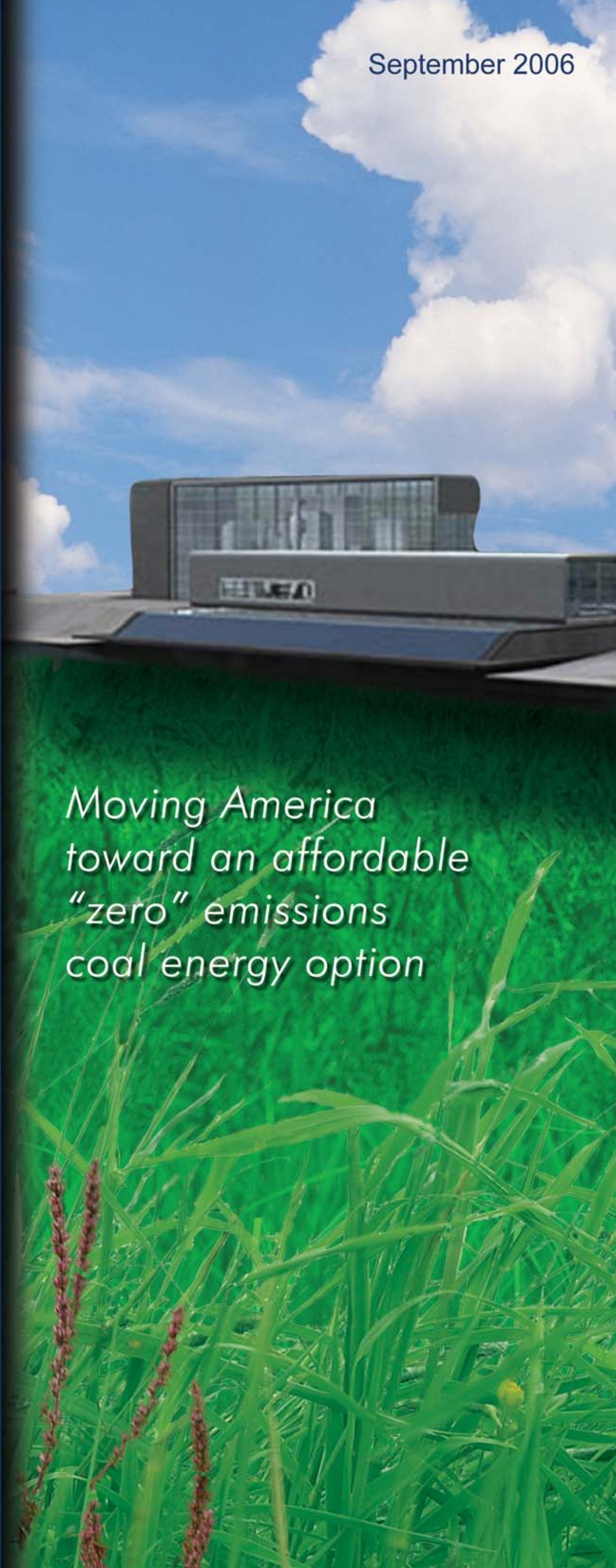
September 2006

Office of Clean Coal

Strategic Plan



Moving America toward an affordable "zero" emissions coal energy option

Office of the Assistant Secretary for Fossil Energy
U.S. Department of Energy

A History of Innovation...

1943

West Virginia Congressman (later Senator) Jennings Randolph flies from Morgantown, WV to Washington, DC in a coal-based synthetic fuel-powered airplane to call attention to the potential for coal to play an expanded role in the Nation's energy future.

1944

Congress passes the Synthetic Liquid Fuels Act authorizing $30 million to construct one or more synthetic fuel demonstration plants. The Act begins the first concentrated effort to study future ways to use America's abundant coal supplies.

1949

The U.S. Bureau of Mines converts a wartime synthetic ammonia plant at Louisiana, MO, into the Nation's first coal-to-liquids demonstration plant. It produces 200 barrels of synthetic oil per day.

1960

With coal research lagging in the late 1950s, West Virginia Senator Robert C. Byrd ushers legislation through Congress to create a new Office of Coal Research in the U.S. Department of the Interior and rejuvenate interest in coal. The Office will eventually become the core of the Fossil Energy organization when the Department of Energy is created.

1967

The engineering firm of Pope, Evans and Robbins installs a single-cell boiler at Alexandria, VA, that employs a new "fluidized bed" method for burning coal. Although originally designed primarily as a more efficient way of burning coal, the test facility also shows promise for reducing air pollutants inside the boiler. It becomes the predecessor of a new generation of environmentally clean, coal-fired boilers.

1971

With the first signs of a possible shortage of natural gas appearing, the federal government, the American Gas Association, and the Institute of Gas Technology start up the HYGAS coal-to-synthetic gas plant outside Chicago. The 75-ton per day facility is one of the Nation's first large-scale pilot plants for testing new ways to convert coal into a substitute for natural gas.

1973

The government begins studying ways to convert coal to a lower-Btu gas that could be burned onsite to generate electric power (earlier efforts had focused on producing a higher-quality substitute natural gas that could be shipped long distances in gas pipelines). This research ultimately evolves into the "integrated gasification combined-cycle" technology that would be the basis of several Clean Coal Technology projects in the 1990s.

1975

The Office of Coal Research and the Bureau of Mine's synthetic fuel programs are transferred to the new Energy Research and Development Administration, created to expand energy research in the aftermath of the 1973-74 oil embargo.

The governments of the United States, West Germany and the United Kingdom sign documents creating the Grimethorpe project in England. Grimethorpe would test a pressurized version of fluidized bed technology, enabling a clean coal combustor to be linked to a high-efficiency gas turbine to generate power.

1977

The U.S. Department of Energy is created, absorbing the Energy Research and Development Administration and other federal energy-related offices.

1940s 1950s 1960s 1970s

Continued on Inside Back Cover

Table of Contents

Our Vision:

An energy-secure America that can tap the full potential of all its energy resources, including coal.

Our Mission:

Ensure the availability of ultra-clean ("zero" emissions), abundant, low-cost domestic energy from coal (including hydrogen) to fuel economic prosperity, strengthen energy security, and enhance environmental quality.

Strategy

Imagine a future in which power from our most abundant and lowest cost energy resource is pollution-free. Imagine a future in which we no longer have concerns about the effects power and fuels production will have on the global climate of our children or their children. Imagine a future in which America's energy security is strengthened by replacing increasing amounts of imported oil with clean-burning, affordable fuels made from plentiful resources within our borders.

The Department of Energy's (DOE) Clean Coal Program is working to make this future possible. For the first time in the long history of fossil fuel use, we now see emerging from our laboratories and test sites the tools and technologies that can make the concept of a virtually zero-emission ("zero" emissions), coal-based energy plant a viable reality — not 50 or 100 years into the future — but within the coming decade.

The aim of "zero" emissions coal is to remove all the environmental concerns (including carbon emissions) over the use of coal. In many ways, coal is the true measure of America's energy strength. Coal is the most abundant U.S. energy resource, with domestic reserves roughly equal to the energy potential of world oil reserves.

How far have we come? Our march towards "zero" emissions started a long time ago. For most of the last 50 years, coal technology evolved primarily to retrofit older plants with better methods to meet environmental concerns. These efforts produced numerous successes: flue gas desulfurization units (scrubbers) were developed to meet concerns over sulfur emissions; low-nitrogen oxide (NO_x) burners and post-combustion catalytic devices helped power stations comply with nitrogen oxide emission standards; and particulate capture devices achieved an amazing 99.9 percent effectiveness in cleaning soot-causing particles from a power plant's exhaust gas. Over the last three decades, the Nation's air became measurably cleaner, largely because new technology made new environmental laws effective and affordable. The U.S. Environmental Protection Agency (EPA) estimates air pollution has declined more than 50 percent, while our economy grew almost 190 percent, and coal use in power plants increased nearly three-fold.

These technological innovations of the 1970s, 80s, and 90s met the demands of the time. But in the 21st century, demands have changed. Today there are new concerns over mercury emissions from coal and the release of microscopic particles so small that 30 would barely equal the width of a human hair. The buildup of carbon gases in the atmosphere is raising concerns about the long-term impact of fossil energy use on the Earth's climate.

At the same time, the Nation's need for energy continues to grow. Despite remarkable improvements in the efficiency of energy use, economic growth continues to depend on producing more and more energy — especially elec-

DOE's Energy Security Strategic Theme:

Promoting America's energy security through reliable, clean, and affordable energy.

Clean Coal Mission:

Ensure the availability of ultra-clean ("zero" emissions), abundant low-cost, domestic energy from coal (including hydrogen) to fuel economic prosperity, strengthen energy security, and enhance environmental quality.

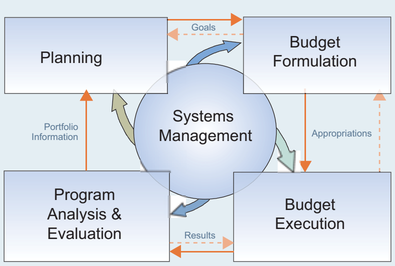
Approach:

Technology Development

- Allow for seamless integration of research, development and demonstration (RD&D) portfolio.

Systems Management

- Use a systems management approach to plan programs, formulate budgets, implement annual operating plans, and evaluate programs throughout the process.



tricity. Today, coal supplies about 50 percent of our Nation's electric power; without it, we could not sustain our current economy.

Years of research into the fundamental physics and chemistry of coal have produced important new insights into ways of removing pollutant-forming impurities. New engineering concepts have been developed to convert coal into versatile gases that can be cleaned to extraordinary levels, then used to generate power or produce fuels. Entirely new approaches to clean power generation, such as fuel cells, are now maturing. The relatively new technologies of carbon capture and sequestration are revealing how it may be possible to prevent greenhouse gases from entering the atmosphere.

Where are we going? The technological progress of recent years has created a remarkable new opportunity for coal. The building blocks for a new generation of coal-fueled energy plants are being created. The objective is to build on these advances and bring these building blocks together into a new, revolutionary concept for future coal-based power and energy production.

The strategic goals and programs described in the following pages are highly aggressive and are intended to lead to a new, affordable breed of coal plant — a "zero" emissions plant that would generate power and produce high-value fuels such as hydrogen with virtually no impact on the surrounding environment. This strategy looks to integrate the most environmentally effective and fuel efficient coal technologies into a new breed of energy plant designed from the very start to function at peak performance levels — and to eliminate, once and for all, concerns over the environmental impact of using America's plentiful, low-cost coal.

The Office of Clean Coal strategy forms the basis for the research needed to carry out the President's priorities and initiatives. The President's commitment to these initiatives and priorities leads us in the direction of ever cleaner coal usage to ensure our energy security with this domestically strategic and abundant, low-cost energy resource.

The fiscal year (FY) 2007 and subsequent year budgets are based on the need to effectively implement a clean coal research program that reflects the President's priorities and initiatives in coal. These include the President's initiatives in Clear Skies, Climate Change, Hydrogen, Clean Coal Power, and FutureGen — all of which form the foundation for the eventual deployment of affordable "zero" emission coal energy systems.

FutureGen is the ultimate manifestation of the research aimed at demonstrating the technical feasibility, economic viability, and broad acceptance of essentially "zero" emissions, coal-based energy. The President recently reiterated his expectations for FutureGen as he stated, "We've got research and development going to FutureGen plants so that we can burn coal in a "zero" emissions way.... That would not only be helpful to the United States, it would be helpful for the world." Further, the White House's Office of Management and Budget reinforced the Administration's commitment to FutureGen in its letter [of February 4, 2005] which stated, "We want to assure you that FutureGen is a top priority of the Administration... The President's 2006 budget requests funding for FutureGen consistent with its funding profile (as stated in the 2004 Report to Congress) including a commitment to FutureGen beyond 2006. In future budget submissions to the Congress, we intend to request sufficient funding to support FutureGen, as well as the other coal research and development programs at the Department of Energy upon which FutureGen depends."

In addition to developing a new integrated concept for a "zero" emission coal plant in the nearer term, the strategy also includes 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. Given the Nation's reliance on coal for the majority of its current electricity supply, innovative pollution control technologies that can be applied to existing power plants remain essential to assuring that our supplies of electricity remain reliable and affordable. Yet, at the same time, we are orienting much of this development toward multi-pollutant control "packages" that can also be applied to the power plants of the future.

A Strategy that Implements the President's Major Energy and Environmental Initiatives

By sustaining coal's role in the Nation's energy portfolio, we can maintain the supply diversity called for in the *National Energy Policy* to strengthen America's energy security.

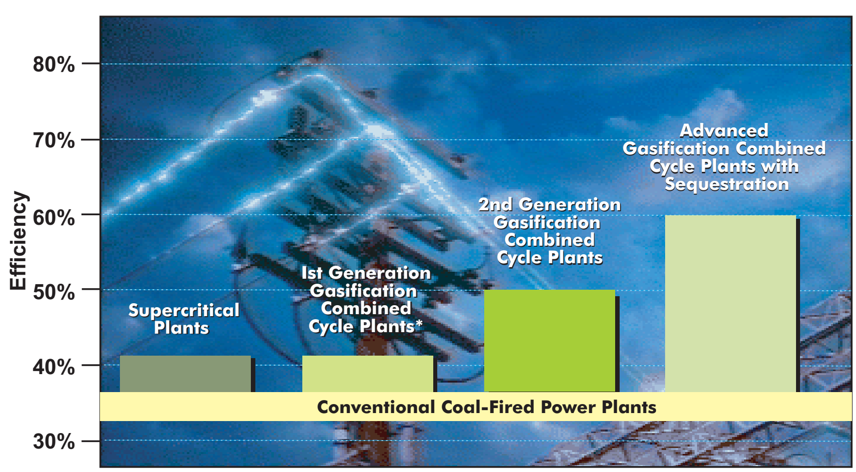
The Office of Clean Coal is working to develop "zero" emissions technologies such as fuel cells, coal gasification, and environmental controls to reduce power plant emissions of three of the most significant air pollutants — nitrogen oxides, sulfur dioxide, and mercury.

By developing cost-effective ways to produce hydrogen from coal, we can provide reliable supply sources to sustain progress toward the President's vision of a "hydrogen economy." The Office of Clean Coal will provide the coal-based gasification technologies to produce clean synthesis gas from which hydrogen can be separated. Advanced catalysts, reactors, and membrane separation units will also be developed to complete the hydrogen separation process.

By providing new options for controlling greenhouse gases, we can help the United States and other nations deal with the issue of global climate change without dampening economic growth. The Office of Clean Coal will develop the next generation of coal-based electric power systems that will nearly double fuel use efficiency compared to today's coal-fired plants. Increasing fuel use efficiency inherently reduces the amount of carbon gases released. Moreover, the power technologies being developed will be compatible with emerging carbon capture and sequestration technologies and the production of hydrogen for carbon-free power generation.

