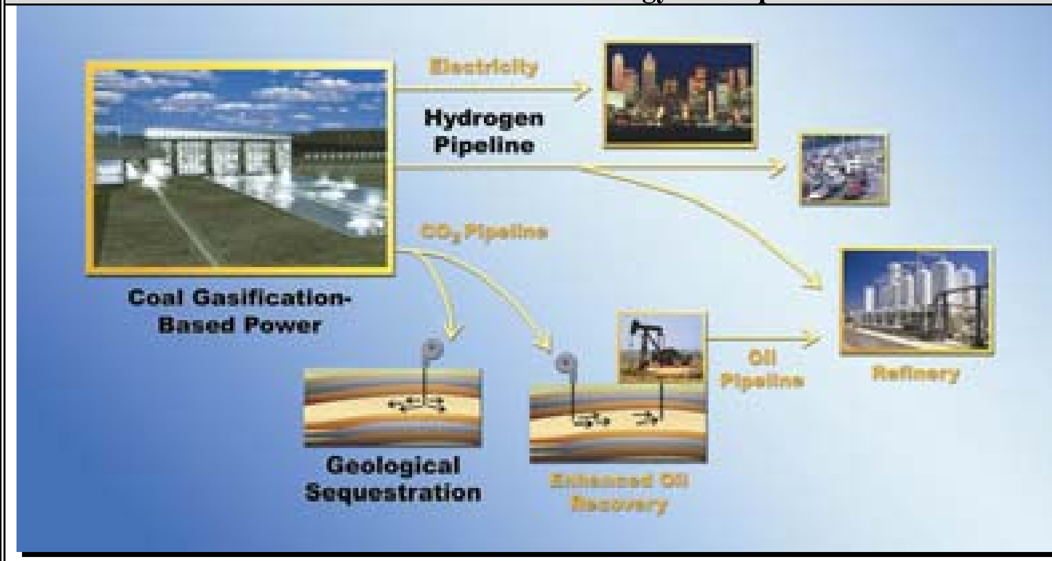
2. REDUCING EMISSIONS FROM ENERGY SUPPLY

2.1 LOW EMISSIONS FOSSIL-BASED FUELS AND POWER

2.1.1 COPRODUCTION/HYDROGEN

Technology Description



FutureGen Power Plant

Coproduction technology focuses on developing plants that coproduce electricity and hydrogen for a transportation fuel from fossil and/or fossil/biomass blends with very large reductions in CO_2 emissions compared to present technologies. Two approaches may be developed. Both approaches employ synthesis gas generated from natural gas reforming or coal gasification. Carbon emissions are reduced in the near-term approach principally by improving process efficiency (e.g. warm gas cleanup, separation membranes); and in the longer term, via more advanced system components such as high-efficiency fuel cells. In both the near and long term, incorporating CO_2 collection into the process, followed by permanent sequestration will be required to achieve zero emissions.

System Concepts

- Synthesis gas is used from a variety of feedstocks including coal, petroleum coke, biomass, opportunity fuel, and natural gas. For solid feedstocks, the initial processing involves gasification followed by gas cleanup (particulate matter, sulfur, nitrogen compounds). For natural gas feed, the initial step is partial oxidation reforming. All new technologies to be developed for the long-term approach of coproduction will work equally well with solid or gas feedstocks.
- The core approach is to employ water gas shifting of syngas to maximize production of hydrogen and carbon dioxide, which allows carbon capture prior to combustion.
- Nominal carbon capture for the near-term approach (including both net power and fuel production) is 90% of feedstock carbon used for conversion. For the long-term approach, carbon capture will be more than 99%.
- Power production is via combustion turbine/steam turbine combined cycle in the near-term approach. Power production is via solid-state fuel cell combined cycle in the long-term approach.
- The near-term approach accomplishes carbon capture by absorption from shifted syngas into a physical solvent such as Selexol. Use of a physical solvent instead of chemical solvents such as amines yields energy savings in CO_2 recovery.
- The principal fuel product anticipated with the near-term approach is Fischer-Tropsch diesel fuel, a premium fuel or blending stock with ultra-low sulfur and aromatics. The principal fuel product with the long-term approach is high-purity hydrogen.
- The long-term approach will employ ceramic membranes for oxygen separation and for hydrogen separation.

