FutureGen

Integrated Hydrogen, Electric Power Production and Carbon Sequestration Research Initiative

Energy Independence through Carbon Sequestration and Hydrogen from Coal

United States Department of Energy
Office of Fossil Energy

March, 2004

A Program Plan for FutureGen

An Integrated Hydrogen, Electric Power Production and Carbon Sequestration Research Initiative

This report is submitted pursuant to Conference Report No. 108-330, dated October 28, 2003, accompanying Public Law 108-108, Department of Interior and Related Agencies Appropriation Act, 2004. The conference report identifies $9,000,000 to initiate the "FutureGen program." It further directs that, "The funds provided for the FutureGen program are contingent on the receipt of a complete program plan that clearly and fully delineates by project and by year the funding for each element of, and milestone associated with, the FutureGen program. This plan should be closely coordinated with industry cooperators and submitted to the House and Senate Committees on Appropriations no later than December 31, 2003. The managers understand the need for a lower cost share for the initial research and planning stages of the FutureGen program, but any demonstration component must include at least a 50 percent industry cost share."

Mission Need and Background

On February 27, 2003, the President announced FutureGen, a $1 billion cost-shared project to create the worlds first coal-based, zero emissions electricity and hydrogen production power plant. This project supports recommendations in the National Energy Policy (NEP) issued in May 2001, which highlights the need for a broad policy to "protect national and economic security by promoting a diverse, secure source of reliable, affordable and environmentally sound energy," and recognizes that "... if rising U.S. electricity demand is to be met, then coal must play a significant role."

FutureGen directly addresses one of the four strategic goals contained in the Department of Energy's (DOE's) 2003 Strategic Plan: "To protect our National and economic security by promoting a diverse supply and delivery of reliable, affordable, and environmentally sound energy." By eliminating environmental issues as barriers to coal use through the use of efficient generation technologies and carbon sequestration, FutureGen will enable the continued use of secure, domestic coal resources for our future energy needs. The production of hydrogen from FutureGen will support the President's Hydrogen Fuel Initiative to create a hydrogen economy for transportation, and FutureGen will also provide a unique real-world opportunity to prove the feasibility of large-scale carbon sequestration, a key potential strategy to reduce the risks of climate change. Widespread replication of this technology by the private sector will help to meet the energy and environmental needs of our Nation's expanding economy, growing population, and rising standard of living. Absent the zero-emission option of FutureGen, coal's contribution to the Nation's energy mix could be severely curtailed, thus limiting the fuel diversity of our electricity supply portfolio, and increasing our dependence on more expensive and less secure sources of energy.

Specifically, DOE's Office of Fossil Energy works to ensure that coal remains part of the Nation's diverse energy supply. The Fossil Energy (FE) program's goals are stated in the Coal and Power Systems Strategic Plan, and include:

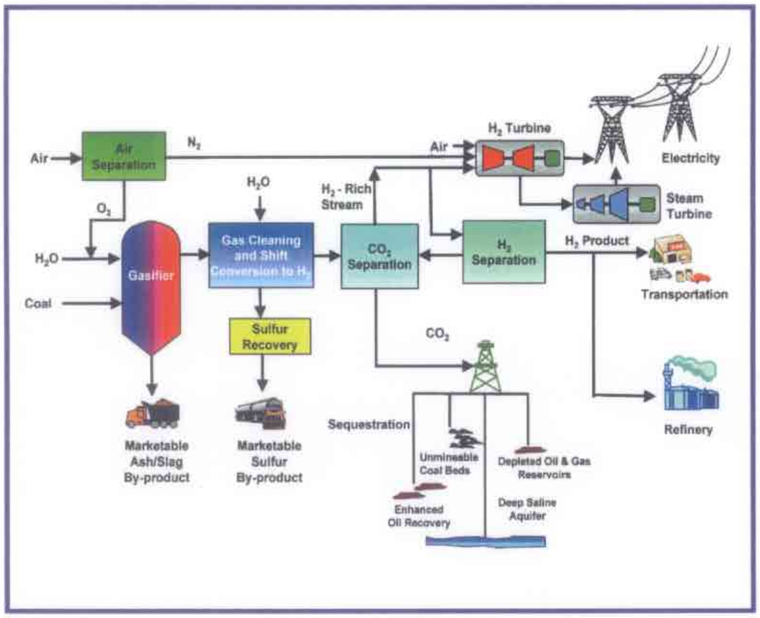
- Eliminating environmental issues as barriers to fossil fuel production and use, while maintaining the availability and affordability of fossil fuels;
- Ensuring the availability of secure, affordable liquid fuels and reliable electricity;
- Providing scientific and technological information and analysis to assist policymakers and regulators in their decision making;
- Focusing on public benefits-driven investment in high-risk, high-return technology that private companies alone cannot undertake; and
- Creating viable fossil energy technology options to address global climate change.

FutureGen's integration of concepts and components is key to proving technical and operational viability to the generally conservative, risk-adverse coal and utility industries. Integration issues such as the dynamics between upstream and downstream subsystems (e.g., between interdependent subsystems such as the coal conversion and power and hydrogen production systems and carbon separation and sequestration systems) can only be addressed by a large-scale integrated facility operation. Unless the production of hydrogen and electricity from coal integrated with sequestering carbon dioxide can be shown to be feasible and cost competitive, the coal industry will not make the investments necessary to fully realize the potential energy security and economic benefits of this plentiful, domestic energy resource.

Summary Project Description and Scope

The FutureGen plant is planned to operate as a nominal 275 MW (net equivalent output) facility that produces both electricity and hydrogen and sequesters one million metric tons of carbon dioxide per year. FutureGen will contain components which constitute high risk research activities as well as components which are commercial demonstration. The FutureGen project will employ advanced generation coal gasification technology integrated with combined cycle electricity generation, hydrogen production, and capture and sequestration of carbon dioxide (CO_2). When operational, this zero-emission facility will be the cleanest fossil fuel-fired power plant in the world. The project will require at least 10 years to complete, with results shared among all participants, industry, the environmental community, and the public. DOE will also invite participation from international partners in the initiative. This will maximize the global applicability and acceptance of FutureGen's results, which is necessary for building an international consensus on the role of coal and sequestration in addressing global climate change and energy security. Broad engagement of stakeholders early on in FutureGen is critical to achieving an understanding and acceptance of sequestration and zero-emission coal utilization.