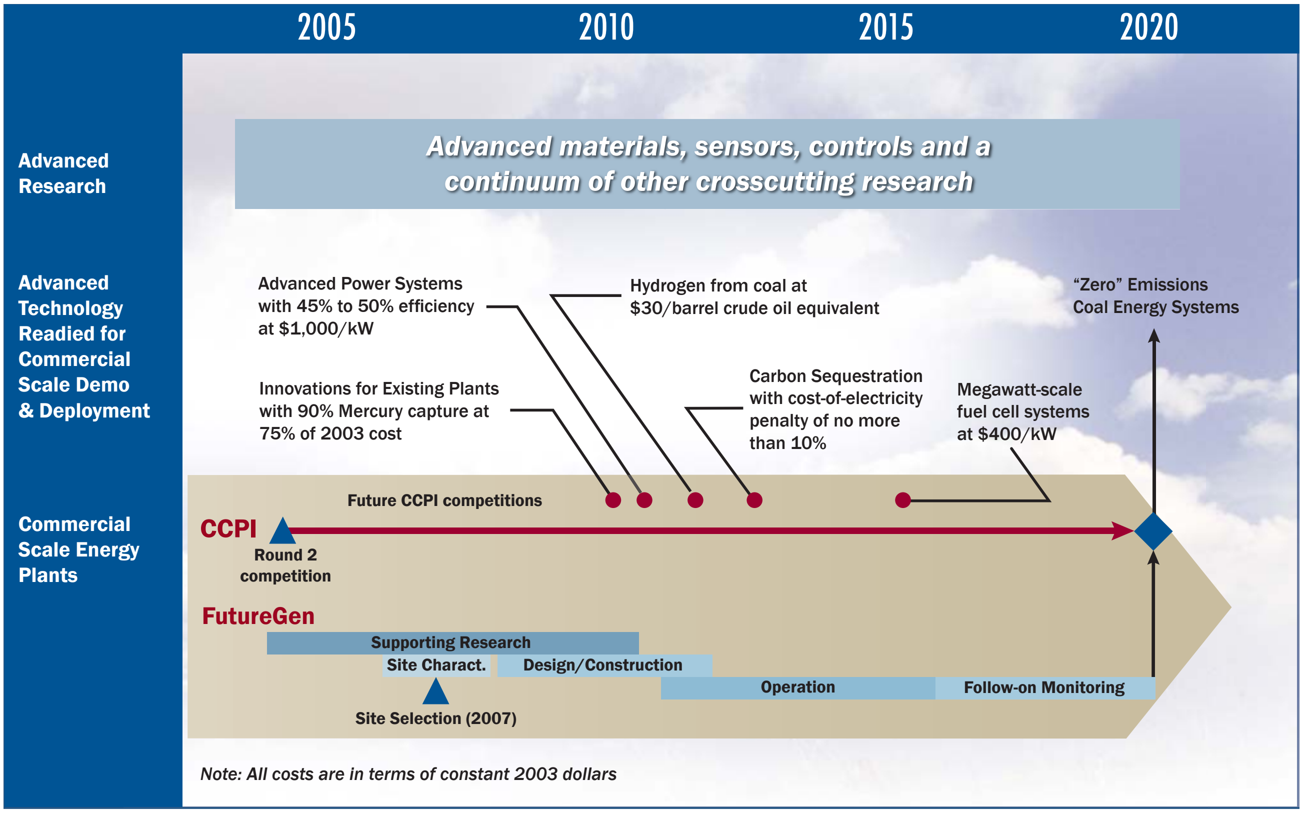
Our program strategy will result in a suite of technologies that, when incorporated into a single integrated system, will form a "new breed" of power plant. President Bush announced such a power plant in FutureGen. FutureGen will be the forerunner of futuristic power plants producing electricity and hydrogen while emitting virtually no airborne pollutants — essentially eliminating environmental concerns over the use of coal.

Figure 1: Efficiency Gains from Next Generation Coal-Based Electric Power Systems



* Demonstrated in original Clean Coal Technology Program

Increasing fuel use efficiency at the power plant can be just as economically and environmentally beneficial as boosting the energy efficiency of end-use applications.



The Fossil Energy 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. A broad portfolio of technologies are being developed within the Clean Coal Program to accomplish this objective. 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 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.

Implementation

To achieve its mission, the Clean Coal program is organized into eight technology programs and an international support program. Specific technological objectives and/or developmental timetables follow:

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.

> ***Objective 1:*** By the end of 2010, have technology ready that can reduce mercury emissions by 90 percent at 50 to 75 percent of today's cost; lower nitrogen oxide emissions to less than 0.15 pounds per million Btu at 75 percent of the cost of today's most effective NO_x control technologies (selective catalytic reduction); reduce fine particulate matter ($PM_{2.5}$) by 99.99 percent for less than $50 to $70 per kilowatt (kW); test technologies for advanced cooling; and increase the use of coal by-products by 66 percent.

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.

> ***Objective 2***: By 2010, develop advanced coal-based power systems capable of achieving 45–50 percent thermal efficiencies at a capital cost of $1,000 per kW or less.

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.

> ***Objective 3:*** By 2012, develop to the point of commercial readiness technologies for direct capture and geologic sequestration of carbon dioxide from fossil fuel conversion processes that result in less than 10 percent increase in the cost of electricity.

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.

> ***Objective 4:*** By 2010, develop modular and scalable 3kW to 10kW distributed generation fuel cell designs with ten-fold cost reduction to $400/kW and 40–60 percent lower heating value (LHV) efficiency (natural gas); by 2015, demonstrate MW-class, coal and carbon sequestration-ready fuel cell, or fuel cell/turbine hybrid

A Three-Pronged Strategy:

The Clean Coal Program strategy consists of three major components:

Component 1: Clean coal research and development (R&D) bringing to readiness all the key technologies — advanced clean-up systems; advanced gasification; turbines capable of burning coal-derived syngas; fuel cells; membrane technologies for gas separation; hydrogen-from-coal conversion processes; and carbon sequestration.

Component 2: The Clean Coal Power Initiative (CCPI) to serve as a "bridge" between R&D and commercial deployment for emerging power generating and environmental control systems.

Component 3: The FutureGen project, combining the most capable technologies emerging from R&D and the CCPI into a new type of power plant that integrates electricity and hydrogen production with carbon sequestration.

Each component is essential to the strategy's ultimate success.

systems with 50 percent higher heating value (HHV) efficiency and adaptable to natural gas with 75 percent LHV efficiency; by 2020, demonstrate 100 MW-class fuel cell or fuel cell/turbine hybrid system being fueled by coal-based gasification.

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.

Objective 5: By 2015, demonstrate integrated hydrogen and electric power production in coal-based, "zero" emission plant that verifies reduction in cost of hydrogen by 25 percent compared to current coal-based plants.

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 CCPI and FutureGen large scale projects share a common objective:

Objective 6: By 2020, demonstrate future integrated coal-based energy plants that offer "zero" emission, including CO_2 capture and sequestration, and multi-product production, including electricity and hydrogen.

Advanced Research – fundamental and applied research programs that are developing the technology base for 21st century power and fuels production and exploring new areas of coal science that could lead to revolutionary breakthroughs. This technology program supports the others and does not have a specific defined objective.

International Collaboration – this cross-cutting effort, designed to support the other technology programs, is intended to create global partnerships, share knowledge, and enhance international awareness of innovations emerging from the Clean Coal Program. This support program does not have a specific defined objective.

A Plan Reflecting Input From Energy Industry and Stakeholders

The success of the Clean Coal Program depends on industry participants moving new technologies that emerge from our development efforts across the commercial threshold. Our strategy and programs, therefore, must reflect a government-industry partnership with input from a broad cross-section of stakeholders.

This strategy is largely an outgrowth of "roadmapping" workshops held between DOE's Fossil Energy (FE) Program, its National Energy Technology Laboratory (NETL), and the coal and power industry, notably the Coal Utilization Research Council (CURC), Electric Power Research Institute (EPRI), and other stakeholders.

The strategy also draws from detailed technology roadmaps developed for specific technology areas in concert with academic and industry experts.

The strategy's framework and priorities are drawn from overarching policy documents such as the Energy Policy Act of 2005, Presidential Initiatives, the DOE Strategic Plan, the FE Strategic Plan, and Congressional appropriations. OCC's strategic goals are in direct alignment with the four strategic goals that comprise Energy Security Strategic Theme 1 contained in DOE's Strategic Plan published in 2006, namely:

Strategic Goal 1.1 – ***Energy Diversity***: Increase our energy options and reduce dependence on oil, thereby reducing vulnerability to disruption and increasing the flexibility of the market to meet U.S. needs.

Strategic Goal 1.2 – ***Environmental Impacts of Energy***: Improve the quality of the environment by reducing greenhouse gas emissions and environmental impacts to land, water, and air from energy production and use.

Strategic Goal 1.3 – ***Energy Infrastructure***: Create a more flexible, more reliable, and higher capacity U.S. energy infrastructure.

Strategic Goal 1.4 – ***Energy Productivity***: Cost-effectively improve the energy efficiency of the U.S. economy.

Defining the Federal Role

The role of the federal government in research is to develop technology options that can be deployed in response to either market failures or policy and regulatory requirements that would impact the energy goals and outcomes designed for the public good. In an era of fluctuating market conditions, especially in the energy sector, the private investment necessary for these new concepts to move out of the laboratory and through the research, development and demonstration (RD&D) process may be minimal or, in some cases, nonexistent.

Additionally, future regulation of CO_2 emissions remains uncertain. While some farsighted companies are exploring carbon capture and sequestration approaches on a relatively small scale, it is unclear whether major segments of the energy industry will invest in greenhouse gas mitigation technologies until there are assurances of financial returns or until regulations or incentives are imminent.

Yet, there is consensus throughout virtually all of the energy and environmental communities that America stands to benefit greatly from investments in new technologies that can improve our environment, reduce our dependence on unstable sources of imported oil, and mitigate greenhouse gas emissions.

Therefore, the Clean Coal Program strategy is based on a federal role that does not duplicate, or substitute for, private RD&D efforts. It is driven by the need for technology innovation to achieve the energy/environmental/economic goals resulting in the public good where market forces and policy/regulation are not sufficient.

It also ensures that innovation continues to thrive and that in an uncertain energy market, promising technologies that benefit all Americans continue their developmental progress.

Our strategy recognizes that public-private cost-sharing is essential to focusing federally supported research on those technologies most likely to be adopted by the energy industry, that cost-sharing leverages taxpayer dollars, and that progressively larger proportions of private-sector cost-sharing provide the best gauge of progress and technological maturity.

Public-private technology partnerships create a powerful force for innovation in America's economy. By using them when appropriate, the Clean Coal Program strategy will help ensure that tomorrow's energy needs continue to be met; that we continue to protect our sensitive air, water, and soil resources; and that America's economy remains the most advanced and productive in the world.

"The role of government is not to create wealth; the role of our government is to create an environment in which the entrepreneur can flourish, in which minds can expand, in which technologies can reach new frontiers."

President George W. Bush

Fossil Energy/Office of Clean Coal Objectives

Energy Diversity

- Clean gaseous fuels from coal (hydrogen)
- Liquid fuels from coal

Environmental Impacts of Energy

- "Zero" emission coal power
- Repowering the existing fleet
- Carbon management

Energy Infrastructure

- Improving the coal infrastructure
- Transportation and storage of coal-derived fuels

Energy Productivity

- Increased conversion efficiency

"...the committee found that the DOE's fossil energy program made a significant contribution over the last 22 years to the well-being of the United States through the development of fossil energy programs that led to realized economic benefits, options for the future, and significant knowledge.... These benefits have substantially exceeded their cost and led to improvements to the economy, the environment, and the security of the Nation."

National Research Council report *Energy Research at DOE – Was It Worth It?*

Metrics and Benefits

Under the Government Performance and Results Act (GPRA) of 1993, strategic plans are the starting point for federal programs to: (1) establish program goals and objectives; (2) define the paths to achieve those goals; and (3) demonstrate program performance measures for achieving those goals. This strategic plan represents a vital tool in establishing program goals and objectives, and defining how the Office of Clean Coal intends to achieve these goals. However, annual tracking of performance in achieving these goals is equally important.

Performance Measures

All high-performance organizations whether public or private are, and must be, interested in developing and deploying effective performance measurement and performance management systems. The Office of Clean Coal is no exception.

In 2001, President Bush challenged the federal government to make itself more efficient, more effective, more results-oriented, and more accountable to the citizens who pay taxes and benefit from programs and services government provides. The President recognized that "government likes to begin things — to declare grand new programs and causes and national objectives. But good beginnings are not the measure of success. What matters in the end is completion. Performance. Results. Not just making promises, but making good on promises."

In response to the President's Management Agenda, the Office of Clean Coal is frequently evaluated on program management performance. To enhance the practical use of performance information, the Office of Management and Budget, in collaboration with other Federal agencies, developed the Program Assessment Rating Tool (PART), comprised of assessment criteria on program performance and management. The PART establishes a high, "good government" standard of performance and is used to rate programs in an open, public fashion. This tool is also used to tie performance to annual budget evaluations and requests.

Another tool used to evaluate the Office of Clean Coal is the Joule system, developed by DOE's Office of Chief Financial Officer. The Joule system is a comprehensive GPRA-driven tool designed for performance management of ongoing R&D portfolios. The Joule system monitors program progress toward achieving strategic objectives and goals by evaluating quarterly milestones As with a stoplight, Joule scores can be red (no success), yellow (mixed success), or green (successful) within the program.

In its most recent evaluation, the Office of Clean Coal received a green rating for the program elements evaluated. These include: mercury control; gasification; advanced capture and sequestration; SECA system design; SECA core technology; Clean Coal Power Initiative demonstrations; and the hydrogen from coal program.

The Office of Clean Coal used both the PART and Joule evaluations (among others) as part of its annual budget preparation to ensure taxpayers receive the highest value from its programs. Each year, funds are directed toward programs and promising technological innovations that stand to benefit all Americans, and away from less promising or completed R&D projects.

For FY 2006, the Office of Clean Coal has re-prioritized some of its research efforts to address emerging priorities in clean coal technology. For example, carbon sequestration, hydrogen from coal research, and gasification technology R&D have requested increased funding, while funding for fuel cell R&D is being reduced and focused more directly on solid oxide fuel cell development and its most promising research avenue — the Solid State Energy Conversion Alliance program.

In addition to the inter- and intra-agency performance evaluations, the Office of Clean Coal program is evaluated through stakeholder input, peer reviews, and independent evaluations, such as those conducted by the National Academy of Sciences.

Ultimately, the success of the Office of Clean Coal's R&D program hinges on the benefits to taxpayers from their investment in clean coal R&D.

Benefits

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

In early 2005, FE conducted an extensive benefits analysis of all of its R&D programs, including those of the Office of Clean Coal. The methodology used to quantify program benefits assumes hypothetical conditions that represent potential future domestic energy scenarios. The primary tool for determining the impacts of FE programs is the U.S. Energy Information Administration (EIA) National Energy Modeling System (NEMS). NEMS is the model used by EIA to generate its Annual Energy Outlook. NEMS was configured for four scenarios with inputs provided by FE. The four scenarios were run with and without the impact of FE R&D. Any changes in the model's predictions were then used as the basis for calculating benefits. Table 2 lists the key Office of Clean Coal Benefits calculated using this methodology.

Addressing Environmental Challenges with Coal – Without clean coal R&D, regulatory pressure to reduce CO_2 emissions would limit pulverized coal plant capacity additions to only about one gigawatt (GW), and integrated gasification combined-cycle

FE R&D Benefits Scenario Definitions

Business-As-Usual

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

Clear Skies

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

High Fuel Prices

- CSI coupled with EIA-AEO 2004 high World Oil Price and constrained natural gas supplies.

Carbon Cap

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

Table 1: FE R&D Programs Reduce Electricity Prices

	Average Price of Electricity (¢/kWh)* 2010	2025
Business-As-Usual		
Without FE R&D	6.7	6.9
With FE R&D	6.6	6.4
Clear Skies		
Without FE R&D	6.9	7.1
With FE R&D	6.8	6.6
High Fuel Prices		
Without FE R&D	7.0	7.5
With FE R&D	6.9	6.6
Carbon Caps		
Without FE R&D	6.8	8.6
With FE R&D	6.8	7.7

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

(IGCC) plants to less than one GW. No natural gas plants would be built because they are not economically competitive. Builds of renewables would increase and new nuclear plants would come on-line. The average price of electricity would be 8.6 ¢/kWh in 2025 (see Table 1).

The picture changes significantly with clean coal R&D, where coal continues to play a key role in generating power, even with a carbon cap. Coal-based power systems grow to nearly 70 GW by 2025 (95 percent of which are IGCC plants with carbon sequestration), and fuel cell capacity grows to 87 GW. Renewables maintain a significant market share at 48 GW, with nuclear plants also making a contribution. The end result is that the Office of Clean Coal's advanced technologies meet the environmental requirements while reducing fuel and electricity prices. With clean coal R&D, in 2025 the average price of electricity drops 0.9 ¢/kWh to 7.7 ¢/kWh.

Providing a Pathway to Hydrogen – The Hydrogen from Coal program within the Office of Clean Coal is developing advanced and novel technologies that will facilitate the use of the Nation's abundant coal resources to produce, store, deliver, and utilize affordable hydrogen and provide a pathway to a hydrogen economy.