Representative Technologies

- Gasifiers for solid feedstocks.
- Partial oxidation reformers for natural gas feedstock.
- Shift reactors (both approaches).
- Hydrogen-fueled combustion turbines (near-term approach).
- Steam turbines for combined cycle power generation (near-term approach).
- Fischer-Tropsch reactors and product recovery train (near-term approach).
- Physical solvent-based absorption system for CO_2 recovery (near-term approach).
- Cryogenic oxygen separation (near-term approach).
- Ion transport membranes for oxygen separation and ceramic membranes for hydrogen recovery (long-term approach).
- Solid-oxide fuel cells (long-term approach).
- CO_2 compression and drying system (both approaches).

Technology Status/Applications

- The only technology module that needs to be developed for the near-term approach is the hydrogen combustion turbine. Major turbine manufacturers (e.g., GE, Siemens-Westinghouse) have performed design studies on the modifications that would be required on existing combustion turbines. Test results indicate the modifications are technically feasible.
- Absorption of CO_2 in a physical solvent has not been practiced commercially at the large scale that will be required at a central coproduction plant (about 5,000 tpd CO_2 for a 250-MW plant). All aspects of the technology are proven, however, so scale-up should be straightforward.
- Fischer-Tropsch conversion is a commercial process used in South Africa (Arge reactors) to convert both coal- and natural-gas-derived syngas to liquid fuels and chemicals. Fischer-Tropsch conversion is also used commercially by Shell in Malaysia to convert natural gas to diesel fuel, solvents, and wax products. In the United States, liquid-phase synthesis with unshifted coal-derived syngas has been practiced at the LaPorte, Texas, pilot facility, and at the Eastman Chemical Co. Clean Coal Technology demonstration project.
- Ceramic membrane reactor development projects for both oxygen separation and hydrogen recovery are underway with industrial partners as part of the DOE Vision 21 program. The Vision 21 roadmap calls for both technologies to be ready for commercial use by 2015.
- Compression, drying, and transport of CO_2 at supercritical pressures already are practiced in recovery and use of CO_2 from underground sources for tertiary oil recovery.

Current Research, Development, and Demonstration

RD&D Goals

- By 2010, design a near-term coproduction plant, configured at a size of 275-MW, which would be suitable for commercial deployment.
- By 2010, demonstrate pilot-scale reactors using ceramic membranes for oxygen separation and hydrogen recovery.
- By 2010, demonstrate a $400/kW solid-oxide fuel cell.
- By 2020, design a long-term coproduction plant at a scale of 275-MW or larger.

RD&D Challenges

- Hydrogen combustion turbine design modifications.
- CO_2 absorber demonstration at full scale.
- Plant integration issues for coproduction of Fischer-Tropsch liquids and power.
- Integration of coproduction plant with sequestration site planning.
- Ion transport membranes for oxygen separation.
- Long-term membrane reactor for hydrogen recovery.
- Low-cost solid-oxide fuel cells.
- Plant integration issues for coproduction of hydrogen and power.

RD&D Activities

- Ion transport oxygen separation membranes
- Hydrogen separation membranes
- Early-entrance coproduction plant designs

Recent Progress

- Air Products' liquefied petroleum methanol pilot plant at LaPorte, Texas, was scaled up to Eastman Chemicals Clean Coal Technology Project.
- Eastman Chemicals Clean Coal Technology Project successfully produced 80,000 gpd of 97% methanol, and was selected for scale-up in Global's early-entrance coproduction plant design study for the Wabash River site.

Commercialization and Deployment Activities

- Early entrance coproduction plant projects begin with a Phase I plant design for eventual commercial scale demonstration in follow-up phases.