To prove viability, sequestration technology must be tested and validated at a meaningfully large scale under real-world conditions. This requires the operation of a large-scale facility using cutting-edge technologies to produce electricity and hydrogen, integrated with CO_2 capture and sequestration. Figure 1 provides a simplified flow diagram of the prototype plant.



Performance Parameters Required to Obtain Desired Outcome

One of FutureGen's fundamental goals is to overcome environmental constraints, especially potential climate change impacts of CO_2 emissions, associated with producing electricity and other forms of energy from coal. It is expected the FutureGen project will prove the technical feasibility and make economically viable zero-emission power plants by producing electricity and hydrogen from coal (the lowest cost and most abundant domestic energy resource), while capturing and sequestering the CO_2 generated in the process.

The plant will employ coal conversion technology to gasify coal, oxygen, and steam to produce a hydrogen-rich "synthesis gas." After exiting the conversion reactor, the composition of the synthesis gas is "shifted" to produce a concentrated gas stream of hydrogen, steam, and CO_2. Following separation of these three components, the produced hydrogen can be used to power a gas turbine and/or a fuel cell to generate clean electricity. Some or all of the hydrogen can also be used as a feedstock for chemical plants or petroleum refineries. Steam from the process can be condensed, treated, and recycled into the gasifier or added to the plant's cooling water circuit. CO_2 from the process will be sequestered in deep underground geologic formations that will be intensively monitored to verify the permanence of CO_2 storage. Suitable geologic reservoirs for sequestration must be located in close proximity to the plant.

The overall project objectives are to:

- Establish technical feasibility and economic viability of producing electricity and hydrogen from coal with near-zero emissions (including CO_2);
- Verify sustained, integrated operation of a coal conversion system with carbon sequestration;
- Verify effectiveness, safety, and permanence of carbon sequestration;
- Establish standardized technologies and protocols for CO_2 measurement, monitoring, and verification; and,
- Gain acceptance by the coal and electricity industries, environmental community, international community, and public-at-large for the concept of coal-based systems with near-zero carbon emissions through the successful operation of FutureGen.

The functional performance requirements of the FutureGen project include plant performance and sequestration monitoring and verification criteria. The *plant performance criteria* are:

- Sequester CO_2 at an operational rate of approximately one million tons/year;
- Produce electricity and hydrogen at ratios (may be variable) consistent with market needs (equivalent to plant capacity of ~275 MW net electricity output);
- Sequester at least 90 percent of CO_2 with potential for 100 percent sequestration;
- Include capability for co-sequestration of contaminants with CO_2;
- Plant location consistent with adequate feedstock availability, market for products, and proximity to geologic formation for sequestration (e.g., unmineable coal seams, depleted oil and natural gas reservoirs, deep saline aquifers, basalt formations);
- Environmental (zero emissions) requirements:
  - > 99 percent sulfur removal
  - < 0.05 lb/million Btu NOx emissions
  - < 0.005 lb/million Btu particulate matter emissions
  - > 90 percent mercury removal
- Design permits full-flow testing of advanced technologies, and is "loosely integrated" to increase flexibility and enhance operability and reliability.

The *CO_2 Sequestration Monitoring and Verification performance criteria* are:

- Accurately quantify storage potential of the geologic formation;

- Detect and monitor surface leakage, if it occurs (capability to measure CO_2 slightly above atmospheric concentration of 370 ppm) and demonstrate effectiveness of mitigation;
- Provide the scientific basis for carbon accounting and assurance of permanent storage;
- Account for co-sequestration of contaminants; and,
- Develop information necessary to estimate costs of future CO_2 management systems.

FutureGen's goals and schedule are aggressive, and include some high-risk activities, but are judged to be achievable by qualified public and private-sector scientists and engineers. When achieved, FutureGen technologies will provide the basis for a potentially huge long-term public benefit. Public investment is required to offset the high risk associated with this challenging endeavor. It is not possible to reach FutureGen's stretch goals using off-the-shelf commercial technology. However, an industrial base now exists for designing several critical FutureGen components, such as gasifiers, clean-up trains, and turbines, although their efficiencies, environmental performance, reliability and economics must be significantly advanced and tested. A key piece of FutureGen is proving the viability of sequestration and its integration with a power facility.

FutureGen also offers the opportunity to incorporate a higher-performance, advanced-generation subsystem, e.g., the transport reactor now at an advanced development stage. Also, while first generation coal-based gas stream clean up trains have successfully operated at commercial scale, there are only two such systems operating in an Integrated Gasification Combine Cycle (IGCC) configuration (the Tampa and Wabash clean coal demonstration projects). These systems do not remove emissions of pollutants and carbon dioxide to the near zero levels required for FutureGen. In addition, while natural gas combustion turbine technology is commercially mature, there are no turbines available today that are capable of running on coal synthesis gas, let alone 100 percent hydrogen, as required to reach FutureGen performance levels. As a final point, no currently operating IGCC plant has an integrated carbon capture and sequestration capability. Although ongoing sequestration R&D efforts will provide key data to support FutureGen, it is critical to establish the capability to sequester carbon in a cost-competitive integrated system – a key FutureGen goal.

Project Cost

The FutureGen project's **total cost,** as estimated by the DOE National Energy Technology Laboratory, is based on a reference facility design for a nominal 275 MW (net equivalent output) prototype that produces electricity and hydrogen and annually sequesters one million metric tons of carbon dioxide. The estimated cost is based on a "bottom-up" cost analysis of expected project management (including stakeholder involvement, regulatory reviews, and indemnification issues), hardware, design, construction, and testing. This cost estimate includes:

- Project definition, baselining and compliance with the National Environmental Policy Act;
- Plant procurement and construction (fuel processing plant, carbon capture, pipeline construction, injection wells, measurement / monitoring / verification);
- Shakedown and full-scale operation;
- Sequestration; and,
- Site monitoring.