Mercury Emissions Reductions – In March 2005, EPA promulgated the final Clean Air Interstate Rule (CAIR) and the companion Clean Air Mercury Rule (CAMR). CAMR establishes national, annual mercury emission caps at 38 tons in 2010 and 15 tons in 2018. The proposed CAMR rule had included a safety valve provision to limit the maximum cost that purchasers could pay for mercury emissions allowances. This mechanism was not included in the final rulemaking, and EPA's final analysis concluded that the 38 ton per year emission cap in 2010 can be met through co-benefits reductions expected under the CAIR program for SO_2 and NO_x. However, EPA also recognized

Table 2: Key Office of Clean Coal Program Benefits

Program Element	Benefits (2002 dollars, discounted at 5 percent)*
IGCC	• Up to 70 GW of IGCC built by 2025, assuming moderate oil and gas prices, with consumer savings of about $20 billion • For higher energy prices, these numbers grow to 104 GW and $104 billion savings
Carbon Sequestration	• Assuming a carbon emission constraint, 70 GW of IGCC with sequestration built by 2025, saving consumers $20 billion
Distributed Generation/Fuel Cells	• Up to 87 GW of operational fuel cells by 2025 • Up to $11 billion electricity costs savings by 2025
Innovations for Existing Plants	• $11.5 billion cost reduction for mercury (Hg) control • $2.6 billion cost reduction for NO_X control • Meets CSI cap without triggering safety valve
Hydrogen *(Hydrogen benefits were determined in a well-to-wheel analysis that was performed outside of the NEMS framework)*	Producing hydrogen from coal and utilizing it in fuel cell vehicles (FCVs) will: • save 370,000 barrels per day of imported oil • save 150 billion cubic feet of imported natural gas per year • reduce the cost of U.S. fossil fuel consumption by almost $4 billion per year • reduce NO_X emissions by 20,000 metric tons per year • reduce sulfur oxide (SO_X) emissions by 5,300 metric tons per year

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

that without significant advances in control technology options and associated reduction in costs, the 2018 cap of 15 tons per year will not be attained.

The President's Clear Skies Initiative (CSI) also would establish national, annual mercury emission caps in 2010 and 2018. This proposed legislation includes a safety valve cap on mercury allowance prices valued at $2,187.50 per ounce ($35,000 per pound) that is intended to address some of the uncertainty associated with the cost of mercury control.

The inclusion of a safety valve concept in CSI and the consideration of this concept in CAMR highlight the legislative and regulatory concerns pertaining to the high cost of mercury controls in the near term. Both recognize the inability of current control technologies to economically meet the 15 ton per year cap in 2018. Clearly, lower cost solutions are needed to reach strategic environmental objectives and the emphasis needs to be on finding near-term solutions.

"... will reach our ambitious air quality goals through a market-based cap-and-trade approach that rewards innovation, reduces cost, and guarantees results."

President George W. Bush

"...it's important for us to continue to explore clean coal technologies, so we can use the energy supply here at home in a way that is...protecting our environment. Technology and research will enable us to do so."

President George W. Bush

Innovations for Existing Plants

Program Goal

By 2007, provide a portfolio of advanced cost-effective emission controls that can:

- Reduce mercury emissions by 50 to 70 percent;
- Lower nitrogen oxide emissions to less than 0.15 pounds per million Btu at 50 to 75 percent of the cost of today's most effective control technologies; and
- Reduce fine particulate matter ($PM_{2.5}$) by 99.99 percent.

By 2010:

- Test technologies for advanced cooling; and
- Provide new technologies that can result in an increase in the reuse of coal by-products from 38 percent today to 50 percent.

Today's environmental compliance landscape is undergoing its most significant changes in the last quarter century.

For the first time, mercury emissions from the Nation's coal-fired power plants will be regulated; power generators must comply with revised National Ambient Air Quality Standards requiring significant reductions in emissions of nitrogen oxides, ozone and fine particulate matter; the President's Clear Skies (CSI) Initiative would establish more stringent emission limits on sulfur dioxide, nitrogen oxide, and mercury; new Clean Water Act regulations will require a power plant's cooling water intake structure to meet technology-based performance standards while water is becoming a limited resource in permitting and operating power plants; and regulations affecting the increasing volumes of solid residue are creating new issues in land use and by-product utilization.

The Innovations for Existing Plants (IEP) program strategic goals are oriented to meet these new requirements.

The primary focus is to provide more effective and affordable compliance options for the more than 320 GW of coal-fired capacity currently operating in the United States. Emerging innovations will also strengthen the technical foundation for even better pollution control systems for the next generation of coal-fueled power plants, and the data generated will provide scientifically sound information for regulatory and policy decision-makers.

Technology Challenges

The IEP program is helping to meet the technology needs of the Nation's power industry in six major environmental areas:

Mercury Controls – R&D for reducing mercury emissions is the highest priority of the IEP program primarily because no single technology currently provides cost-effective, add-on mercury control for all power plant configurations or all coal types. The President's CSI proposed legislation and EPA's Clean Air Mercury Rule (CAMR) recognize the need for advanced control technologies to economically meet the stringent mercury emission reductions targeted for the year 2018. Advanced research is needed today to ensure that these technologies are ready for tomorrow.

In a power plant's flue gas, mercury can make up as little as one part per *billion* which alone creates significant challenges. Mercury is also released in one of two basic forms — as elemental mercury vapor or as a solid mercury oxide. Mercury vapor is the most difficult to capture. When low-rank subbituminous and lignite coals are burned, the proportion of mercury vapor is relatively high compared to bituminous coals that tend to release mercury in the most or more easily controllable solid state.

Injecting powdered activated carbon into flue gas to capture mercury has shown the most promise, but the process applied to coal-fired boilers is still in its early stages and its effectiveness under varied conditions (e.g., fuel properties, flue gas temperatures, and trace-gas constituents) is still being investigated. Costs can be prohibitive, ranging from $50,000 to $70,000 per pound of mercury captured, and residual carbon can compromise the commercial value of the plant's fly ash.

Electrostatic precipitators, baghouses, or flue gas scrubbers can capture solid mercury oxide particles or mercury adhering to a sorbent, but conditions inside these devices often cause mercury to convert to its vapor state, reducing effectiveness. Optimizing conditions for mercury capture — for example, lowering flue gas temperatures in a wet scrubber — can form equipment-damaging acids.

A "spider" is a mechanical device that splits activated carbon for mercury control from a single tube to multiple tubes and directs the carbon into injection lances before entering the flue gas duct.

The IEP program is developing alternatives to powdered activated carbon, including low-cost carbon and non-carbon mercury sorbents. New catalysts and advanced electro-catalytic devices are being developed to convert mercury vapor to its solid oxidized state. Research is also underway to integrate mercury adsorption and oxidation with wet flue gas desulfurization or advanced particulate control devices. Magnesium-based alkali injection is being explored as a way to prevent acid formation in lower temperature flue gases.

Nitrogen Oxide (NO_x) Controls – Low-NO_x burners and reburning systems, many of which were pioneered in DOE's Clean Coal Technology (CCT) program, provided a cost-effective means to meet emission limits set for the year 2000 by the Clean Air Act Amendments.

Environmental laws since then, however, have tightened. Low-NO_x burners demonstrated in the original CCT Program reduce NO_x emissions from roughly 0.65 to 0.25 pounds per million Btu. Revised National Ambient Air Quality Standards, however, restrict NO_x emissions to as low as 0.15 pounds per million Btu.

Furthermore, President Bush's CSI would lower the nationwide cap on NO_x emissions and likely require major NO_x reduction measures at virtually all of the nation's coal-fired power plants. New limits on microscopic particulate matter ($PM_{2.5}$) will also lead to more stringent NO_x limits, since NO_x can be a precursor of these airborne particles.

To meet more stringent NO_x emission limits, power plant operators currently have only one technology option: selective catalytic reduction (SCR). The drawback to SCR is cost, typically running $80 to $100 per kW and over $2,000 per ton of NO_x removed.

The IEP program is developing lower cost approaches to stand-alone SCR. For example, advanced combustor designs are leading to a new generation of ultra-low NO_x burners capable of achieving 0.15 pound per million Btu emission levels. Selective *non*-catalytic reduction and other chemical processes are being developed to reduce NO_x from coal combustors. Lower-cost combinations

Technology Targets

The IEP program has set the following technology targets for advanced pollution control technologies:

- A near-term goal to achieve 50 to 70 percent mercury capture with cost savings of 25 percent or more compared to current powdered activated carbon injection with technologies available for commercial demonstration by 2007 for all coal ranks.
- A longer-term goal to develop by 2010, more advanced mercury control technologies that can achieve 90 percent or greater capture at 50 to 75 percent of today's cost of $50,000 to $70,000 per pound of mercury.

Technology Targets

In addition to mercury (see previous page), the IEP program has set targets for:

- **NO_x controls** – By 2007, complete initial demonstrations of NO_x control technology that can achieve emission rates of less than 0.15 pounds per million Btu with cost savings of 25 percent relative to SCR; and
- **Particulate controls –** By 2007, reduce $PM_{2.5}$ fly ash emission levels by 99.99 percent for less than $50 to $70 per kW.

of combustion modification and SCR are being explored. Burner control systems are being developed that use the latest in neural network technology to maintain optimal combustion conditions and retard the formation of NO_x.

Fine Particulate and Acid Gas Controls – Today's power plants can capture large volumes of fly ash particles with diameters as small as 10 microns. But new regulations target particles less than or equal to 2.5 microns in diameter ($PM_{2.5}$) as well as the precursor gases that can form these tiny particles in the atmosphere.

Baghouses suffer severe economic penalties when designed to capture large volumes of these fine particulates, while existing preconditioning agents that enhance the effectiveness of electrostatic precipitators (ESPs) rely on large quantities of ammonia, now classified as extremely hazardous under recent legislation. Consequently, neither baghouses nor ESPs currently can comply with a 99.99 percent removal requirement for $PM_{2.5}$.

The IEP program is developing technology to support advanced hybrids of baghouses and ESPs that leverage the best particulate control features of both. Non-hazardous preconditioning agents are being developed to agglomerate fine particles into larger sizes that can be more easily captured by ESPs. Techniques are being developed to concentrate particulate matter in the ESP outlet streams and recycle the concentrated stream. By reducing the volume of gases directed to the baghouse, its performance is enhanced.

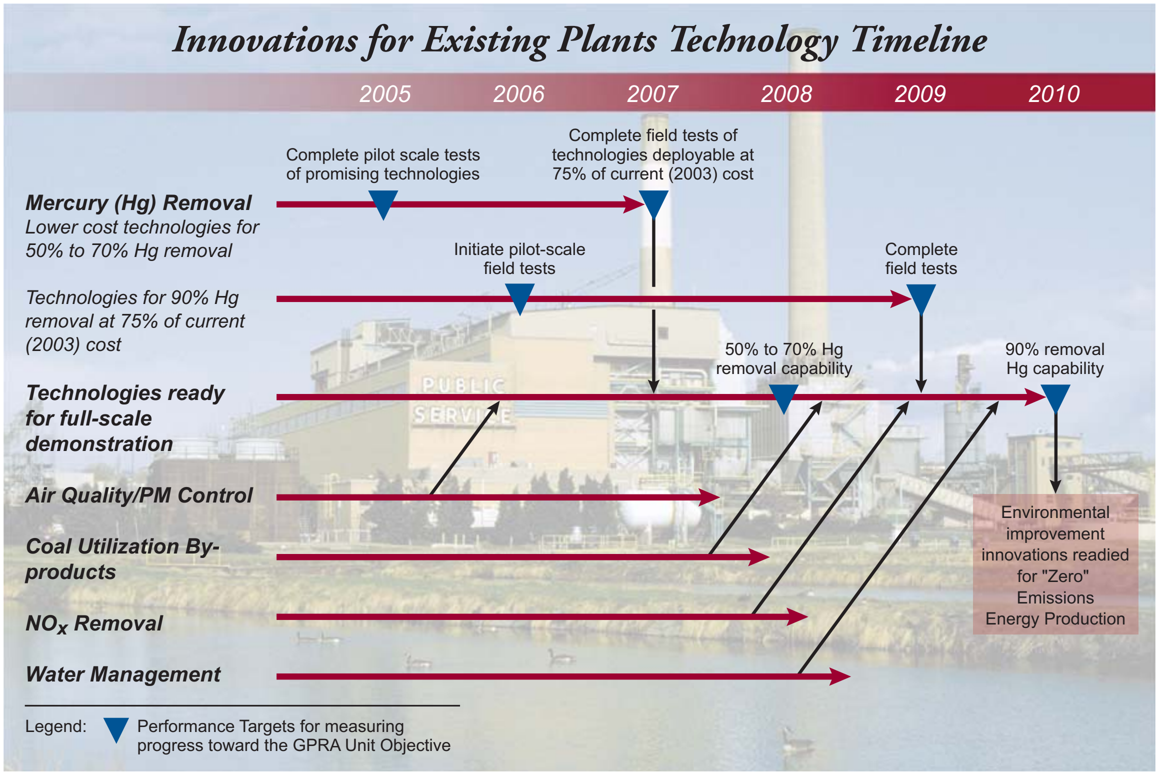
Acid gases are another pollutant that can readily escape conventional control devices. Sulfuric acid aerosols can be released when the sulfur in coal oxidizes and combines with water vapor. Similarly, hydrochloric and hydrofluoric acid formed by reaction of coal constituents with water vapor can add to the acid gas release. To reduce acid gases, the IEP program is developing new alkaline injection techniques for sulfur trioxide, acid aerosol precursor control, and control of hydrochloric and hydrofluoric acids.

Air Quality Research – Microscopic airborne particles can be released by a number of human and natural sources. This element of the IEP program is studying the chemical and physical "signatures" of airborne particles to provide a better understanding of where they originate and how they are transported.

Knowing how and where fossil-fueled energy operations contribute to atmospheric particulate levels can lead to better policy decisions. Research in the IEP program will provide important information for the "mid-course" review of emission reduction progress under the Clean Air Act Amendments as well as for the target-attainment reviews called for in the CSI. It could also provide valuable insights into how mercury is transported in the atmosphere.

Coal Utilization By-Products – Coal plant by-products represent a potentially valuable resource as construction materials and soil conditioners, but less than one-third of the approximately 130 million tons of coal by-products generated today in the United States are recycled. This amount could be further reduced if mercury control technologies lead to higher levels of mercury residue and sorbents in these by-products, or new NO_x control devices increase concentrations of unburned carbon and ammonia in fly ash. Moreover, landfill space is becoming more and more limited and disposal costs are increasing.

The IEP program is addressing these issues by studying the fate of mercury and other trace metals in coal utilization by-products, developing new separation technology to remove carbon and mer-



cury, and exploring novel applications to expand the market value and future use of these materials.

Water Management – There is an inextricable link between coal-based power plants and water. Thermoelectric power plants rank only slightly behind irrigation in terms of freshwater use in the United States, withdrawing over 132 billion gallons per day, primarily for cooling. Nearly three-fourths of this water goes to fossil-fuel-based power plants. Concerns about freshwater sustainability brought on by persistent drought; competition with domestic, industrial, agricultural, and in-stream use sectors; and other factors are impacting the operation of existing coal-based power plants and the siting and permitting of new plants. This has become most apparent in parts of the West, Southwest, and Southeast where conflicts over water rights are almost a daily occurrence. Further restrictions on cooling water withdrawal under the Clean Water Act and potential tighter drinking water and effluent standards for mercury, arsenic, and other trace metals will also place added pressures in the future on how coal-fired power systems use and impact the Nation's limited freshwater resources.

Efforts in the IEP program are directed at the development of advanced technologies and concepts to ensure that sufficient water is available to operate and permit coal-based power systems, and to minimize potential impacts of power plant operations on water quality. The research is focused on: (1) the use of non-traditional water sources (e.g., mine water and produced water from oil and gas extraction) for cooling; (2) advanced water recovery and cooling technology; (3) advanced cooling water intake technology; and (4) advanced wastewater treatment and detection technology.