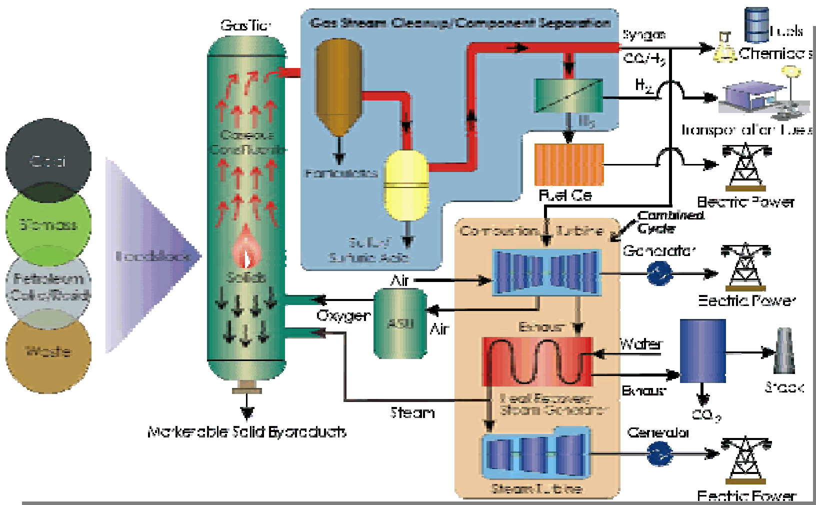
Market Context

- Coproduction plants like those described here address both the power and transportation sectors, providing energy with very large reductions in carbon intensity from large point sources of CO_2 (such as central generating stations) and could become the new world standard for providing environmentally responsible power and transportation.

2.1.2 ADVANCED POWER SYSTEMS

Technology Description

Advanced Gasification System



Advanced coal-fired, power-generation technologies can achieve significant reductions in CO_2 emissions while providing a reliable, efficient supply of electricity. Significant improvements in reducing CO_2 and other emissions have been demonstrated via efficiency improvements and cofiring of coal and biomass. Achieving the efficiency improvements and reducing emissions must be accomplished in a cost-effective manner. While current power plant efficiencies are about 33%, increasing efficiencies ultimately to 60% or more will reduce CO_2 emissions by more than 50% per unit of electricity. Future development of CO_2 sequestration could reduce carbon emissions to near-zero levels.

System Concepts

- Gasification technology increases the coal power-generation cycle efficiency by combining two or more energy cycles, a high-temperature gas turbine, and a steam turbine. In a typical configuration, the gasifier converts coal into a low- or medium-BTU gas, which is burned in the combustion section of the gas turbine to produce electric power. The exhaust gases from the gas turbine are cooled in the heat-recovery steam generator. The steam is routed to the steam turbine, producing additional electric power. Depending on the quality of the gas produced, the gas also may be used as the feedstock to coproduce a variety of chemicals and fuels.
- Combustion technology, including chemical looping, may use oxygen separation coupled to a coal-fired power plant featuring oxygen combustion, carbon capture, and ultra-supercritical steam-cycle operation.

Representative Technologies

- FutureGen – the ultra-clean energy plant of the future.
- Integrated gasification combined cycle (IGCC).
- Advanced combustion systems.
- Unconventional combustion (e.g., use of chemical cycling for CO_2 enrichment).

Technology Status/Applications

- Current IGCC systems based on oxygen-blown, entrained-bed gasifiers are 40%-42% efficient.
- IGCC systems with efficiencies of 40%-42% are available for commercial deployment.
- Efficiencies of a portfolio of IGCC technologies are expected to average 48%-52% by 2010 and 60% by 2020.
- The cost of electricity for these technologies is expected to be 3¢/kWh (in 2003$) by 2015.