Cost Element	Estimated Costs ($M)
Plant Definition, Baselining, and NEPA	81
Plant Procurement and Construction	480
Shakedown and Full-Scale Operation	188
Sequestration (design and construction)	191
Site Monitoring	10
Total	**950**

Project Cost Sharing

Of the $950 million of total **funding** required to accomplish FutureGen's objectives, $250 million (26 percent) of direct funding is expected to be provided by the existing industry consortium. DOE will provide $500 million in direct funding for FutureGen and $120 million will be funded from the DOE sequestration program. DOE will use its best efforts to achieve or exceed a minimum 80/20 cost share for the $120 million R&D from partners outside the existing consortium. To the extent that the existing consortium members are involved in the sequestration R&D scope, their overall project cost share will be capped at $250 million. International partners are expected to provide an additional $80 million (8 percent). This cost-share allocation is based on the following considerations:

- The project's mix of research and demonstration;
- The maturity of the technologies, including the need for integration and testing of unproven technologies at full-scale (especially integrating the sequestration aspects);
- The size of the eventual market, years to market, expectations of market penetration, and potential domestic and foreign licensing revenues to be generated, balanced by the relatively long-term horizon for the investment and the risk involved;
- The absence of a clear market or regulatory driver for carbon management technologies for U.S. power generation facilities; and,

- The unknown nature of liabilities which may result from this first-of-a-kind integrated project encompassing large-scale carbon sequestration.

Participation from state governments and foreign government entities is also expected. The amount of contributions expected from foreign and domestic governments is $80 million. Negotiations on foreign participation and cost share will be at the Department level through the Carbon Sequestration Leadership Forum, and coordinated with FutureGen through its Program Director. Funding for FutureGen is proposed in the President's FY2005 Budget as part of the Clean Coal Power Initiative within the Fossil Energy Research and Development account. Assuming a project start in FY2004, the projected fiscal year funding levels are shown below. Industry will be encouraged to provide more cost share funding early on in order to accelerate the schedule.

FutureGen Project Funding Profile ($M)

FY	Cash Flows				
	DOE Direct	DOE Sequestration*	FutureGen Consortium	International	Total
2004	9		2		11
2005	18		7		25
2006	18		7		25
2007	50		20	5	75
2008	100		38	6	144
2009	89	24	43	8	164
2010	57	24	32	10	123
2011	33	4	18	10	65
2012	23	34	18	12	87
2013	26	34	19	12	91
2014	34		19	7	60
2015	39		24	7	70
2016-2018	4		3	3	10
Total	**500**	**120**	**250**	**80**	**950**

* See discussion on page 6 for Sequestration funding details.

The FutureGen project funding profile is presented graphically in Figure 2 below.

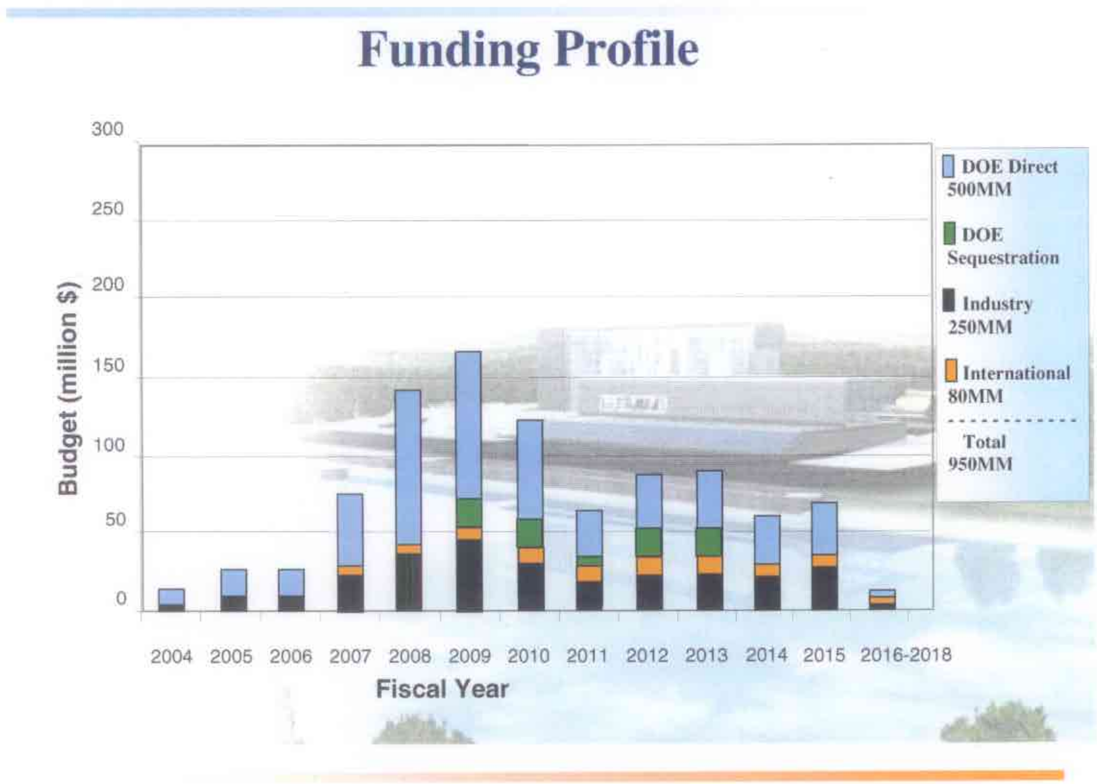


Figure 2

Figure 3 presents the project funding required for each major FutureGen cost element by fiscal year.

FutureGen Major Cost Elements by Fiscal Year ($'s millions)														
Major Cost Elements	FY 2004	FY 2005	FY 2006	FY 2007	FY 2008	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	2016-2018	*Total*
Plant Def. & NEPA	11	25	25	20										*81*
Base Plant Proc. & Const.				55	140	134	79	15			27	30		*480*
Shakedown & Operation								40	35	40	33	40		*188*
Sequestration					4	30	44	10	52	51				*191*
Monitoring													10	*10*
FY Totals	*11*	*25*	*25*	*75*	*144*	*164*	*123*	*65*	*87*	*91*	*60*	*70*	*10*	*950*

Figure 3

Fiscal Year Activities and Milestones

The following is a profile of the principal FutureGen project activities and milestones by fiscal year. These milestones are aggressive and dependent on the actual timing and availability of funds for project expenditures, and will have to be updated to reflect the actual funding situation. Although not broken out explicitly, each of these activities includes inherent costs for industry's involvement with all aspects of project management. Included in project management is an important continuing effort on broad stakeholder involvement, education and outreach that goes beyond that associated with the National Energy Policy Act (NEPA) process. This effort is intended to work towards broad understanding necessary for general acceptance of sequestration and the zero emissions coal concept.