"More than half of the electricity generated in America today comes from coal. If we weren't blessed with this natural resource, we would face even greater [electric power] shortages and higher prices today. Yet, coal presents an environmental challenge. So our plan funds research into new, clean coal technologies."

President George W. Bush

Advanced Power Systems

Program Goal

The Advanced Power Systems activity will:

- By 2010, complete R&D for advanced gasification combined-cycle technology that can produce electricity from coal at 45 to 50 percent efficiency (HHV).
- By 2012, complete R&D to integrate this technology with CO_2 separation, capture, and sequestration into a "zero" emission configuration(s) that can provide electricity with less than a 10 percent increase in cost.

Within the coming decade, the U.S. power industry will be approaching the threshold of another major era of power plant construction. Electricity demand is likely to grow significantly, requiring a new fleet of power plants both to meet rising demand and to replace aging plants as they are slated to be retired. More than 100 GW of new coal plants are likely to be required by 2020.

The Advanced Power Systems (APS) program is providing the technological foundation for this new fleet of coal-fired power plants. The strategic goal for this program reflects the fast-approaching opportunity to introduce a "new breed" of power plant in time for the next wave of plant construction — a coal-fueled power plant that is highly efficient, capable of producing multiple products, and most importantly, virtually pollution-free.

Technology Challenges

To meet the 2010 strategic goal, the APS program is focusing on the primary technology platforms for tomorrow's coal-fueled power plants: (1) coal gasification for both power and fuels production; and (2) high-performance turbines operating on coal-derived fuels:

Coal Gasification – There is government and industry consensus that integrated gasification combined-cycle (IGCC) currently shows the greatest promise for meeting 2010 cost and performance goals. A significant Research, Development and Demonstration (RD&D) effort must be mounted, however, because today's IGCC capital costs are approximately $1,500/kW, efficiencies are typically 40 percent, reliability falls short of industry standards, and pollutant emissions exceed those of natural gas plants (although emissions are much better than from pulverized coal plants).

The gasification research portfolio includes development of both new gasifiers and the necessary supporting equipment such as advanced air separation units, gas cleanup, and hydrogen/carbon dioxide separation technology.

Advanced Gasifier Development – Gasifiers convert the hydrocarbon constituent of coal to synthesis gas, and the bulk of the ash to slag. The gasifier represents the heart of an IGCC project and constitutes up to 15 percent of its capital cost.

RD&D is focused on developing: erosion resistant materials for the feed system; refractory with a life expectancy greater than 3 years under optimum gasifier operating conditions (versus 6–18 months for existing refractory); and instrumentation that can withstand the rigors of the gasifier environment. Advanced gasification concepts being pursued include the transport gasifier and compact gasifiers, which offer a high degree of fuel flexibility and relatively small size because of high throughput.

RD&D, advanced materials, and instrumentation for existing gasifier operations have the potential to improve plant availability by more than 5 percentage points, reduce annual operating and maintenance costs by $1–2 million, and improve thermal efficiency by 1 percentage point. Advanced gasification concepts have the potential for capital cost reductions of 7–15 percent compared to today's gasifiers, with some concepts even providing concentrated streams of H_2 and CO_2 directly from the gasifier.

Additionally, improvements in thermal efficiency in the range of 2 – 4 percentage points are likely from the deployment of advanced gasifiers integrated into commercial facilities in the post 2010 timeframe.

Advanced Air Separation Units – Air separation units provide nearly pure oxygen to the gasifier, and nitrogen for balance of plant support. The use of pure oxygen in lieu of air, which is 78 percent nitrogen, in gasification processes keeps gas streams concentrated, enhancing the efficiency of cleanup and CO_2 separation for sequestration. Conventional air separators constitute 12–15 percent of the capital cost of an IGCC facility and are energy and capital intensive cryogenic systems, which consume upwards of 10 percent of the gross power output.

RD&D is focused on membrane-based air separation units. Membranes apply intrinsic electrochemical behavior rather than physical means, which makes them more efficient. The membranes currently being developed are dense ceramic materials known as Ion Transport Membranes (ITM). At high temperatures and with a sufficient pressure gradient across the membrane, these materials simultaneously transfer both oxygen ions and electrons through the membrane structure to maintain electrical neutrality, thereby obviating the need for an external electric circuit to drive the separation process. RD&D is expected to yield capital cost savings of approximately $100/kW for a conventional IGCC plant with a concomitant increase in overall thermal efficiency of 1–2 percentage points.

*H_2/CO_2 Separation** – Hydrogen production and CO_2 capture and sequestration require systems to transform clean synthesis gas into H_2/CO_2, and to separate H_2/CO_2 into an H_2 product and CO_2 by-product. H_2/CO_2 gas mixtures are produced by reacting synthesis gas with water over a catalyst which converts the CO to CO_2 and produces more hydrogen, in what is called a water-gas shift. Current glycol solvent-based chemical systems for H_2/CO_2 separation are cost and energy intensive. The cost for separating CO_2 from the shifted gas and sequestering it is $40/ton of CO_2, and the required selling price of the product hydrogen is $8 per million Btu.

RD&D is focused on advanced chemical and gas separation membrane-based systems for separation of H_2/CO_2 gas mixtures. Proton exchange membranes that apply intrinsic electrochemical behavior to efficiently separate H_2 from the CO_2 have shown particular promise. These advanced technologies have the potential to reduce CO_2 capture costs to less than $10 per ton of CO_2, and H_2 production costs to $6 per million Btu (and potentially below $4 per million Btu when solid oxide fuel cells — being developed under the Fuel Cells program — are incorporated into the IGCC system).

Gas Cleanup – Gas cleanup components first remove particulate matter and then the sulfur, nitrogen, acid, and trace contaminant (including mercury) bearing gases to produce clean synthesis gas. Current gas cleanup systems represent 10–15 percent of the capital cost of an IGCC facility, and fall short of the nearly 100 percent removal of all contaminants required for advanced gas turbines and

Technology Targets

To achieve coal-based power systems that approach 50 percent fuel use efficiencies and can serve as the basis for future ultra-clean energy plants:

- By mid-2006, test advances in coal feed, char recycle, and ash removal systems for low cost gasifiers.
- By 2007, conduct pilot tests of gas cleanup technology that eliminates virtually all pollutant precursors and contributes up to 1–2 points to overall system efficiency gains at costs reduced to $60–80/kW.

continued on page 20

** Hydrogen separation is part of the Hydrogen from Coal program element and is coordinated as part of the Advanced Power System program element.*

fuel cells needed in the combined-cycle power block to meet APS goals. Gas cleanup systems used in today's IGCC plants are low-temperature amine-based systems typically designed for 97 percent sulfur removal.

RD&D efforts are primarily focused on an array of multi-contaminant control systems capable of operating at temperatures of 300 – 700 ºF, which provides increased compatibility with downstream process components and enhances efficiency. RD&D has the potential to realize nearly 100 percent removal of all contaminants, reduce IGCC capital costs by $60 – 80/kW, and increase efficiency by 1–2 percent.

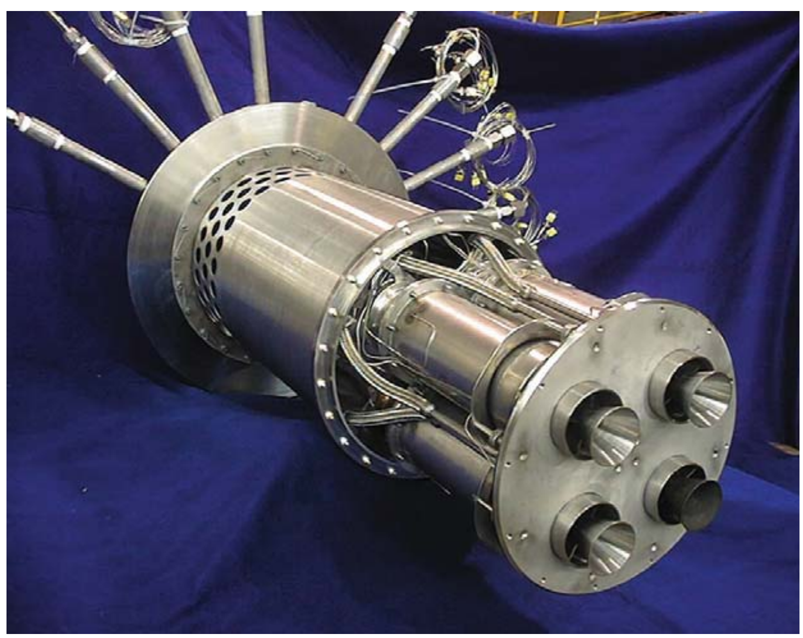
Although alternative routes to "zero" emissions, such as advanced combustion, are possible, these technologies are at an early research stage and would not be able to meet the "zero" emission goals within the required 2020 timeframe. For this reason, the Advanced Power Systems program has focused on the more mature IGCC technology. However, many of the technologies developed as part of the IGCC effort *(e.g.*, oxygen membranes, CO_2 capture, and hybrid gasification/combustion systems), may also be applicable to some advanced combustion concepts.

Coal-Based Turbine Technology – In an IGCC mode, gas turbines are fueled by the gasification-derived fuels, drive electricity generators, and provide heat to produce steam for a steam turbine. To achieve 2010 APS performance goals: the efficiency of advanced turbines firing synthesis gas must be improved; they must be made capable of operating on hydrogen-rich gas, without compromising performance; and even lower NO_x emissions must be achieved — less than 2 ppm.

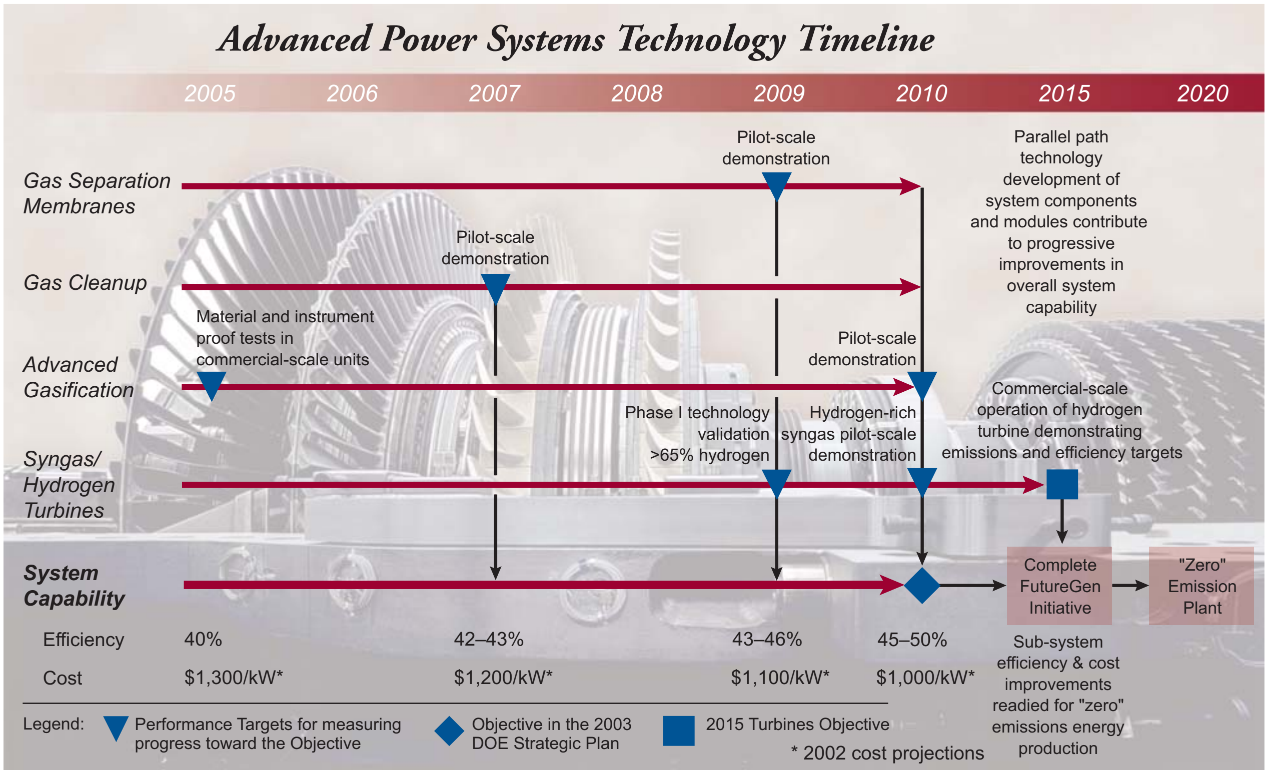
Keeping combustor temperatures low while maintaining combustion stability is the key to low NO_x performance. At the same time, turbine inlet temperatures are being increased to realize higher ef-

Technology Targets (cont.)

- By 2009, test at pilot scale advanced air separation systems that contribute up to 3 percentage points to overall system efficiencies at costs reduced by more than 40 percent to $100/kW.
- By 2010, complete pilot-scale test of advanced fuel-flexible, high-throughput, lower cost gasifiers.
- By 2010, test advanced syngas-fueled turbine combustors that will form the core of gasifier/turbine systems that contribute 2–3 percentage points to overall efficiency improvements (based on a Frame-FB Turbine).



Photograph of a set of PCI's Rich-Catalytic Lean-burn (RCL®) injectors tested in a modified industrial engine with natural gas fuel. PCI's Rich-Catalytic syngas injector for IGCC applications is based on this demonstrated natural gas RCL® design.



ficiency, creating the need to protect the turbine's hot gas path components from heat damage.

Combustion research is exploring use of diluents to reduce hydrogen combustor temperatures, and applying catalytic and physical techniques for flame stability. Diluents could include steam, as well as nitrogen (a by-product of oxygen production for IGCC systems). Differences in the properties of the working fluids produced by hydrogen combustion in gas turbines will also require new technologies related to turbine components, in the areas of materials as well as cooling.

Retaining advanced turbine performance on coal-derived synthesis gas and hydrogen-rich fuels represents as much as a 2–3 percentage points efficiency gain in an IGCC system and more than a $100/kW reduction in the capital cost through higher output.

"... our investment in advanced energy and sequestration technologies will provide the breakthroughs we need to dramatically reduce our [greenhouse gas] emissions in the longer term."

President George W. Bush

Carbon Sequestration

Program Goal

By 2012, provide a cost-effective, environmentally sound option for reducing greenhouse gas intensity and stabilizing atmospheric concentrations of CO_2 by developing:

- CO_2 capture and storage technologies that result in less than a 10 percent increase in the cost of energy services;
- CO_2 storage options that are safe and environmentally acceptable, and have storage capacities that are predictable within a 30 percent accuracy range;
- Cost-effective monitoring, mitigation, and verification protocols that enable stored CO_2 to be credited as net emissions reductions;
- Commercially ready technologies for mitigating non-CO_2 fugitive emissions from energy systems; and
- The beginnings of a self-sustaining infrastructure for deploying sequestration technologies.

Of all the available options for reducing the buildup of greenhouse gases in the atmosphere, carbon sequestration is an option that will not require large-scale and potentially costly changes to our energy infrastructure. "Carbon Sequestration" is a family of methods for capturing and permanently isolating gases that could contribute to global climate change. For a Nation whose economic prosperity depends on an intricate, tightly coupled energy system, the potential of carbon sequestration to provide valuable time for an affordable transition to a carbon-free energy future makes it one of DOE's highest research priorities.

The Office of Clean Coal program added "Carbon Sequestration" to its research portfolio in 1997. Today, largely because of joint government-industry research investments, advanced devices that capture CO_2 at the power plant or industrial factory are showing significant promise for lower costs and higher performance. The first heavily instrumented field tests of CO_2 injections into geologic formations have begun. New techniques are being developed to track the fate of CO_2 in storage and the effectiveness of enhancing natural carbon uptake processes. Also, novel chemical and biological concepts for converting CO_2 to fuels or benign solids are revealing exciting new pathways that could lead to future breakthroughs.

Together these advances are fundamentally altering the way coal is viewed in the world's energy future. In the last three decades, technology has made great strides in reducing pollutant-forming contaminants in coal, but the release of carbon gases was generally considered an inevitable consequence of coal use. Today that thinking is changing. Carbon sequestration could lead to a truly emission-free, coal-fueled power plant — one that would release no harmful gases of any type, and permit the world to tap the *full* potential of one of its predominant energy resources.

