing accelerated to deliver SECA to market by 2012
  - For Utility FC, assume manufacturing accelerates hybrid development and delivery to market in 2012
- Baseline (without R&D) capital cost, O&M costs, and heat rates based on AEO2006
- Variable O&M costs for "with R&D" case = 5 mills/kWh (Surdoval), Fixed O&M are unchanged from AEO2006
- Capital costs include project contingency
- Typical unit size for DG is 1-2 MW and for FC is 10s of MW
- Linear interpolation used between phase years

Online Year	Utility FC (NEMS Category = FC)				Utility DG (NEMS Category = DG)			
	Capital Cost $/kW ($2004)		Heat Rate (Btu/kWh)		Capital Cost $/kW ($2004)		Heat Rate (Btu/kWh)	
	Without R&D	With R&D	Without R&D	With R&D	Without R&D	With R&D	Without R&D	With R&D
2005	4374	4811	7930	7930	831	831	9650	9650
2006	4374	4811	7930	7930	831	831	9650	9650
2007	4330	4763	7873	7873	827	827	9500	9500
2008	4287	4715	7816	7816	823	823	9340	9340
2009	4243	4667	7759	7759	819	819	9200	9200
2010	4199	4619	7702	7702	814	814	9050	9050
2011	4155	4571	7645	7645	810	810	8900	8900
2012	4112	880	7588	7335	806	800	8900	8554
2013	4068	798	7531	7025	802	725	8900	8209
2014	4024	743	7474	6715	798	675	8900	7863
2015	3980	660	7417	6405	794	600	8900	7517
2016	3937	550	7359	6095	789	500	8900	7172
2017	3893	**400**	7302	**5785**	785	**400**	8900	**6826**
2018	3849	400	7245	5785	781	400	8900	6826
2019	3805	400	7188	5785	777	400	8900	6826
2020	3762	400	7131	5785	773	400	8900	6826
2021	3718	400	7074	5785	769	400	8900	6826
2022	3674	400	7017	5785	764	400	8900	6826
2023	3630	400	6960	5785	760	400	8900	6826
2024	3587	400	6960	5785	756	400	8900	6826
2025	3543	400	6960	5785	752	400	8900	6826
2026	3499	400	6960	5785	748	400	8900	6826
2027	3456	400	6960	5785	744	400	8900	6826
2028	3412	400	6960	5785	740	400	8900	6826
2029	3368	400	6960	5785	735	400	8900	6826
2030	3324	400	6960	5785	731	400	8900	6826

Table 32. Residential DG NEMS Input

Residential Sector SECA DG (kW scale)				
Online Year	Electrical Efficiency (HHV)	Overall Efficiency (HHV)	Capital Cost $/kW ($2004)	Annual Maint.Cost ($/kW, $2004)
2005	0.300	0.787	AEO2006	AEO2006
2006	0.304	0.789	AEO2006	AEO2006
2007	0.308	0.790	AEO2006	AEO2006
2008	0.312	0.792	AEO2006	AEO2006
2009	0.316	0.793	AEO2006	AEO2006
2010	0.320	0.795	AEO2006	AEO2006
2011	0.323	0.797	AEO2006	AEO2006
2012	0.399	0.760	800	AEO2006
1013	0.416	0.766	725	AEO2006
2014	0.434	0.774	675	AEO2006
2015	0.454	0.782	600	AEO2006
2016	0.476	0.790	500	AEO2006
2017	**0.500**	0.800	**400**	37.5
2018	0.500	0.800	400	37.5
2019	0.500	0.800	400	37.5
2020	0.500	0.800	400	37.5
2021	0.500	0.800	400	37.5
2022	0.500	0.800	400	37.5
2023	0.500	0.800	400	37.5
2024	0.500	0.800	400	37.5
2025	0.500	0.800	400	37.5
2026	0.500	0.800	400	37.5
2027	0.500	0.800	400	37.5
2028	0.500	0.800	400	37.5
2029	0.500	0.800	400	37.5
2030	0.500	0.800	400	37.5

Table 33. Commercial DG NEMS Inputs

Commercial Sector SECA DG (kW scale)				
Online Year	Electrical Efficiency (HHV)	Overall Efficiency (HHV)	Capital Cost $/kW ($2004)	Annual Maint.Cost ($/kW, $2004)
2005	0.300	0.787	AEO2006	AEO2006
2006	0.304	0.789	AEO2006	AEO2006
2007	0.308	0.790	AEO2006	AEO2006
2008	0.312	0.792	AEO2006	AEO2006
2009	0.316	0.793	AEO2006	AEO2006
2010	0.320	0.795	AEO2006	AEO2006
2011	0.323	0.797	AEO2006	AEO2006
2012	0.399	0.729	800	AEO2006
1013	0.416	0.737	725	AEO2006
2014	0.434	0.745	675	AEO2006
2015	0.454	0.754	600	AEO2006
2016	0.476	0.764	500	AEO2006
2017	**0.500**	0.775	**400**	37.5
2018	0.500	0.775	400	37.5
2019	0.500	0.775	400	37.5
2020	0.500	0.775	400	37.5
2021	0.500	0.775	400	37.5
2022	0.500	0.775	400	37.5
2023	0.500	0.775	400	37.5
2024	0.500	0.775	400	37.5
2025	0.500	0.775	400	37.5
2026	0.500	0.775	400	37.5
2027	0.500	0.775	400	37.5
2028	0.500	0.775	400	37.5
2029	0.500	0.775	400	37.5
2030	0.500	0.775	400	37.5

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