Principal FY04 Activities

Planning and project-initiation activities include continuing technology assessment activities initiated in FY2003, gathering information on candidate sites and preparation of National Environmental Policy Act (NEPA) and environmental impact statement (EIS) documentation. Assuming an award is made to industry in July 2004, FutureGen preliminary design activities will be initiated.

NEPA / EIS – The National Environmental Policy Act (NEPA) requires DOE to fully consider all environmental impacts before proceeding with detailed design and/or construction. Fulfillment of this requirement will likely be a critical path activity and will necessitate: Collection of extensive environmental information on both the site and proposed project facilities; public participation to include at least one major public meeting (Project Scoping); and, sufficient public comment periods to allow for informed discussions on the environmental and socio-economic impacts of the project. Work on a draft Environmental Impact Statement (EIS) will be initiated during FY2004. The EIS will be reviewed by subject matter experts and mitigation strategies developed to address significant environmental impacts. DOE funding for this activity will be $2 million in FY2004.

Site Assessment / Selection – To expedite NEPA, the Industry Consortium will need to complete the process for identifying candidate project site(s) prior to the end of FY2004. The Consortium will identify candidate sites and gather environmental information so that potential sites can be fully characterized and analyzed. During FY2004, the Consortium must also secure evidence of site ownership and access. DOE funding for this activity will be $1 million in FY2004.

Technology Assessment / Preliminary Facility Design – 'Preliminary design', consisting of early or conceptual design and engineering activities, can proceed in advance of NEPA-related activities. NEPA precludes DOE sharing in any design and/or construction costs that would extend beyond preliminary design, until after NEPA is completed. Maintaining the project schedule will require that DOE spend $6 million and the Consortium spend $2 million on this activity in FY2004.

Principal FY05 Activities

NEPA / EIS – NEPA activities will continue through FY2005. Following issuance of the Draft EIS, public comments will be solicited and a public meeting held on the Draft EIS.

Responses to public comments will be assembled and incorporated into a Final EIS. The EIS will be reviewed by subject matter experts, and mitigation strategies developed to address significant environmental impacts. DOE funding for this activity will be $2 million in FY2005.

Site Monitoring and Characterization – Site monitoring and characterization will be initiated during FY2005. Information gleaned from design/engineering studies will be incorporated into detailed design activities, as appropriate. Typically, baseline environmental monitoring data must be gathered to support not only NEPA and Permitting activities, but also Design/Engineering. These data will likely include air quality, water quality, geological/soil, seismic, wildlife, and sound/noise level surveys of the site as it exists before construction begins. After the plant is built, these surveys may be repeated and compared to site baselines to determine the environmental characteristics of operation. DOE funding for this activity will be $3 million in FY2005.

Technology Assessment / Preliminary Design – Candidate technologies will be considered and evaluated under this activity. Options will be considered in terms of success potential and leading edge characteristics. Preliminary design activity will include conceptual design of the plant's power train, air separation units, turbine and steam cycles and other generic balance of plant auxiliary systems. DOE will spend $13 million and the Consortium $7 million on technology assessment and preliminary design in FY2005.

Principal FY06 Activities

NEPA / EIS – The NEPA process will be completed with review and approval of the Final EIS. Subsequent to Final EIS approval, the NEPA process will be completed with the issuance of a Record of Decision. DOE funding for this activity will be $1 million during FY2006.

Permitting – Permitting activities will be initiated during FY2006 and necessary permitting will be completed before start of detailed design. Ordinarily, only a few permits (e.g., air, water, construction) require long lead times and/or public hearings. However, a large project such as FutureGen will require many state and local permits, and their issuance will therefore be staggered between FY2006 and FY2007. Another factor affecting the permitting schedule is likely to be the 'first instance' nature of many technical and environmental aspects of FutureGen and the ability of state and local regulatory officials to develop and adopt novel permitting strategies in an expedient manner. DOE funding for this activity will be $1 million in FY2006.

Site Monitoring and Characterization – Site monitoring and characterization activities will continue in FY2006. DOE funding for this activity will be $3 million in FY2006.

Technology Assessment / Preliminary Design – Technology assessment and preliminary design will continue in FY2006. DOE will spend $13 million and the Consortium will spend $7 million for this activity during FY2006.

In summary, funding requirements, major activities, and cost share responsibilities for the FY2004, FY2005, and FY2006 are shown in Figure 4 below.

Funding Requirements for FY04 thru FY06 Activities ($'s millions)

Major Activity	FY2004		FY2005		FY2006	
	DOE	Consortium	DOE	Consortium	DOE	Consortium
NEPA/EIS	2	---	2	---	1	---
Site Assessment/Selection	1	---	---	---	---	---
Permitting	---	---	---	---	1	---
Site monitoring/Characterization	---	---	3	---	3	---
Technology Assessment/ Preliminary Facility design	6	2	13	7	13	7
Fiscal Year Totals	9	2	18	7	18	7

Figure 4

Principal FY07 Activities

Permitting – Permitting activities will be completed in late FY2007, and will likely be tied to a successful outcome of the NEPA review. Permits must be in hand prior to the start of construction. DOE funding for this activity will be $2 million in FY2007.

Site Monitoring and Characterization – Site monitoring and characterization activities will be completed. DOE funding will be $3 million and the Consortium will spend $1 million for this activity in FY2007.

Technology Assessment / Preliminary Design – Technology assessment and preliminary design will nearly be completed by the end of FY2007. DOE will spend $11 million and the Consortium will spend $3 million for this activity during FY2007.

Detailed Plant Design and Procurement – Detailed design activities will be initiated during FY2007. The largest project funding expenditures generally occur in construction, beginning with the identification and purchase of long-lead equipment. Major bid packages will be defined and issued to subcontractors for construction. Procurement activities can affect budget and schedule significantly, so it is important that they be planned well and tracked closely. Long-lead procurement activities will begin in FY2007, so that construction activities can proceed smoothly. DOE funding will be $34 million and the Consortium will spend $16 million for this activity during FY2007. International contributions to this activity are expected to be $5 million in FY 2007.