Technology Challenges

The Carbon Sequestration program concentrates on three primary types of work: core research, infrastructure development, and integration of technologies.

Core Research – Core R&D is the laboratory, pilot plant, and field work aimed at developing new technologies and new systems for CO_2 (and other greenhouse gas) mitigation. It includes: CO_2 separation and capture; storage; monitoring, mitigation, and verification; breakthrough concepts; and non-CO_2 greenhouse gas (mostly methane and nitrogen oxides) control.

Carbon Separation and Capture – Before CO_2 can be sequestered from power plants and other point sources, it must be captured as a relatively pure gas. Existing capture technologies, however, are not cost-effective when applied to power plants. Most power plants and other large point sources use air-fired combustors which introduce large quantities of nitrogen into flue gases (since air is 78 percent nitrogen) and dilute CO_2 levels to as little as 3 to 15 percent by volume, making capture extremely inefficient. Conventional (amine-based) capture technologies are also extremely energy-intensive, requiring as much as one-third of a traditional coal plant's power output. Burning coal in oxygen instead of air creates highly pure CO_2 but the high cost of producing oxygen is a major obstacle. Gasifying coal produces "synthesis gas" with CO_2 volumes as high as 40 to 60 percent by volume, making it highly amenable to CO_2 capture, particularly if lower cost techniques can be developed to capture CO_2 from the plant's emissions.

Researchers in the Carbon Sequestration program are exploring a variety of potentially lower-cost, more effective CO_2 capture approaches, including liquid and solid chemical absorbents, physical sorbents, solvents, membranes, conversion to hydrates (ice-like substances), and combinations of these approaches.

CO_2 Storage R&D – Sequestration/storage is defined as the placement of CO_2 into a naturally occurring repository in such a way that it will remain isolated from the atmosphere for hundreds to thousands of years. Storage includes three sub-areas: geologic, terrestrial, and ocean sequestration.

Geologic sequestration is likely to be one of the most promising near-term sequestration options if ongoing research and field tests can assure its environmental acceptability and safety. Possible geologic storage formations could include depleted oil and gas reservoirs, unmineable coal beds, and deep saline formations. Proving that CO_2 will not escape from these formations and either migrate to the earth's surface or contaminate drinking water supplies is a key aspect of sequestration research.

Terrestrial sequestration — enhancing the natural processes that remove CO_2 from the atmosphere — may be one of the most cost-effective means of reducing atmospheric levels of CO_2. Forestation and deforestation abatement efforts are already under way. The challenge in this R&D area is to increase the rate of terrestrial sequestration while properly considering all the ecological, social, and economic implications.

Ocean sequestration is not yet considered a viable approach due primarily to the uncertainty of its environmental impacts. Technology exists for the direct injection of CO_2 into deep areas of the ocean; however, the knowledge base is not adequate to optimize the costs, determine the effectiveness of the sequestration, and understand the resulting changes in the biogeochemical cycles of the ocean. Ocean sequestration, however, has huge potential as a carbon storage sink if the long-term environmental uncertainties can be resolved.

Monitoring, Mitigation, and Verification (MM&V) – Accurate techniques and instruments for measuring and verifying that CO_2 is being safely stored in geologic formations or absorbed in forests and soils will be essential if a wide scale carbon emissions accounting and trading system is to be put into place in the future. Moreover, all large scale sequestration operations likely will have the capability to detect CO_2 leakage and mitigate ecological damage in the unlikely event that leakage would occur. Several technical challenges exist. For example, pinpointing possible leakage paths from geologic formations requires the capability to detect small changes to CO_2 levels already present in the atmosphere. Verification protocols must be developed with sufficient validity to ensure permanent storage.

Breakthrough Concepts – This program element pursues revolutionary sequestration approaches having the potential for low cost, high permanence, and large global capacity. Processes that mimic those found in nature are of particular interest, primarily because they represent

Technology Targets

For carbon capture technologies:

- By 2007, conduct pilot-scale tests that show the potential for lower cost pre- and post-combustion CO_2 capture.
- By 2012, develop systems to commercial readiness that can capture and sequester carbon gases from fossil fuel plants with less than a 10 percent cost of energy increase for gasification systems and less than a 20 percent cost increase for combustion systems.
- By 2018, develop carbon capture and sequestration systems that result in "zero" emissions with no net cost increase for energy services.

low-energy pathways and do not require pure, compressed CO_2. Examples are photosynthesis, microbiological conversion of CO_2 to methane and acetate, and mineral uptake of CO_2 to form carbonates. Replicating these natural processes is challenging. CO_2 is a highly stable compound containing a very low amount of chemical energy which makes natural conversion processes typically slow and inefficient. R&D aims to improve the speed and energy efficiency of CO_2 conversion processes, and to identify processes that produce high-value byproducts, making CO_2 conversion less costly to implement in energy systems.

Non-CO_2 Greenhouse Gas Controls – Methane can be 20 times more potent than carbon dioxide as a greenhouse gas; consequently, capturing methane as well as other non-CO_2 greenhouse gases is an important component of an overall climate change mitigation strategy. Moreover, methane and other high global warming potential gases can have economic value, making their capture both environmentally and commercially beneficial. Because coal mines and landfills are major sources of fugitive methane emissions, the carbon sequestration sub-program is initially focusing on ways to mitigate methane releases from mine ventilation systems and on the development of methane-capturing technologies for landfill gas recovery. Work is also underway to separate nitrogen and methane, making methane capture from coal mines and landfills more effective. DOE and the EPA are also identifying priority areas for future non-CO_2 greenhouse gas control R&D.

Infrastructure Development – Infrastructure development activities set the groundwork for future carbon sequestration research and ultimately if necessary, the wide scale deployment of sequestration methods.

The Office of Clean Coal strategy calls for two major sequestration infrastructure and collaboration efforts, one on a nationwide scale and the other on a global scale:

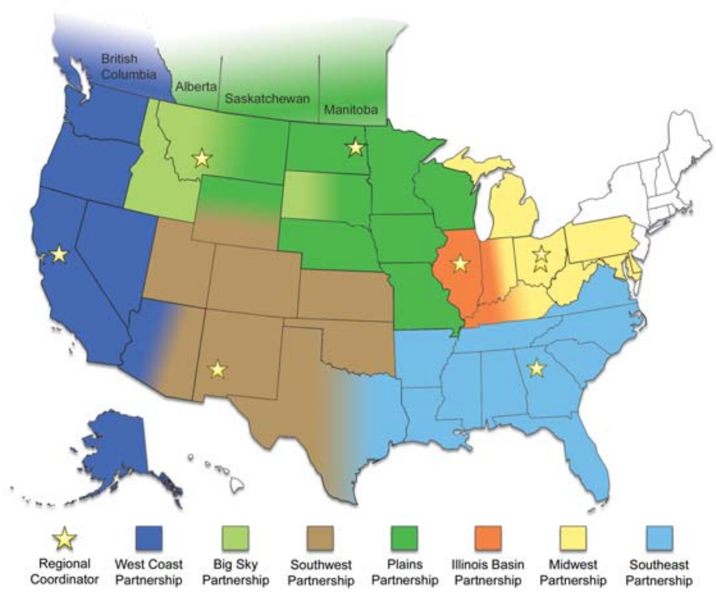
Regional Carbon Sequestration Partnerships – Regional Partnerships have been formed within the United States and Canada to: (1) establish baselines

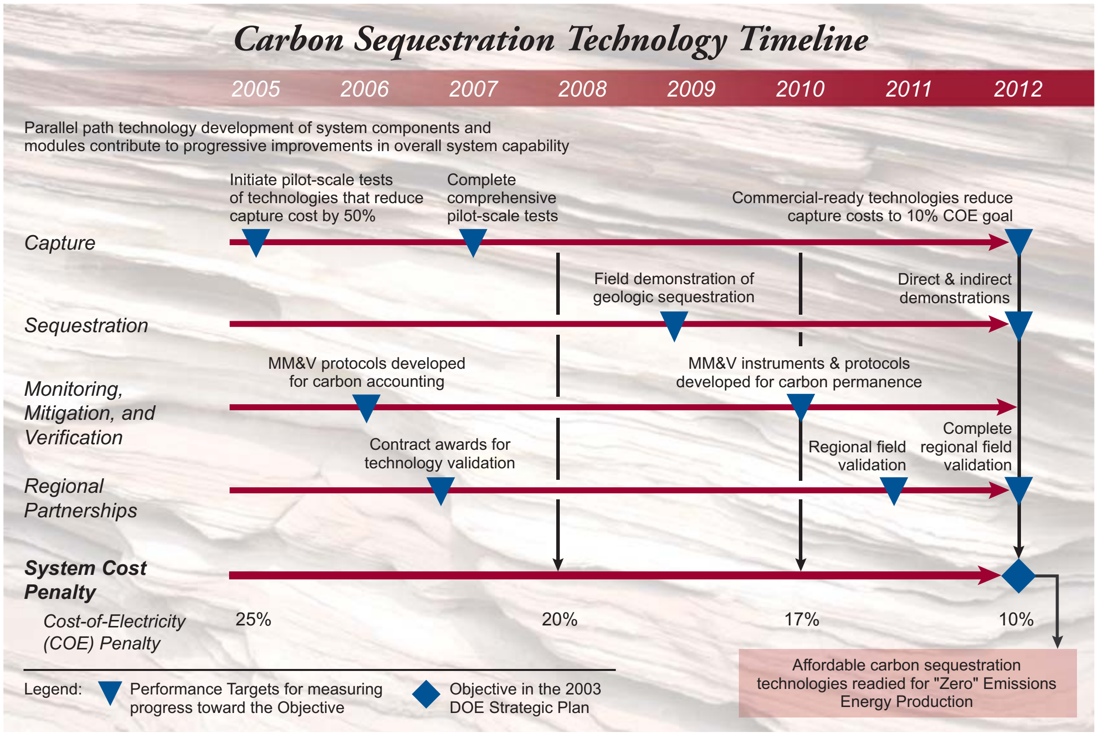
Technology Targets

For CO_2 storage technologies:

- By 2007, show in field tests that CO_2 storage in unmineable coal seams is technically feasible by mitigating coal swelling effects sufficiently to retain 90 percent of the coal's initial permeability.
- By 2008, develop to commercial readiness techniques for sequestering CO_2 in terrestrial ecosystems at costs of no more than $10 per metric ton of carbon sequestered.
- By 2009, begin at least one large-scale demonstration of CO_2 storage (greater than 1 million tons CO_2 per year) in a geologic formation.
- By 2012, validate geologic CO_2 storage with the capability to predict capacities to within 30 percent.

Regional Carbon Sequestration Partnerships





for regional CO_2 sources and sinks; (2) identify the most promising region-specific sequestration technologies and most opportune sites; (3) address regulatory, environmental, and outreach issues associated with the most promising opportunities; (4) develop appropriate MM&V protocols; and (5) support sequestration demonstration and deployment. On August 16, 2003, following a competitive solicitation, the Secretary of Energy named an initial seven Regional Carbon Sequestration Partnerships. Today the partnerships include more than 240 organizations spanning 40 States, 3 Indian nations, and 4 Canadian provinces.

Carbon Sequestration Leadership Forum – On February 27, 2003, President Bush directed the Departments of Energy and State to initiate the formation of the Carbon Sequestration Leadership Forum (CSLF). The CSLF is an international climate change initiative that will focus on development of carbon capture and storage technologies as a means to accomplishing long-term stabilization of greenhouse gas levels in the atmosphere. This initiative is designed to improve carbon capture and storage technologies through coordinated R&D with international partners and private industry.

Integration of Technologies – Should concerns over global climate change dictate and should ongoing R&D efforts prove successful, the fleet of coal-fueled energy plants built in the 2020 timeframe could incorporate carbon sequestration as a core technology. Rather than treating carbon capture and handling systems as separate, stand-alone equipment — similar to the way early scrubbers and other pollution controls were initially treated — it is likely that the more effective, lowest cost approach will be to integrate sequestration technology into overall power plant designs from the very start.

In the Office of Clean Coal strategy, the FutureGen project will be the focal point for pioneering this type of first-of-a-kind integration. FutureGen will be the first power plant in the world to incorporate carbon sequestration as an inherent component of its coal-to-energy process. CO_2 will be separated from coal gases and captured at the FutureGen plant for permanent geologic storage.

Technology Targets

To ensure valid monitoring, mitigation, and verification of sequestration approaches:

- By 2006, develop instrumentation and measurement protocols for sequestering carbon gases in geologic formations and in forests and soils.
- By 2010, develop instrumentation and protocols to accurately monitor carbon storage and protect human health and ecosystems at costs of no more than 10 percent of the total sequestration system cost.

"We happen to believe that fuel cells are the wave of the future; that fuel cells offer incredible opportunity."

President George W. Bush

Solid State Energy Conversion Alliance (SECA) Fuel Cells

Program Goal

- By 2010, produce 3- to 10-kW solid oxide fuel cell modules having a capital cost of $400/kW.
- By 2015, demonstrate megawatt-class fuel cells or fuel cell/turbine hybrids adaptable to coal and having a capital cost of $400/kW.
- By 2020, demonstrate 100 MW-class coal based fuel cells or fuel cell/turbine hybrids.

Fuel cells have the potential to reshape the future of power generation. They are virtually pollution-free, combustion-less power sources. By harnessing the chemical energy of fuels — much like a battery — they generate power quietly at high efficiencies with few moving parts. They can be sited in downtown urban areas or in remote regions, making them ideal candidates for distributed power generation as well as a core component of future central power stations.

Fuel cells have the added advantage of being able to generate power from a variety of carbon and/or hydrogen-rich fuels. To date, most electric power fuel cells have operated using natural gas, but future fuel cells could use gas made from coal or biomass or perhaps pure hydrogen from traditional or renewable energy sources.

Cost stands as the one remaining barrier to fuel cells entering mainstream markets. The first commercial-entry fuel cells cost more than $4,000 per installed kilowatt of power generating capacity, well above the cost of conventional power generating technologies. Incremental improvements in the early market-entry technologies could potentially reduce cost, but to achieve widespread market acceptance, fuel cell cost will have to be lowered dramatically — to as low as $400/kW.

The Clean Coal Program strategy continues to endorse the $400/kW cost goal. The target is achievable primarily because advances in solid-state components and manufacturing techniques continue to be made at a remarkable rate. Ceramic-based technology — similar in many respects to the technology that revolutionized the electronics industry and brought low-cost digital devices to consumers — continues to show the most promise for achieving the dramatic cost reductions needed to make fuel cells widely competitive in tomorrow's energy markets.

In June 2000, DOE's National Energy Technology Laboratory and Pacific Northwest National Laboratory created the Solid State Energy Conversion Alliance (SECA) to accelerate development of low-cost, high power density solid-state fuel cells. Comprised of government agencies, commercial developers, universities, and national laboratories, SECA will create the industrial base that can produce affordable fuel cells for a broad range of applications beginning in the coming decade.

Technology Challenges

Solid oxide fuel cells (SOFC) are the current focus of the Office of Clean Coal fuel cell program because of a number of beneficial characteristics. They operate in the range of 650 –1,000 °C. The high operating temperature supports effective fuel processing and thermal efficiencies of 85 percent in combined heat and power applications. High temperature makes SOFCs desirable in fuel cell/turbine hybrid applications as well, where the fuel cell serves as the turbine combustor. Also, SOFCs are tolerant of, and use, the carbon monoxide constituent of synthesis gas, which can be a problem for other types of fuel cells. In addition, SOFCs use ceramic materials rather than precious metals for key cell components, offer the potential for very high power density, and their solid-state composition makes them compatible with a number of mass production manufacturing advancements that are emerging from the semiconductor industry.

SOFC Mass Customization – SECA is using a mass customization approach to resolve the market entry dilemma. When introducing a new product, production is usually limited because targeted markets are relatively small, which inflates costs. This tempers the market expansion that would trigger the high volume production needed to bring costs down. Applying mass customization, standard 3- to 10-kW fuel cell modules are to be mass-produced that can be aggregated like a series of batteries to meet a broad range of market needs. A broader market provides some assurance of reasonably high initial production, and permits much lower unit pricing from the start that will sustain and expand the market.