Principal FY08 Activities

Detailed Plant Design – Detailed design activities will continue in FY2008. DOE will spend $11 million and the Consortium $5 million for this activity in FY2008.

Procurement and Construction – FutureGen will involve construction of an advanced power plant and a sequestration facility. This will basically entail two parallel, large-scale construction efforts, both starting in FY2008. Major construction activities will include construction management (e.g., time, cost and quality), contractor mobilization and coordination, and safety management. During FY2008, construction will focus on civil and structural; with a strong geo-technical emphasis for the sequestration facility. DOE will spend $89 million and the Consortium will spend $33 million for this activity during FY2008. International contributions to this activity are expected to be $6 million in FY 2008.

Principal FY09 Activities

Detailed Plant Design – Detailed plant design will be completed in FY2009. DOE will spend $12 million and the Industry $5 million for this activity in FY2009.

Procurement and Construction – Construction activities will continue through FY2009 for both the power plant and the sequestration facility. DOE will spend $101 million and the Industry will contribute $38 million for these activities in FY2009. International contributions to this activity are expected to be $8 million in FY 2009.

Principal FY10 Activities

Construction – Construction activities will continue through FY2010. Mechanical activities will be completed, including the installation of major equipment. DOE will spend $81 million and the Industry will spend $32 million for these activities in FY2010. International contributions to this activity are expected to be $10 million in FY 2010.

Principal FY11 Activities

Construction – Construction activities will be completed by the end of FY2011 for both the power plant and the sequestration facility. DOE will spend $15 million and the Industry will spend $10 million for construction in FY2011.

Shakedown and Start-up – Start-up operations for the power plant and sequestration facility will commence. Operations data will be logged and monitored. Project reports will be reviewed and issued. Early operations typically involve some degree of debugging, and perhaps even some re-design and/or engineering fixes. Subsystems (including control systems) at both the power plant and sequestration facility will be checked and tested. Vendors will be consulted and required to make warranty repairs or to replace any equipment that does not perform to specification. Plant operations personnel will receive classroom and/or plant simulator training, to be followed by hands-on training throughout shakedown and start-up operations. DOE funding for shakedown and start-up will be $22 million and the Industry will spend $8 million on this activity in FY2011. International contributions to this activity are expected to be $10 million in FY2011.

Principal FY12 Activities

Full-Scale Operation – Phase 1 operations will include data collection and reporting. Emphasis will shift squarely toward completion of test plans and achieving maximum run duration. Continuous power will be generated resulting in the first plant revenue. Lessons learned during the previous year of start-up and early operations will be documented and built upon. DOE will spend $20 million and the Industry $13 million, on full-scale operations during FY2012. International contributions to this activity are expected to be $2 million in FY 2012.

Phase 2 Sequestration (Design and Procurement) – In mid-FY2012, Phase 2 Sequestration (design and procurement activity) will begin and proceed in parallel with Phase 1 Sequestration operations. Supplemental NEPA compliance documents will be prepared, if necessary. Phase 2 construction activities will extend the sequestration monitoring grid from 1-mile x 1-mile (Phase 1) to 9-miles x 9-miles (Phase 2) in geographic coverage. DOE will spend $37 million and the Industry $5 million on this activity during FY2012. International contributions to this activity are expected to be $10 million in FY 2012.

Principal FY13 Activities

Full-Scale Operation – Operations will continue through FY2013, including data collection and reporting. Emphasis will begin to shift toward maximizing reliability, availability and maintainability (RAM). Following completion of Phase 2 Construction (Sequestration), Phase 2 operations will commence. DOE will spend $29 million and the Industry $9 million, on full-scale operations in FY2013. International contributions to this activity are expected to be $2 million in FY 2013.

Phase 2 Sequestration (Design, Procurement and Construction) – Phase 2 sequestration system installation will be completed and operations will begin in mid-FY2013. DOE will spend $31 million and the Industry $10 million for these activities in FY2013. International contributions to this activity are expected to be $10 million in FY 2013.

Principal FY14 Activities

Full-Scale Operation – Operations will continue in FY2014, with emphasis on maximizing RAM and on Phase 2 (sequestration) operations. Data collection and reporting will continue, and the final report will be outlined. DOE will spend $34 million and the Consortium $19 million, on full-scale operations during FY2014. International contributions to this activity are expected to be $7 million in FY 2014.

Principal FY15 Activities

Full-Scale Operation – Operations will continue in FY2015, including data collection and reporting. Emphasis will be on maximizing RAM, conducting Phase 2 (advanced technology) operations, and drafting the final report (to be issued in FY2014, and likely consisting of multiple volumes). DOE will spend $39 million and the Consortium $24 million, on full-scale operations during FY2015. International contributions to this activity are expected to be $7 million in FY 2007.

Principal Activities – FY16 to FY18

Site Monitoring – Monitoring of sequestered CO_2 will be carried out during FY2016 through FY2018 following completion of the FutureGen power plant and sequestration facility operations. Sequestered CO_2 will be monitored geologically, and remediation measures developed as necessary. DOE funding for site monitoring will total $4 million and the Consortium will spend $3 million for this activity. International contributions to this activity are expected to be $3 million.

The FutureGen project schedule is shown in Figure 5 below.