The SECA program employs a unique parallel program structure to focus the resources of government, industry, and the scientific community.

Industrial Development Teams – Six teams of industry partners are developing a solid oxide fuel cell power generation system to meet performance objectives established by the government. These teams are also responsible for developing the manufacturing capability and packaging needed for different markets.

Industry teams must meet criteria that become more rigorous for each of three program phases and include design lifetime expectancies, allowed maintenance frequency intervals, efficiency, availability, power degradation, number of transient cycles, and production cost. The program goal is $400/kW when produced in quantities of at least 50,000 units. Cost reduction will be validated

Photo of a 20-cell SOFC stack. This stack is a building block for an 80-cell tower.

Technology Targets

To achieve fuel cell systems that meet cost and performance characteristics and timelines identified below:

- By 2010, develop modular and scalable 3 kW to 10 kW SECA fuel cell designs with ten-fold cost reduction to $400/kW and 40 to 60 percent efficiency (LHV).
- By 2015, demonstrate MW-class coal- and carbon sequestration-ready fuel cell or fuel cell/turbine hybrid systems with 50 percent efficiency (HHV).
- By 2020, demonstrate a 60 percent HHV efficient, 100 MW class fuel cell/turbine hybrid system being fueled by coal gasification.

at the end of each phase in this three phase program. Cost goals for phase I and II will be determined through system and engineering analysis using data from prototype testing. Although commercial production is not required prior to completion of phase III, the potential to achieve further cost reduction must be demonstrated at the end of phases I and II. Currently, six industry teams are creating a range of fuel cell configurations, fabrication techniques, operating temperatures, fuels and fuel processing approaches, and a full range of market targets.

The Core Technology Program – This effort supports the six industrial development teams by providing problem-solving research needed to overcome barriers identified by the industry teams. The Core Technology results will be made available to all industrial teams, universities, national laboratories, and other research organizations participating in this program. There are six program elements: (1) materials; (2) manufacturing; (3) fuel processing; (4) power electronics; (5) controls and diagnostics; and (6) modeling and simulation. These elements reflect the issues being addressed, which are delineated below.

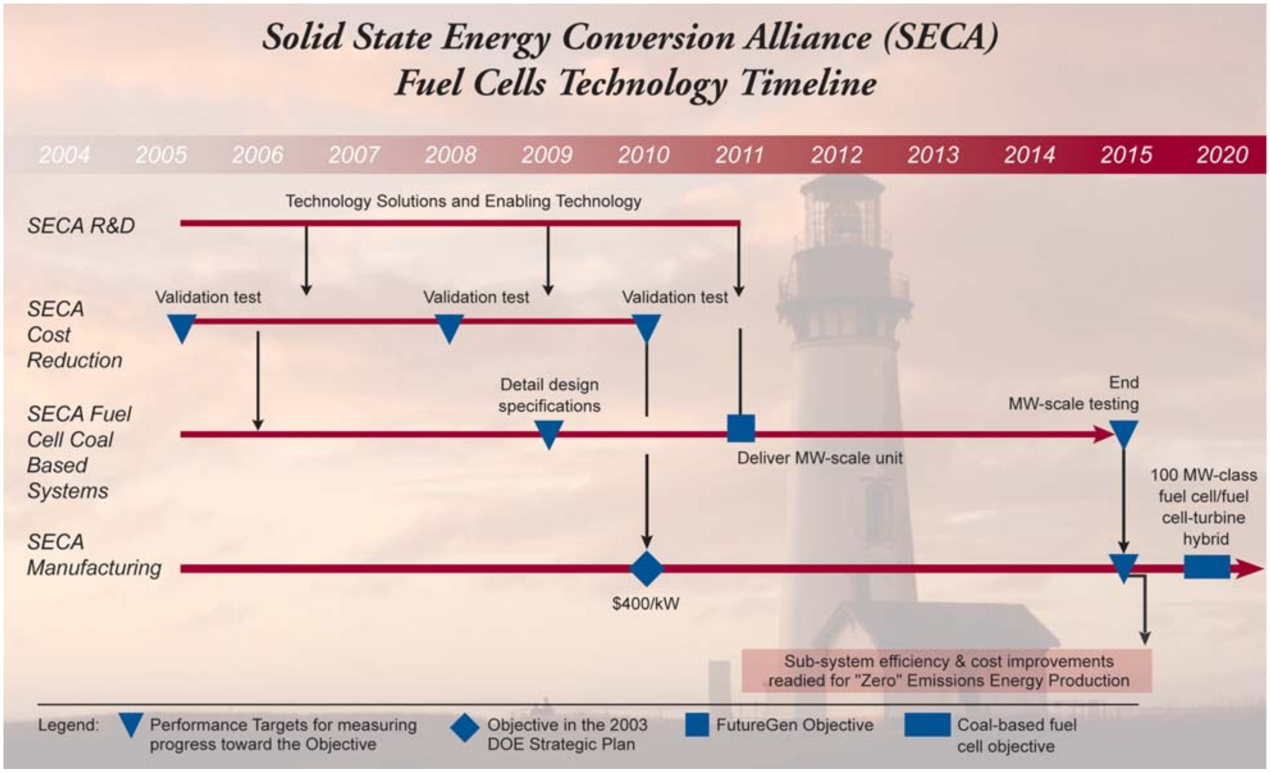
Materials – Materials research encompasses issues associated with cathodes, anodes/fuel processing catalysts, interconnects, and seals. Existing cathode materials do not display the reactivity needed at targeted operating temperatures. Current anodes and fuel processing catalysts are susceptible to poisoning by sulfur and carbon and damage from oxidation. Use of metallic interconnects to reduce cost is a desired course of action by most industry teams, which requires more corrosion resistant materials to sustain extreme oxidation and reduction environments at the high temperatures involved. Planar SOFC stacks require seals to prevent leakage of fuel and oxidant at cell component boundaries; current seals are subject to cracking under thermal cycling. Tubular SOFC configurations are not expected to present significant sealing issues.

Manufacturing – Materials manufacturing development is largely carried out by the Industry Teams and adopts techniques applied in the semiconductor industry, such as “tape casting,” “tape calendaring,” and “screen printing.” The challenge is to design the process so that cell components operate effectively together when joined to make a cell. This requires integration of materials science with advanced fabrication technology. Ultimately, these processes must be translatable to automated, high-volume manufacturing.

Fuel Processing – System thermal integration is critical to meeting SECA goals. The fuel processing is an integral part of the system thermal integration. Requirements include a fully integrated fuel processor with multi-fuel capability that is small, and either removes sulfur before fuel processing, or uses sulfur tolerant materials during the process. Also, the fuel processor must have operational stability during load variations, start-up, and shutdown.

Power Electronics – Power electronics is an important element of a SOFC system. It converts and conditions the relatively low voltage and direct current output of the fuel cell stack to the requirements of the application. R&D has focused on developing a DC to DC voltage converter to raise voltages of fuel cell stacks making power conditioning more efficient, compact, and less expensive. Reducing costs of all power electronics components remains a focus.

Controls & Diagnostics – This program element addresses the issue of measuring concentrations of reactant gases and gases potentially damaging to fuel cell components in harsh environments. Sensors using new gas sensing behavior and composite materials are being explored.



Modeling and Simulation **–** Use of modeling and simulation tools can substantially reduce the need to conduct expensive and time consuming hardware tests and will allow for the determination of the operation window of the systems. This would be prohibitively expensive in cost and time if operating complete SOFC systems to failure were required. Modeling aids Industry Teams in optimizing design, predicting performance, minimizing cost, and assessing reliability and life expectancy of SOFC cells, stacks, and systems.

Hybrid Development – In parallel with SOFC module development, efforts are underway to address issues related to integrating SECA SOFCs with gas turbines into a hybrid system to increase thermal efficiencies to program goals established for 2015 – 2020. The technical challenges associated with developing a truly synergistic hybrid primarily reside in achieving optimal operating characteristics between the fuel cell and turbine under various operating conditions.

The Fuel Cell Coal Based Systems (FCCBS) Program – Beginning in FY 2005, the SECA Program includes the scale up of SECA fuel cell modules for central power station applications. FC-CBS is expected to achieve an efficiency of 50 percent (HHV) from coal while capturing 90 percent of the CO_2 with near-zero NO_x emissions. Delivery of a MW-scale unit is currently planned for 2011 (~50 MW).

"Hydrogen can be produced from domestic sources – initially natural gas; eventually clean coal.... That's important. If you can produce something yourself, it means you're less dependant upon somebody else to produce it."

President George W. Bush

Hydrogen from Coal

Program Goal

By 2015, develop and demonstrate an affordable system for producing hydrogen from coal with cost savings of 25 percent compared to existing technology that can be integrated into "zero" emission, coal-based energy plants.

In his 2003 State of the Union address, President Bush announced a $1.2 billion initiative to develop the technology for producing and using hydrogen in tomorrow's cars, trucks, homes, and businesses. Fossil fuels, especially coal, can provide the transition to this hydrogen future by delivering a near- to mid-term source of hydrogen. With carbon sequestration, coal could be used to produce hydrogen for many decades without adding to concerns over the buildup of carbon gases in the atmosphere.

The Hydrogen from Coal program is a direct outgrowth of President Bush's Hydrogen Fuel Initiative. The President has proposed that America begin moving toward a hydrogen future to achieve two primary goals:

Energy Security – Hydrogen-powered fuel cell vehicles offer the best hope of dramatically reversing the Nation's growing dependence on foreign oil.

Climate Change – Vehicles are a significant source of air pollution in America's cities and urban areas. Hydrogen can power cars and trucks without any vehicle pollution.

A related Presidential initiative also envisions hydrogen production as a key core component:

FutureGen –The FutureGen plant is to be the prototype for future pollution-free coal-based facilities that produce electricity and transportation-grade hydrogen while sequestering carbon gases. The plant will employ advanced catalysts, reactors, and membrane separation units developed in the Hydrogen from Coal program.

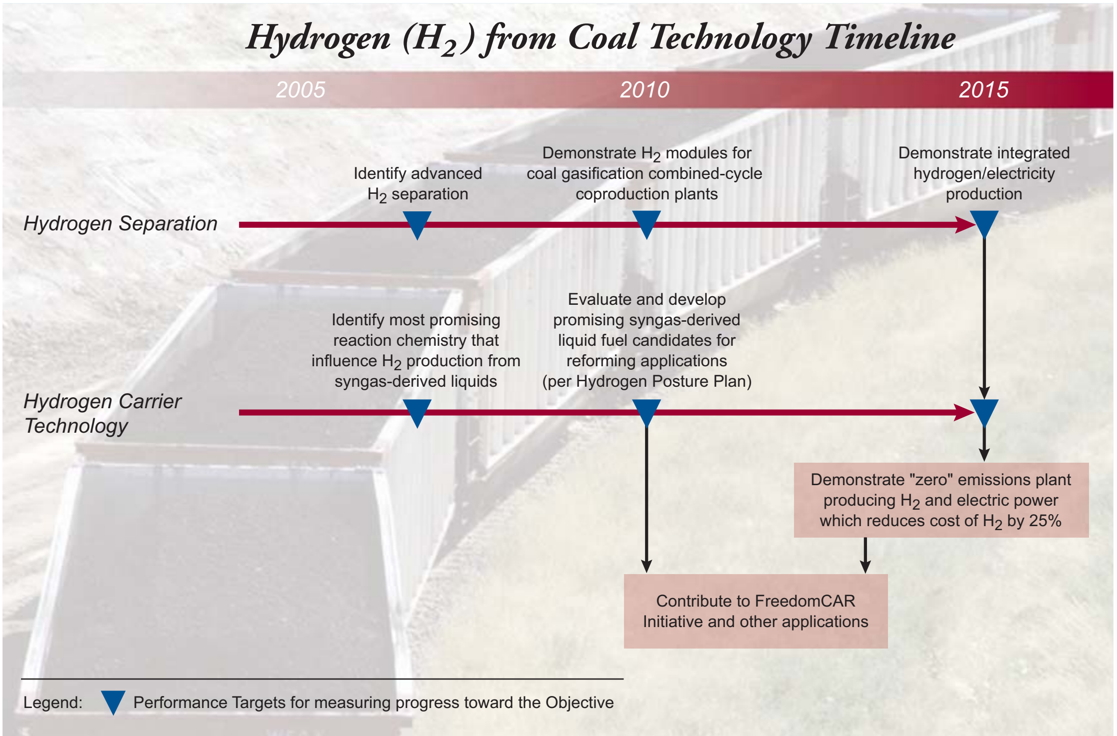
Technology Challenges

Hydrogen can be produced by gasifying coal to generate a synthesis gas consisting mainly of hydrogen and carbon monoxide. The synthesis gas is cleaned, and a water-gas shift reaction increases the hydrogen content and converts carbon monoxide to CO_2. Hydrogen is then separated from the mixed gas stream. Alternatively, the synthesis gas can be converted to hydrogen-rich liquids that can be transported and reformed to produce hydrogen near the end-user.

The Hydrogen from Coal program is focusing on the development of novel technologies in the following areas:

Advanced Water-Gas Shift Reactions – Impurities in synthesis gas can poison catalysts currently used in water-gas shift reactors. Researchers are investigating more sulfur-tolerant catalysts and more durable reactor systems that operate more effectively at a wider range of temperatures (eliminating the need for both high- and low-temperature shift reactions).

Hydrogen Separation – Current hydrogen separation methods all have disadvantages, particularly when subjected to the operating conditions of advanced coal plants. Pressure swing adsorption is limited to modest temperatures; cryogenic systems are economical only in large liquid hydrocarbon facilities; and membranes can be damaged by impuri-



ties in the gas stream and temperature fluctuations. R&D is focused on more durable, thermally tolerant membranes that can separate hydrogen from carbon dioxide. Other approaches being explored include reverse selective membranes and a low-temperature process that forms ice-like hydrates to separate CO_2 from hydrogen.

Alternate Hydrogen Production Pathway – Computational studies and laboratory/bench scale research and analysis are being conducted to determine candidate liquid fuel hydrogen carriers which would use the existing delivery infrastructure.

Hydrogen Delivery – Because of the small size of its molecules, hydrogen can leak easily from conventional gas and oil pipeline and handling systems – a barrier that must be overcome. Also, hydrogen is known to cause embrittlement of high strength steels, requiring new materials and system modifications if natural gas pipelines are to deliver hydrogen/natural gas mixtures. As an alternative to gas pipeline transport, researchers are also developing ways to extract hydrogen from liquid fuels cost effectively at or near the end-use site.

Hydrogen Storage – The energy density of hydrogen is the lowest of any gaseous fuel. The Fossil Energy hydrogen program is working with the DOE Office of Energy Efficiency and Renewable Energy to study advanced storage devices with adequate energy densities.

Component Integration – Combining several stages of the hydrogen from coal process could achieve higher throughputs and lower overall costs. Researchers are examining ways to integrate hydrogen separation and the water-gas shift reaction into novel processing concepts. Similarly, technologies are being studied that reduce the steps needed to separate CO_2, hydrogen sulfide, and other impurities from hydrogen in synthesis gas streams.

"Let's make sure we utilize coal in America. Clean coal technology is important."
President George W. Bush

Clean Coal Power Initiative

Program Goal

- To reinvigorate private sector development of new coal-based power technologies that can meet increasingly stringent environmental regulations; and
- To begin establishing the technological foundation within the Nation's power industry for "zero" emission coal-based energy facilities.

The Clean Coal Power Initiative (CCPI) is a cost-shared partnership between the government and industry to develop and demonstrate advanced coal-based power generation technologies, structured as a series of nationwide competitions conducted in response to President Bush's pledge to invest $2 billion over a 10-year period in a new generation of clean coal technologies. The mission of the CCPI is to enable and accelerate deployment of advanced technologies to ensure that the United States has clean, reliable, and affordable electricity.

When the President announced his clean coal commitment in 2001, it had been nearly a decade since a major competition had been held to solicit industry's most promising concepts for clean coal-based power generation.[1]

During that time, new technologies had emerged from public and private sector R&D.

Improved coal burner and gasifier designs, better gas cleaning systems, higher performance turbines, and lower cost fuel cells, for example, have shown promise for lowering emissions and boosting fuel efficiencies. Advances in computational technology have produced new control systems running off neural networks and computational intelligence that can "fine-tune" combustion processes to peak efficiency, reducing air emissions and lowering operating costs.

Also since the last major clean coal technology competition, more stringent environmental standards have been put into place, most directly affecting coal-burning power plants. For example, mercury emissions from coal-fired power plants will be regulated for the first time; National Ambient Air Quality Standards have been revised to reduce the levels of airborne particulate matter; and new regulations to reduce the regional transport of ozone now require many utilities to further reduce nitrogen oxide emissions. Moreover, the Administration has proposed the Clear Skies Initiative (CSI) which calls for 70 percent reductions in sulfur dioxide, nitrogen oxides, and mercury over 15 years, the most aggressive environmental initiative in the Nation's history.

Begun in 2002, CCPI competitions are modeled after the original Clean Coal Technology Program, and winning projects are carried out as joint Government-industry ventures with private industry responsible for proposing candidate technologies, selecting sites, and designing, constructing, and operating the projects. Private sector cost-sharing must be at least 50 percent.

[1] The final solicitation in the original Clean Coal Technology Program was issued in July 1992. In 2001, DOE conducted a more narrowly focused competition in the Power Plant Improvement Initiative that called for technologies that could be implemented rapidly to enhance the reliability of the Nation's power grid.

CCPI Round I Projects

New Technologies for Clear Skies

One of the projects in Round I is directed at demonstrating a new way to comply with the President's Clear Skies initiative, which calls for dramatic reductions in air pollutants from power plants over the decade-and-a-half. It was proposed by:

- **Wisconsin Electric Power Company, Milwaukee, WI**, which would install a high-tech process called "TOXECON," that will absorb mercury and other air toxic emissions from the flue gases of its Presque Isle Power Plant in Marquette, MI. Mercury is one of the most difficult of air pollutants to reduce, and if this project is successful, the technology could become one of the most effective choices for mercury control on power plants that burn western coals. The project will also include testing of chemical additives that could also reduce nitrogen oxide and sulfur dioxide emissions. DOE is providing $24.8 million of the project's $50 million total cost.

Higher Efficiencies to Meet Climate Change Goals

Three other projects are expected to contribute to President Bush's Climate Change initiative to reduce greenhouse gases. Two of the projects will reduce carbon dioxide, a primary greenhouse gas, by boosting the fuel use efficiency of power plants. A third project will demonstrate a potential alternative to conventional Portland cement manufacturing, a large emitter of carbon dioxide. The three were proposed by:

- **Great River Energy of Underwood, ND,** will team with the Electric Power Research Institute to enhance the fuel value of lignite by using the waste heat of a power plant to dry nearly a quarter of the moisture in the lignite before it is fed into a power plant boiler. For power plants that burn high-moisture lignite, the technology could boost overall generating capacity, meaning power would be produced more efficiently from a lower volume of fuel. The $25.6 million project will take place at the company's Coal Creek Station in Underwood. DOE is expected to provide $11 million of the cost.

- **NeuCo, Inc., of Boston, MA,** will apply a series of sophisticated computational techniques, including neural networks, advanced algorithms, and "fuzzy" logic, to achieve peak performances from a power plant's combustor, soot removal system, and emission controls - the first time ever that all of these modules have been integrated into a computerized process network. The $19.1 million demonstration will take place at Dynegy Midwest Generation's Baldwin Energy Complex in Baldwin, IL. DOE is providing $8.6 million.

- **University of Kentucky Research Foundation, Lexington, KY,** will team with LG&E Energy Corporation, for a second project at the Ghent Power Station in Ghent, KY. The team proposes to demonstrate an advanced process for separating unburned carbon from power plant ash or from ash ponds and recycling it for fuel. The process upgrades the ash to make it suitable for producing a high-strength alternative to Portland cement called "pozzolan." The climate change benefit comes from the potential of the new process to reduce the manufacture of Portland cement, one of the highest generators of carbon dioxide, a greenhouse gas, of any industrial process. DOE is providing $4.5 million of the project's $9.0 million cost.

Clean Energy from Coal Waste Piles

Two additional projects will reduce air pollution through advanced gasification and combustion systems designed to extract the energy potential of waste coal piles scattered throughout many areas of Pennsylvania and West Virginia as a new source of fuel. The unsightly legacy of old mining practices, these waste piles are a potential sources of soil and water contamination. As much as 400 million tons of this material exist in West Virginia alone with some 200–300 million tons found across Pennsylvania. The two projects are proposed by:

- **Waste Management and Processors Inc. (WMPI PTY., LLC) of Gilberton, PA,** which will head a team to build and operate a power plant that will produce clean electricity, high-value industrial heat, and nearly 5,000 barrels per day of clean-burning diesel fuel from raw anthracite wastes. At the core of the advanced process will be a coal gasification process that will turn the wastes into a chemically-rich source of gas. A portion of the gas will be converted into diesel while the rest will be combusted to make electricity and steam. Planned for a 75-acre site adjacent to the existing Gilberton Power plant, the $612 million project is the largest of the eight projects selected. DOE's share is proposed at $100 million.

- **Western Greenbrier Co-Generation, LLC,** a newly-formed public service entity serving the West Virginia municipalities of Rainelle, Rupert and Quinwood, will team with several research and engineering firms to demonstrate an innovative circulating fluidized bed coal combustor linked to an advanced multi-pollutant control system. The 75-megawatt plant will be fueled by a four million ton refuse site at Anjean, WV. The plant will also produce steam for industrial use and district heating. Integrated into the power facility will be a technology to convert ash from the boiler and green wood waste into structural bricks. The facility is expected to serve as the "anchor tenant" for a new "Eco-Park." DOE's share of the $215 million project is $107.5 million.

Round I – The initial CCPI competition began in March 2002 when DOE issued a solicitation offering $330 million in federal matching funds for industry-proposed projects. In January 2003, the Secretary of Energy announced that eight projects, valued at more than $1.3 billion, would make up the first round of the CCPI. Subsequently, two of the eight projects were withdrawn.

In Round I, the criteria for candidate projects was very broad — specifically, the solicitation was open to “any technology advancement related to coal-based power generation that results in efficiency, environmental, and economic improvement compared to currently available state-of-the-art alternatives.” In many respects, Round I was intended to capture a snapshot of the full range of technological advancements made since the last major clean coal technology solicitation had been issued in the early 1990s.

Round II – Round II began in February 2004, when DOE issued a solicitation offering approximately $280 million in Federal funds. In this round, the Department cited four major categories of technologies in which it had specific interest: (1) gasification and new power plant technologies, (2) mercury control technologies, (3) carbon management technologies, and (4) environmental control technologies. The choice of these categories reflected the Department’s judgment of the most pressing technological needs confronting the Nation’s power industry in the 2010 to 2020 time period.

In October 2004, the Secretary of Energy announced that four projects, valued at $1.8 billion, would comprise the second round of the CCPI. Of the four projects, two will demonstrate advanced IGCC technology; one will demonstrate an innovative multi-pollutant control process for NO_x, SO_x, and mercury; and one will demonstrate a neural network control process for advanced multi-pollutant controls by means of plant optimization.

Strategies for Future CCPI Competitions – The Office of Clean Coal Strategic Plan envisions future rounds of CCPI competitions to increasingly emphasize cutting-edge technologies. For example, rather than reducing emissions of a single pollutant, future pollution control projects will be encouraged to combine technologies into multi-pollutant control “packages” that can achieve superior environmental effectiveness at the lowest possible costs. The remaining competitions are also likely to emphasize advanced technologies for reducing greenhouse gas emissions through dramatic improvements in fuel use and power generating efficiencies, or by carbon capture and sequestration, or perhaps a combination of both.

CCPI Round II Projects

The following projects were selected from 13 proposals in the 2nd round of competition for joint government-industry financing:

- ***The Peabody Mustang Clean Coal Project*** teams Peabody Energy with co-sponsor Airborne Clean Energy, along with Veolia Water North America, and Icon Construction, in a commercial-scale demonstration of the "Airborne Process" scrubber, regeneration system, and fertilizer production systems at the Mustang Energy Company LLC's 300 MW coal-fired Mustang Generating Station in Milan, New Mexico.

  The $79 million project, for which the Energy Department will provide $19.7 million, will develop an innovative and cost-competitive multi-pollutant control process for achieving 99.5 percent removal of sulfur dioxide, 98 percent removal of SO_3 (sulfuric acid mist precursor), 98 percent removal of nitrogen oxides, and 90 percent total system removal of mercury from plant emissions, while turning the byproducts into a high-quality high-value granular fertilizer.

- ***Southern Company Services***, in a team effort with Southern Power Company, Orlando Utilities Commission, and Kellogg Brown and Root, will construct a 285-megawatt coal-based gasification plant near Orlando at the Orlando Utilities Commission's Stanton Energy Center in Orange County, Florida. Southern Company plans to demonstrate use of an air-blown integrated gasification combined cycle power plant based on the transport gasifier, which employs Kellogg Brown and Root's catalytic cracking technology that has been used successfully for over 50 years in the petroleum refining industry. The total cost for the demonstration project is $557 million, of which DOE will contribute $235 million as the federal cost share.

- ***Excelsior Energy Inc.***, in a team effort with ConocoPhillips, will receive $36 million in DOE funds for partial support of a $1.18 billion project to construct and operate the 531-megawatt Mesaba Energy Project in Hoyt Lakes, Minnesota. DOE's contribution would be used to demonstrate the next generation of Integrated Gasification Combined Cycle power plants. The Mesaba project would upgrade the performance of gasification-based power plants based on lessons learned at the Wabash River Coal Gasification Repowering Project in Terre Haute, Indiana, which was constructed under the Department of Energy's Clean Coal Technology Program and has been operating since 1995. Excelsior expects the Mesaba Project to achieve 15 percent improvement in gasification plant availability and improved thermal efficiency at lower installed costs.

- ***Pegasus Technologies, Inc.***, in a joint effort with Texas Genco, will demonstrate advanced multi-pollutant controls, including mercury reduction, at an existing 890-megawatt utility boiler at Jewett, Texas. Using non-intrusive advanced sensor and optimization technologies, the demonstration project is intended to minimize emissions while maximizing the electric power generating efficiency of the plant. Pegasus plans to apply advanced state-of-the-art sensors and neural network based optimization and control technologies to maximize the oxidation or capture of mercury vapor in the boiler flue gas. Artificial intelligence and simulation technologies would control and optimize all the major facets of a power plant. A "cold-side Electrostatic Precipitator" rated at approximately 99.8 percent particulate removal efficiency and a wet limestone flue gas desulfurization system rated at approximately 90 percent SO_2 removal efficiency will also be used to reduce air emissions. Both of the devices would potentially be capable of removing mercury from the unit's flue gas. Pegasus will receive $6.1 million in DOE funds to conduct this $12.2 million project.

"...it's conceivable and hopeful we'll have a zero-emissions coal plant, which will be not only good for the United States, but it would be good for the world."

President George W. Bush

FutureGen Project

Program Goal

- The primary goal of FutureGen is to validate the technical feasibility and the economic viability of "zero" emissions energy from coal and in the process gain broad acceptance of this concept as one solution for future energy and environmental security. The key to successfully achieving this goal is the large-scale system integration and testing of scaled-up technologies for incorporation into the FutureGen project.
- By 2012, begin operation of a nominal 275-megawatt (MW) prototype plant that will produce electricity and hydrogen from coal with "zero" emissions and prove the effectiveness, safety, and performance of CO_2 sequestration.
- By 2016, complete operation of the FutureGen plant. The successful prototype would result in the replication of "zero" emission coal plants that could produce electricity at no more than a 10 percent increase in cost over a conventional plant and produce hydrogen at $4/million Btu (wholesale).

FutureGen will be the forerunner of futuristic power plants that could essentially eliminate environmental concerns over the use of coal. It will emit virtually no airborne pollutants, and no wastewater will be discharged. Solid wastes will be converted to commercially valuable, environmentally benign products. Carbon dioxide will be captured and permanently sequestered.

When it becomes operational early in the next decade, FutureGen will produce both electricity and commercial-grade hydrogen — the first plant in the world to produce these two products simultaneously.

FutureGen will be sized to produce the nominal equivalent of 275 MW of electricity — the scale necessary to adequately validate emerging technologies. The project is estimated to cost approximately $1 billion which will be shared by the U.S. Government, industry, and international partners.

In the Office of Clean Coal strategy, FutureGen is not a separate program. Rather, it is a large-scale research project that will serve as the proving ground for many of the major technology products pioneered elsewhere in the Office of Clean Coal. Many of these new concepts initially will be developed as individual sub-systems. FutureGen, however, is to be a "new breed" of power plant that will incorporate these concepts into a single integrated system. Designed from the start to function at optimum efficiency, this combination of high-tech concepts will push the environmental and economic performance of tomorrow's power plants to levels unimaginable a few years ago.

Technology Challenges

FutureGen's critical enabling technologies include advanced gasification, oxygen production, hydrogen production, gas cleanup, hydrogen turbines, fuel cells, and fuel cell/turbine hybrids, advanced materials, instrumentation, sensors and controls, by-product utilization, carbon sequestration, and integration.

Advanced Gasification – The transport gasifier is one of several promising candidates for FutureGen because of its high throughput relative to size, simplicity, and reduced operating temperature compared to current gasifiers. The transport gasifier has been operated in the air-blown mode at the Power Systems Development Facility (PSDF) in Wilsonville, Alabama; however, oxygen-blown operation is required for FutureGen, and PSDF's oxygen-blown testing is in its early stages.

Oxygen Production – Initially, FutureGen will employ state-of-the-art cryogenic air separation to provide the 2,000 tons per day of oxygen to operate the gasifier. Current oxygen production equipment, however, can result in substantial efficiency and cost penalties for an integrated gasification combined cycle plant, consuming 15 to 20 percent of a plant's power output and accounting for 15 to 25 percent of the plant's operating cost. Therefore, if successfully developed, advanced ion transport membranes could be integrated into FutureGen as a lower-cost, more efficient approach to oxygen production.

Hydrogen Production – Similarly, today's conventional means for producing hydrogen from coal are energy intensive and reduce a plant's fuel efficiency dramatically. Hydrogen separation membranes are one alternative that could reduce cost and improve the efficiency of hydrogen production. R&D is focused on overcoming obstacles that prevent the use of large-scale membranes in commercial systems.

in Clean Coal Power Initiative projects and are likely to be ready in time for FutureGen testing.

Hydrogen Turbines – Limited short-term testing has indicated that pure hydrogen can be fired in current ("F-Class") turbines now used in the Wabash River and Tampa Electric integrated gasification power plants. Key technical issues remain, however, including hydrogen embrittlement, premix flame flashback, hot section material degradation, and effective NO_x control.