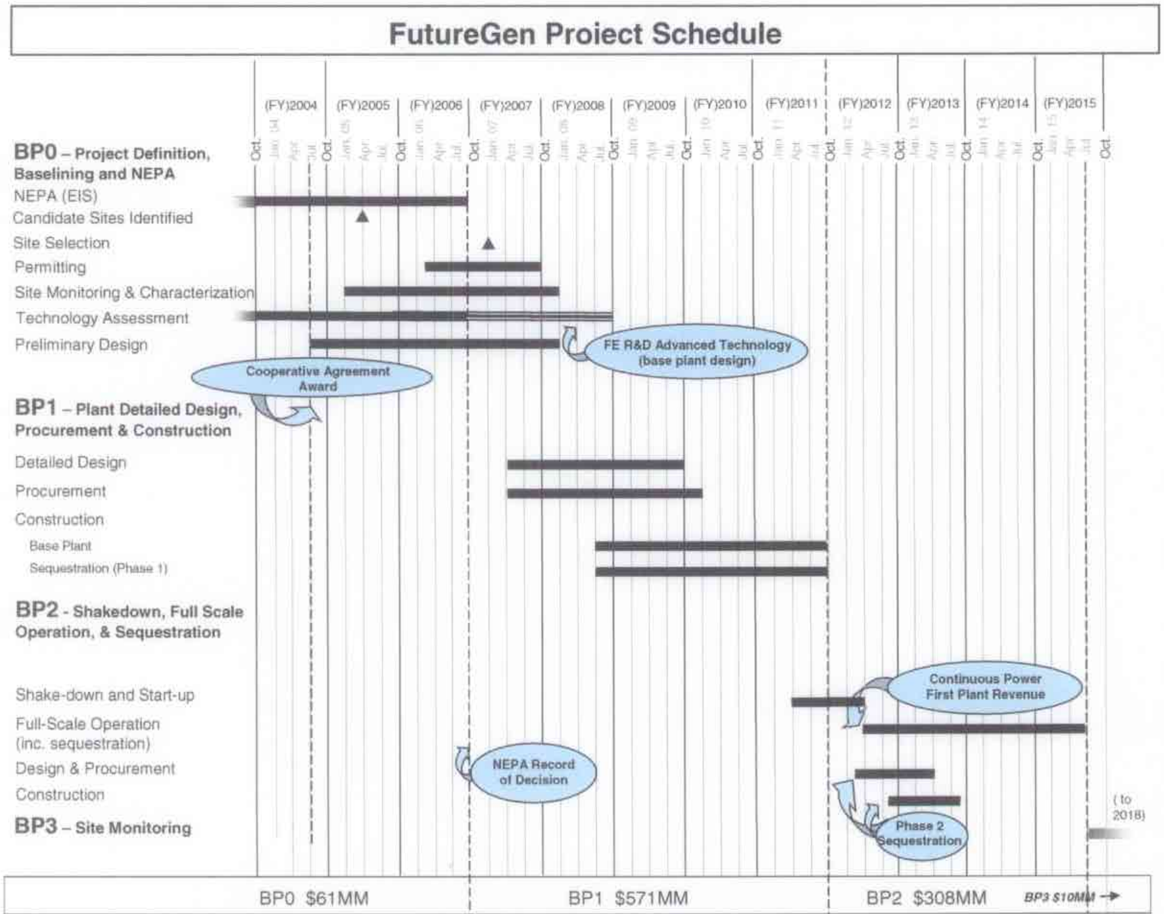


Figure 5

Public / Private Partnership

The President has challenged American businesses to voluntarily make specific commitments to improve the greenhouse gas intensity of their operations, and to reduce emissions.

In support of this challenge, FutureGen will be structured as a public / private partnership between DOE, leading companies in the coal and electricity industries, and international entities. It will enable the coal and power industry to voluntarily step up — *as a whole* — to validate technology options that will reduce carbon emissions while ensuring the continued use of low-cost, indigenous coal to produce electricity.

To make FutureGen as successful as possible, DOE will seek to include a broad spectrum of the leading companies associated with the coal and power industries. Industry involvement will be sought at the executive management level. This

Consortium will develop and define its project charter for the FutureGen project consistent with the requirements, goals and objectives of DOE.

DOE envisions that companies will form a Consortium that will enter into a cooperative agreement with DOE to design, construct, and operate the FutureGen advanced hydrogen/power plant with carbon sequestration. The Consortium may then competitively select the system designers, equipment vendors, and research organizations needed to design, construct, and operate the prototype. Because DOE is providing most of the funding, it will provide federal technical and programmatic direction for the project as a requirement to be included in the cooperative agreement.

To maximize public acceptance for the effectiveness, safety, and permanence of carbon sequestration, the environmental community, state agencies, and research organizations will be intimately involved in the project from its onset. Representatives from these groups will be included in the management Consortium as advisors or consultants. Technical experts from these groups will be involved in the design of the project, including testing protocols for carbon sequestration and by-product utilization.

Critical Contributions of the Coal Power RD&D Program to FutureGen's Success

Current conventional technologies are insufficient for FutureGen to achieve its performance and economic goals. Studies at the Massachusetts Institute of Technology (MIT) show that capturing carbon from integrated gasification combined cycle (IGCC) plants entails substantial efficiency and cost penalties. MIT (Herzog, 1998; David & Herzog, 2001) compared the results of six independent analyses, including those of EPRI, and concluded that carbon capture using today's technology results in efficiency penalties of 9 percent – 23 percent and bus bar cost-of-electricity increases of $0.013 - $0.026/kWh, or 22 – 44 percent. MIT also estimated capital costs to increase from $1,401 to $1,909/kW with carbon capture, an increase of 36 percent. All of these figures are for capture only and do not include the cost of sequestration. Innovative technologies, particularly those that decrease efficiency losses, can sharply reduce these cost penalties.

FutureGen's critical enabling technologies include advanced gasification, oxygen production, hydrogen production, gas cleanup, hydrogen turbines, fuel cells and fuel cell/turbine hybrids, carbon sequestration, advanced materials, instrumentation, sensors and controls, and byproduct utilization. A brief discussion of the current status and profile for each technology and its potential pathway for incorporation into FutureGen is provided below. Several technology options will be pursued in order to manage the risk associated with using cutting-edge technologies in FutureGen.

Advanced Gasification

The transport gasifier is one of several promising candidate options for the FutureGen gasifier because its high throughput relative to size, simplicity, and reduced temperature of operation compared with current gasifiers, will yield benefits throughout the FutureGen plant. The transport gasifier has been successfully operated in the air-blown mode at the Power Systems Development Facility (PSDF); however, oxygen-blown operation is required for FutureGen, and PSDF's operational phase in the oxygen-blown mode is in its early stages.

Current efforts at the PSDF are focused on developing the performance database for the transport gasifier in the oxygen-blown mode using a variety of coal feedstocks from lignite or through bituminous coals. With planned upgrades to the oxygen supply and related systems, the capacity of the existing transport gasifier is expected to nearly double. Planned improvements in the coal feed system, particulate control device, and the char cooling and removal system will significantly increase overall reliability of the transport gasifier, which would further reduce costs. The target is to achieve 95 percent availability rather than the 75 – 80 percent availability typical of today's gasifiers.

Because of its simplicity in design and lower temperature of operation, the transport gasifier can potentially reduce the capital cost of an IGCC plant by up to 20 percent (or from $1,400 to $1,120 /kW) over those employing today's technologies. In addition, the operations and maintenance costs are expected to be lower and availability higher because of the lower temperature of operation. DOE's advanced power systems program performance target is to develop technologies that will enable 50 percent cycle efficiency at $1,000/kWe by 2008.

Oxygen Production

In the initial phase of the FutureGen project, state-of-the art cryogenic air separation technologies will provide the 2,000 tons per day of oxygen required to operate the gasifier. Current oxygen production in IGCC can result in substantial efficiency and cost penalties, consuming 15 – 20 percent of a plant's power output and accounting for 15 percent – 25 percent of the cost of operating the plant. However, advanced ion transport membranes (ITMs) are being developed in the R&D program as a low-cost, high-efficiency approach for large-volume production of oxygen.

ITM technologies are currently being scaled to a production level of one to five tons per day. Upon successful completion of testing at this scale, plans are to scale the technology to 25 - 50 tons per day for integrated testing at the PSDF beginning in FY2006. When this phase is completed, it is expected that the technology will be scaled to 250 tons per day and provided for integrated operation in FutureGen. Full-scale commercial demonstration will occur through the CCPI program or through the incorporation of additional modules in the FutureGen plant. ITM technology is expected to result in a capital cost savings of $75 - $100/kWe and to provide an efficiency improvement of one to two percentage points over conventional IGCC plants.

Developing ITMs may result in additional benefits. Their high operating temperatures create opportunities for thermal integration with advanced power generation systems. In one approach being investigated in the R&D program, an ITM has been integrated with a solid oxide fuel cell. The ITM is used to burn any residual fuel in the fuel cell exhaust, providing a more efficient method of utilizing the unconverted fuel, and resulting in a fuel cell exhaust comprising only steam and CO_2, from which the CO_2 can be inexpensively separated for sequestration.

Hydrogen Production

If a FutureGen type of plant were in operation today, its production of hydrogen and the capture of carbon dioxide for sequestration would most likely be accomplished using conventional solvent-based absorption processes as, for example, Selexol followed by pressure swing adsorption (PSA). However, such processes are very energy intensive, and adversely impact the thermal efficiency of the plant.

Several approaches currently under development in DOE's coal R&D program are being directed to reduce cost and improve the efficiency of hydrogen production. Based upon bench-scale data, a 2.5 MW skid-mounted CO_2 Hydrate Process module will be designed and constructed in FY2004 / 2005 and tested in FY2006 on a slipstream from a commercial coal gasifier.

Membranes for hydrogen separation are also being developed in the R&D program. R&D efforts are focused on overcoming obstacles that prevent the use of membranes at large-scale in commercial systems. These obstacles include achieving satisfactory hydrogen fluxes, membrane stability in aggressive environments, effective seals, and satisfactory manufacturing processes. With steady progress in the R&D program, it is anticipated that the first membrane modules could be tested at the PSDF in FY2006 / 2007. These novel hydrogen production technologies are significantly more thermally efficient than existing conventional technologies and have potential for reducing the cost of hydrogen by nearly 25 percent.

In addition, advanced hydrogen production from coal gasification will be optimized and made flexible to accommodate the market demand while co-producing it with power generation. The outcome of the hydrogen production research will provide a cutting edge candidate process for incorporation into FutureGen.

Gas Cleanup

Gas cleanup is required not only to achieve zero emissions, but also to remove gas contaminants that could damage downstream equipment such as gas turbines and fuel cells. The gas cleanup technology to be deployed initially in the FutureGen project is expected to be one of two existing technologies, Rectisol or Selexol. Rectisol can achieve much lower emission levels than Selexol, but at a significantly increased cost. Both technologies use either a physical or chemical solvent, operate at low temperatures, and require significant energy for solvent regeneration, reducing plant thermal efficiency by as much as five percentage points.

In the R&D program, technologies are being developed to achieve the zero emissions goals of FutureGen with greatly reduced efficiency penalties. Novel sorbents have been developed and testing will begin on coal-derived synthesis gas from pilot-scale coal gasifiers in FY2004. Technologies for the removal of mercury, chlorides, and ammonia are also scheduled for testing on coal-derived gas in FY2005. These technologies are expected to be further demonstrated on a slipstream from a commercial gasifier as part of a CCPI proposal in FY2004, and to be ready in time for FutureGen testing in FY2008.

Selective catalytic oxidation of hydrogen sulfide is another novel approach to achieving zero levels of contaminants in the synthesis gas. In FY2005, a small, continuous laboratory unit will be built and tested to be followed by the construction of a skid-mounted unit for testing on coal-derived gas at the PSDF in FY2008, and inclusion in FutureGen around FY2010. These advanced synthesis gas cleaning technologies have potential for reducing the capital cost of an IGCC plant by \$60 - \$80/kWe and increasing thermal efficiency by one to two percentage points, while achieving zero levels of all emissions.

Hydrogen Turbines

In the early operations of FutureGen, advanced generation oxygen-blown gasification technology will be integrated with a hydrogen-fueled gas turbine to produce electric power. F-Class turbines currently operate effectively in integrated gasification systems on coal-based synthesis gas with hydrogen contents between 25 percent and 38 percent (Wabash River and Tampa Electric, respectively). Similar turbines have operated on syngas with hydrogen contents as high as 60 percent. The higher hydrogen content can help to reduce NOx emissions in the combustion process by extending the lean premix combustion limit.

The current turbine program is assessing the effects and benefits of hydrogen content in fuels as the goal of zero emissions is pursued. Limited short-term testing has indicated that nearly 100 percent hydrogen fuel can be fired in F-class turbines. However, there are significant technical issues that will be addressed in the turbine research program. These include hydrogen embrittlement of materials, premix flame flashback, hot section material degradation due to increased heat transfer, and effective NOx control. Firing 100 percent hydrogen can cause drastic reductions in the service lifetimes of turbine components; lowering temperature to compensate can cause substantial decreases in efficiency. Research in this area is focused on improved maintenance/efficiency tradeoffs. As lower-cost oxygen separation techniques evolve, research on hydrogen turbines will also focus on new approaches for integration of the gasification, air separation, and turbine systems.