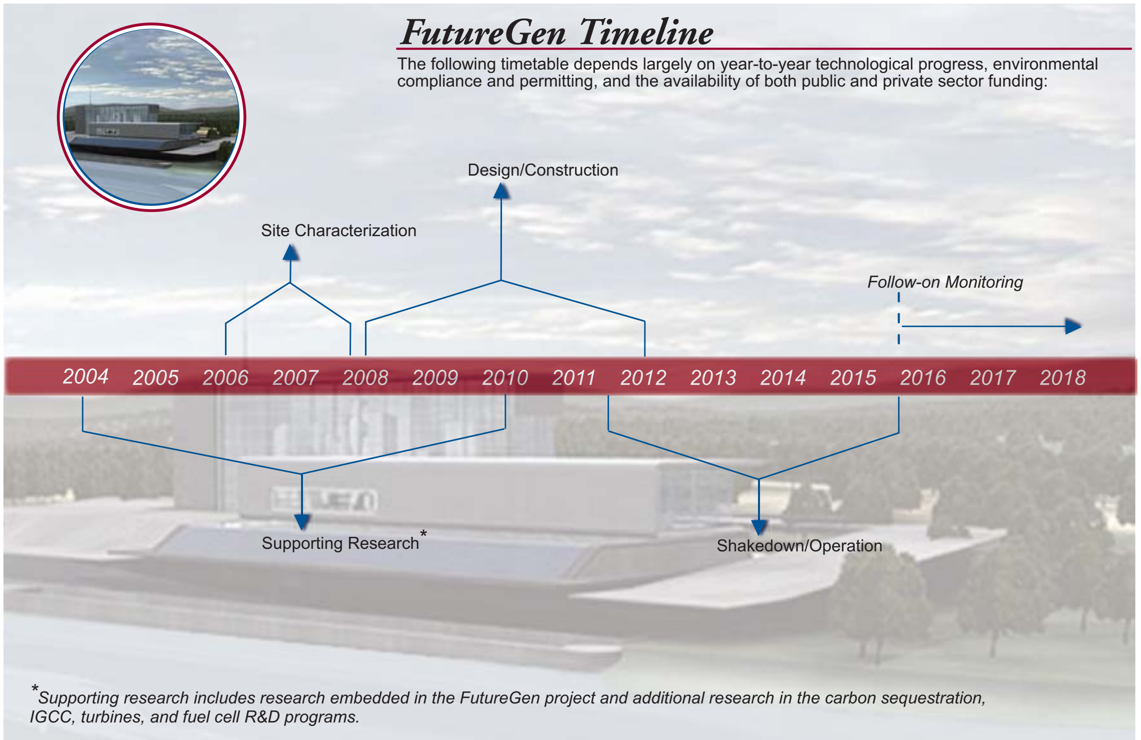
Fuel Cells and Fuel Cell/Turbine Hybrids – DOE has a major R&D effort underway to reduce fuel cell costs by nearly ten-fold while improving performance and operating life. These lower cost, solid-state fuel cells are likely to

A DOE laboratory researcher holds a metal-supported ceramic membrane. The thin membranes are applied to the inner surface of the tubular supports. These membranes are used for the separation and purification of hydrogen.

Gas Cleanup – Gas cleanup is necessary not only to eliminate harmful emissions but to protect downstream components from damaging contaminants. New gas cleanup technologies, including novel sorbents and selective catalytic oxidation, are being developed to remove mercury, chlorides, and ammonia. Several are expected to be tested on slipstreams

be the building blocks of future fuel cell/turbine hybrid power systems. At the current pace of development, these hybrid power systems should be ready for testing at FutureGen.

Advanced Materials, Instrumentation, Sensors, and Controls – DOE's R&D is developing materials, sensors,



and other components for use in the hostile, high-temperature environments likely to be encountered in FutureGen and other advanced power and fuels systems. New steels for boiler tubes could be especially important in improving combined cycle efficiencies by increasing the temperature and pressures of the steam used in the bottoming cycle. Super alloys could play important roles in high-performance gas turbines. FutureGen also could be a showcase for "smart" plants in which advanced sensors and diagnostic equipment enhance reliability while reducing the need for costly redundant components.

By-product Utilization – The "zero" emission goal of FutureGen will require new concepts for recycling or converting liquid and solid waste effluents. Many by-product utilization concepts being developed in this R&D effort, especially the commercial application of slag/bottom ash and the production of sulfur/sulfuric acid, could be demonstrated in FutureGen.

Carbon Sequestration – Integration with carbon capture and sequestration distinguishes FutureGen from other power projects and also represents its highest technical risk. Carbon dioxide will be separated from coal gases and captured at the plant for permanent placement in stable geologic formations (possibly deep, non-potable salt water reservoirs, oil or gas reservoirs, unmineable coal seams, or volcanic basalt formations). No plant in the world has been built with this capability. Importantly, FutureGen will pioneer geologic sequestration on a scale large enough to help determine whether it is a viable approach for 21st century carbon management. It will sequester one million metric tons or more of CO_2 per year, sufficient to gauge the behavior and retentive capabilities of geologic formations for future commercial sequestration.

Integration – Integrating these advanced technologies into a reliable, interdependent energy system will likely prove one of FutureGen's most daunting technical challenges. "Virtual engineering" could be an important innovation in this effort. Sophisticated computer modeling may soon be capable of engineering new power and fuels processes and simulating their integrated performance. FutureGen could be the proving ground for many of these "virtual engineering" concepts.

Pioneering New Partnerships

FutureGen will pioneer more than just new technologies. It will create an opportunity for new partnerships that could lead to worldwide acceptance of carbon sequestration and "zero" emission coal plants.

Under guidance of a government steering committee, an industry consortium will choose a host site and design, construct, and operate the FutureGen plant. To ensure that concepts pioneered at FutureGen are adopted by a broad cross-section of the coal and electricity industries, DOE is requiring that consortium members collectively own and produce at least one-third of the Nation's coal and generate at least one-fifth of the Nation's coal-fueled electricity. The consortium will be expected to contribute at least 20-25 percent of the project's total cost.

DOE also expects the consortium to be "open" — working to expand its initial membership to include other coal producers and power generators from the United States and abroad. International participation in FutureGen is being encouraged through various mechanisms, including the Carbon Sequestration Leadership Forum. DOE will also provide opportunities for other governments to become members of the steering committee.

"The quality of research produced by our universities, industrial and national laboratories is unsurpassed by any other Nation…As we act to make our system even stronger, let us be proud of the strengths of the United States research and development enterprise."

John H. Marburger, III
Director, Office of Science and Technology Policy
Executive Office of the President

Advanced Research

Program Goal

To support the Office of Clean Coal mission by:

- Developing a scientifically sound understanding of critical process issues confronting new coal-based energy systems;
- Exploring new avenues around critical crosscutting barriers;
- Advancing scientific knowledge across all coal and power systems areas; and
- Engaging the Nation's academic institutions to expand knowledge in critical research areas and educate and train future generations of technological leaders.

An underlying strength of the Office of Clean Coal is its continuing effort to translate knowledge acquired in the Nation's basic research laboratories into new frontiers of science and engineering that can be applied to the coal-fueled energy plants of tomorrow.

The Advanced Research program serves as this "bridge" between fundamental research and the program's core technology development efforts. Researchers and program managers work closely with their counterparts in DOE's Office of Science and other research centers to screen advances in energy science for possible application to future coal and power systems. The emphasis is on pre-competitive engineering research that can foster transformational breakthroughs in materials, sensors and controls, biotechnology and bioprocessing, pollutant formation and removal, and advanced computational processes.

Technology Challenges

The Advanced Research program supports the Office of Clean Coal vision of a future fleet of ultra-clean, multi-product, coal-fueled energy plants. Some of the major technology challenges being addressed are:

Scientific Understanding of Critical Process Issues – Researchers in this area are investigating the way coal burns, changes into useful gases, or behaves in advanced energy systems. The objective is to discern rates and mechanisms that control coal combustion or gasification. This research has already produced important advances in the science of coal utilization. Many of today's low-NO_x burners and advanced reburning technologies are based on the kinetic data and models developed in this area. Several commercial and research-oriented combustion and fluid dynamics codes rely on the mechanistic models that originated in Advanced Research projects.

Now, with EPA regulations and the President's Clear Skies Initiative setting new emission control targets, this area of research is focusing on enabling technologies that can lead to even more advanced combustion and gasification processes as well as more effective means for separating pollutant-forming gases.

New Concepts – It is in this area of Advanced Research where innovative ideas first take shape. The strategy is to first explore the technical feasibility of promising concepts at the laboratory- and bench-scale. If the concepts continue to show promise for advancing the program's mission, they are ultimately transferred into existing or new core technology development efforts.

One new concept taking shape in the Advanced Research program is mineral carbonation — a promising way to sequester carbon dioxide. Groundbreaking research is underway to accelerate the uptake of CO_2 in chemical reactions that form solid, stable carbonates. Where once it took several days for the reaction to absorb most of the CO_2, researchers have reduced the time to minutes. The focus is now on reducing overall energy consumption and exploring ways for the carbonation process to take place deep underground, possibly within saline aquifers.

Bioprocessing is another cutting-edge concept being explored for its potential applications to future coal-based energy systems. Researchers are studying ways to use microbes to extract clean-burning hydrogen for carbon-containing waste products, opening a new low-cost path towards the President's goal of a future hydrogen-based transportation system. Biotechnology could also help remediate fly ash ponds and waste discharges from coal-fueled power plants, or perhaps one day absorb high levels of greenhouse gases from a power plant's exhaust gas or from the atmosphere itself.

Crosscutting Research – Several areas of Advanced Research can benefit multiple Office of Clean Coal technologies. One of the newest focus areas of research is in Computational Energy Sciences. Software engineers are developing new computational tools capable of assessing design options, resolving engineering problems, and simulating the operation of scaled-up subsystems and components. When fully developed, these tools will reduce the number of large and expensive demonstration-scale tests needed.

Advanced sensors and controls are another area that can benefit multiple advanced coal-based processes. High-tech sensors and integrated control systems are being developed to provide more accurate, real-time measurement of key parameters in harsh, in-situ combustion and gasification environments.

Materials research is another area that is vital to higher performance and more economic fossil energy systems. Research is evaluating improved alloys for application to ultra-supercritical steam cycles (up to 1400 ºF and 5,500 pounds per square inch). New high-temperature, corrosion-resistant structural ceramic composites and alloys are being developed for the FutureGen prototype power plant. Studies are also underway on new membrane materials that could achieve very low-cost hydrogen and oxygen separation from mixed gas streams.

Engaging Academic Institutions – The Nation's universities have been, and continue to be, important partners in the Office of Clean Coal strategy. By providing research grants to the Nation's academic institutions, opportunities are created for new discoveries in coal-based science and technology. Equally important, future generations of scientists and engineers receive hands-on experience in coal research.

The Office of Clean Coal sponsors academic research grants in the University Coal Research Program. Annual competitions are held to fund the best coal science and technology research proposals submitted in response to specific areas of emphasis identified by the department. Since these grants became available, more than $100 million has been provided and more than 1,700 students have acquired invaluable experience in understanding the science and technology of coal.

"We must work with our international partners to encourage all nations...to create positive investment climates and utilize the latest technologies and alternative energy sources to meet their energy needs in the most efficient and environmentally sensitive ways."

Energy Secretary Samuel Bodman

International Collaboration

Program Goal

The International program supports the Office of Clean Coal strategic goals by:

- Engaging the global scientific and policy-making community through partnerships and organizations to address common fossil energy-related environmental issues;
- Leveraging U.S. resources and influencing international attitudes toward clean coal technologies;
- Contributing to domestic energy security by encouraging global energy diversity through increased use of coal and clean coal technology;
- Obtaining pre-commercial research data to accelerate the achievement of U.S. research objectives; and
- Creating opportunities for the sale of clean coal technologies (goods and services).

Many of America's energy challenges are not confined by the Nation's borders — nor are their solutions. Concerns over climate change and the airborne transport of pollutants are matters that affect citizens both within and outside the United States.

The Office of Clean Coal strategy recognizes the value of global alliances in meeting both energy and environmental challenges. Many nations depend on the same fuel sources as the United States. China and India, for example — two countries that are projected to account for 30 percent of the world's total increase in energy consumption over the next 20 years — are powering much of their economic growth with steadily increasing amounts of coal.

If our strategy is successful in producing a new generation of coal plants that are both ultra-clean and affordable, the technology may be used throughout the world, yielding global environmental benefits, improving social and economic stability, and providing significant trade and investment opportunities to U.S. businesses. If we can show the effectiveness of carbon sequestration, the world will have an important new option for countering concerns over global climate change.

For these reasons, the Office of Clean Coal strategy places a high priority on encouraging the active engagement of U.S. researchers and technology developers in international forums. The strategy emphasizes the importance of strong bilateral and multilateral relationships that focus the expertise of the international technical community on sustainable technologies that make the most efficient use of the world's most abundant energy resources, including coal.

Mechanisms

The Clean Energy Collaboration Office coordinates the international initiatives of the Office of Clean Coal. Following are examples of the mechanisms applied in each of the support areas identified above:

Engaging the Global Community – The strategy calls for a continuing leadership role in the long established International Energy Agency Working Party on Fossil Fuels, the World Energy Council, and the United Nations Economic Commission for Europe, which address a broad range of coal-related environmental issues. The Administration launched the Carbon Sequestration Leadership Forum (CSLF) in June 2003. It is an organization of 17 members and is an international climate change initiative that is focused on development of improved, cost-effective technologies for the separation and capture of carbon dioxide for its transport and long-term safe storage. The CSLF is implemented within the Office of Clean Coal, which is responsible for Secretariat functions.

International participants at the 2nd Ministerial Meeting of the CSLF held September 13-15, 2004, in Melbourne, Australia.

Facilitating Export of U.S. Technology – International collaboration activity includes maintaining an active role in the Asia-Pacific Economic Cooperation's Regional Energy Cooperation Working Group, designed to share knowledge for the purpose of defining market requirements and building institutional infrastructures conducive to trade. Bilateral agreements are in place with China and India, where the greatest expansion in coal-based power generation will occur over the next two decades; these agreements encompass training of personnel, creating trade-friendly business environments, information exchange, and joint projects. Key elements of this strategy are technical training, operational skills development, and technical information transfer to impart knowledge of U.S. technologies abroad.

Through bilateral mechanisms, the Office of Clean Coal maintains a capability to facilitate direct dialogues between key decision makers in partner countries with developers and operators of advanced U.S. clean coal technologies. These dialogues are implemented through media such as plant tours and events specifically focused on developing opportunities through the bilateral relationships.

Continued from Inside Front Cover

1980s

1984
The "Cool Water" experimental power plant comes on line near Daggett, CA, demonstrating the "integrated gasification combined-cycle" technology.

1986
The U.S. begins the first Clean Coal Technology Program to demonstrate cleaner ways to use coal.

1987
The Nation's first utility fluidized bed combustion system starts up at the Nucla plant in Colorado.

1990s

1991
The first of a new generation of "low-NOx" combustors are installed in utility power plants as part of the Clean Coal Technology Program. Ultimately, more than 3/4ths of all coal-fired utility power plants in the United States will install these types of cleaner coal burners.

1993
With mercury singled out as a "hazardous air pollutant" by the 1990 CLean Air Act Amendments, DOE begins an intensive effort to provide EPA with critical data on utility mercury emissions.

1995
The U.S. electric utility industry takes a major step into the future of clean, high-efficiency electricity from coal with the dedication of the Wabash River Coal Gasification Power Plant in West Terre Haute, IN. The joint government-industry Clean Coal project "repowers" an aging coal-fired power plant with a much cleaner, more efficient 260-megawatt "integrated gasification combined cycle" process.

1997
The nation's second full-scale integrated gasification combined-cycle plant is dedicated outside Lakeland, FL. The Tampa Electric Polk Power Station, also a Clean Coal Technology project, is the first U.S. utility station to be built solely as a "grassroots" gasification power plant.

2000s

2000
DOE's Fossil Energy program awards funding for the first full-scale testing of two advanced approaches for reducing mercury emissions from coal-fired power plants.

With R&D support from DOE, GE Power Systems unveils the first gas turbine slated for the U.S. market that would break through the temperature barriers that had essentially capped the efficiencies of older turbines. GE's H-System turbine would soon be joined by Siemens-Westinghouse's W501G turbine, another product of DOE's research program, as the two most advanced gas turbines in the world.

2002
The largest fluidized bed combustors ever installed in a utility power plant begin operating in Jacksonville, FL, as part of the Clean Coal Technology Program.

2003
President Bush announces the FutureGen initiative to build a $1 billion, coal-fueled prototype plant that will co-produce electricity and hydrogen while preventing air pollutants and greenhouse gases from being released into the atmosphere.

... A Commitment to a Cleaner Future

For More Information,
Please Contact:

Office of Fossil Energy
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585
(202) 586-6503

National Energy Technology Laboratory (NETL)
U.S. Department of Energy

Morgantown Location:

3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507-0880
(304) 285-4764

Pittsburgh Location:

626 Cochrans Mill Road
Pittsburgh, PA 15236-0940
(412) 386-4687

Printed in the United States on Recycled Paper

September 2006