Fuel Cells and Fuel Cell / Turbine Hybrids

High-temperature, low-cost fuel cells are important candidates for application to FutureGen because they have extremely low emissions and, because of their high operating temperatures, can readily integrate with coal systems. Moreover, they will be one option for achieving the higher power generation efficiencies to meet commercial cost-of-electricity projections from a FutureGen class of plants. Major improvements in fuel cell technology are being pursued to realize their use. These include: Increasing tolerance to contaminants in coal-derived fuel; reducing costs for the fuel cell system from the current $2,000 - $4,000/kW to $400/kW; improving performance (e.g. power density – kW per unit of fuel cell volume); increasing operating life; and, scaling-up from the current maximum size of about one megawatt to more than 50 MW.

SECA is developing a low cost $400/kW fuel cell that will be the building block for the fuel cell / turbine hybrid. SECA is also resolving issues pertaining to scale-up and aggregation of SECA fuel cells into modules required for large coal-based power plants, including FutureGen.

Carbon Sequestration

Sequestration Program R&D is critical to the success of FutureGen and can be divided into five categories: CO_2 capture, transport, storage, measurement / monitoring / verification (MM&V), and infrastructure:

- Capture - Carbon dioxide capture is generally estimated to represent three-fourths of the total cost of a carbon capture, storage, transport, and sequestration system. Several innovative schemes have been proposed that could significantly reduce CO_2 capture costs, compared to conventional processes;

- Transport — R&D is developing strategies to minimize corrosion and pipeline derating from transportation of CO_2 containing minor constituents, such as water and sulfur compounds, which will be present in CO_2 from the FutureGen plant;

- Storage — R&D is developing strategies to identify optimal geologic reservoirs, and reservoir management practices to maximize CO_2 storage. This will provide FutureGen with site selection guidelines for FY2005, and reservoir management practices throughout the lifetime of FutureGen;

- MM&V — Measurement, monitoring, and verification are critical to ensure permanence and safety of CO_2 sequestration. R&D in this area is focused on developing technologies that limit leakage to less than 0.01 percent per year. Developments in sub-surface tracking are evolving so that movement of very small amounts of CO_2 can be tracked. Methods to track surface leakage are being developed to identify small surface leaks at nearly any point above the surface of a geologic formation. Technologies likely to be available for FutureGen will involve a combination of reflective laser technology and satellite spectra; and,

- Infrastructure — The Carbon Sequestration Leadership Forum and Regional Carbon Sequestration Partnerships are developing the infrastructure, regulatory framework, and other sequestration protocols that are critical to FutureGen and subsequent widespread deployment of FutureGen technologies.

The research nature of the sequestration subsystem in FutureGen represents the highest risk and liability associated with zero emissions coal-based energy systems. In addition, the sequestration testing, research, verification and monitoring is site specific, i.e., dependent on the geologic setting. In contrast, the power test facility aspect of FutureGen is less dependent on the geologic constraints and attributes.

Advanced Materials, Instrumentation, Sensors, and Controls

Advanced, crosscutting research in materials and in instrumentation, sensors, and controls is critical to the success of FutureGen. The Advanced Materials Research program is addressing materials requirements for the advanced power generation technologies for FutureGen, with a focus on developing a scientific understanding of materials behavior under aggressive operating conditions. Research is focused on developing materials for use in components for high-efficiency coal-based systems that will operate in hostile, high-temperature environments. These components include boiler tube materials for steam bottoming cycles, blading for high-temperature gas turbines, and membranes and molecular sieves for gas separation.

Improving the efficiency of advanced power plants by increasing the temperature and pressure of the working fluid (steam) in the bottoming cycle, a key component of FutureGen, may be economically achieved by developing highly creep resistant ferritic and austenitic steels for service at temperatures up to 760°C. In gas turbine applications, nickel-base super alloys have outstanding oxidation and mechanical properties at elevated temperatures, but their service temperatures are inherently limited to around 1000°C. To increase the thermodynamic cycle efficiency and achieve FutureGen performance and economic targets, strong, tough and oxidation resistant turbine blade materials, capable of service at temperatures higher than 1000°C, are being developed. The materials program is also supporting the development of K-25 molecular sieves for hydrogen separation, which have exhibited high potential for FutureGen plant performance because of their inherent resistance to sulfur attack.

Research is also addressing the development of instrumentation, sensors, and controls that are critical to the reliable, economic operation of advanced coal-based power generation and hydrogen production technologies. One exciting prospect is the development of sensors and diagnostics for 'smart' plants that minimize the use of redundant components, improve reliability and availability, and reduce costs. Smart design requires condition monitoring of critical components in order to anticipate failures before they occur and take remedial action. Sensors under development are aimed at having the ability to operate reliably in severe environments, as well as advanced data acquisition and computer algorithms, essential to realizing this advance.

Byproduct Utilization

The concept of near-zero emissions is not limited to air emissions but applies to all effluents of the FutureGen plant, including liquid and solid effluents. Currently, about one third of the 121 million tons of coal byproducts generated each year in the United States are beneficially used, with the balance ending up in landfills. The Innovations for Existing Plants R&D program has a goal of increasing the beneficial use of coal byproducts, including the solid residues from coal, to 50 percent by 2010. This goal will be challenging in light of increasingly stringent regulations regarding byproduct use.

In response to this challenge, research is underway to characterize the environmental acceptability of coal byproducts and develop new high-volume uses. Relative to FutureGen, research is focusing on end-use markets for the two largest volume byproducts – slag / bottom ash and sulfur / sulfuric acid. Characterization using current and developing leaching protocols is also being conducted to ensure the safe utilization of byproducts from the FutureGen plant.

Input from Industry Cooperators

In keeping with the Conference Report request that DOE closely coordinate with industry cooperators, communications with the industry have occurred during the drafting of this report. However, the industry has not had sufficient time to review or comment on this final report.