- Gasifier capital costs are expected to decrease to 90% of current costs as these technologies mature around 2012.
- Supercritical coal-fired technologies without carbon sequestration are available now with efficiencies of 42%.
- Ultra-critical steam cycles using coal-fired technologies with efficiencies in the 45% range are expected by 2010.
- Coal-fired technologies with significant potential for carbon capture are expected by 2015.
- Oxygen-fed, coal-fired power plants with near-zero CO_2 emissions are expected by 2020.

Current Research, Development, and Demonstration

R&D Goals

- The research program goal in the Advanced Power Systems area is to increase efficiency of new systems to levels ranging from 48% to 52% by 2010, and to more than 60% by 2020.
- By 2020, achieve an overall electricity production cost that is between 75% and 90% of current pulverized-coal-based power generation.

RD&D Challenges

- Long-term systems need to maintain relatively high temperatures between the combustion/gasification stage and the turbine stage to achieve efficiency goals.
- High-temperature materials that are stable and resistant to corrosion, erosion, and decrepitation are a primary technology development need.
- Advanced materials are needed for heat exchangers, turbine components, particulate filters, and SO_2 removal. Other challenges include the use of alternate working fluids and heat-exchange cycles, CO_2 capture methods, cycle optimization, environmental control technologies with low energy penalties, and solids handling.

RD&D Activities

- The portfolio of high-efficiency coal power systems under development through DOE is comprised of IGCC, pressurized fluidized bed combustion, and Vision 21 plants.
- DOE activities are supplemented by up to 50% cost share from the private sector.
- Current development encompasses a broad range of activities including major efforts by Boeing, Alstom, Southern Company Services, and others to develop a new class of gasifiers.
- Four IGCC clean coal demonstration projects are in various stages of completion.

Recent Progress

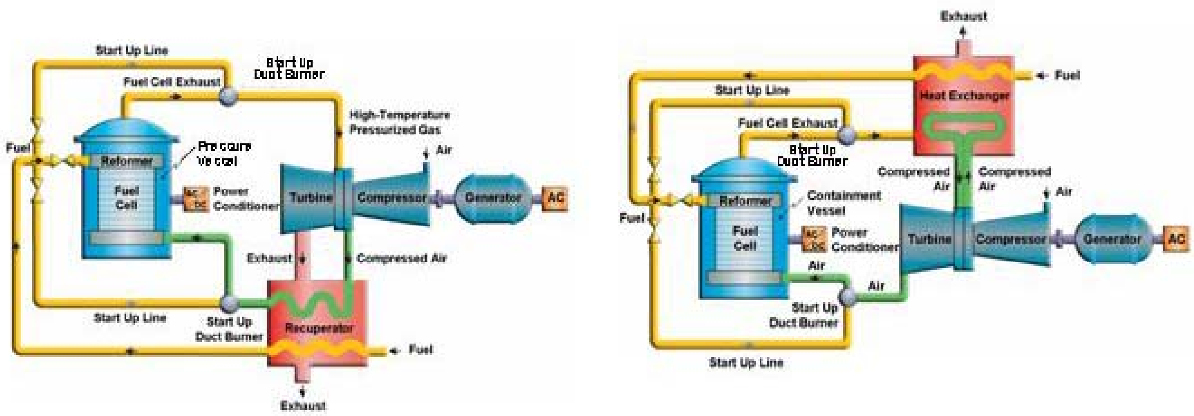
- Incorporating the results from technology studies and lessons learned at the Wabash River Integrated Gasification Combined Cycle (IGCC) power plant in Terre Haute, Indiana, Excelsior Energy Inc. and ConocoPhillips will construct and operate the 531-megawatt Mesaba Energy Project in Hoyt Lakes, Minnesota, to reduce costs and improve efficiency and availability for a next generation, oxygen-blown gasification plant using bituminous coal. Mesaba will advance such across-the-board performance to achieve criteria pollutant emission levels (SO_x, NO_x, mercury, and particulate) equal to or below the current LAER rates for coal-fired generation. Carbon dioxide emissions will be 15% to 20% less than most existing coal-fired power plants as well.
- A Demonstration Plant will be built in Orange County, Florida, and co-owned by Orlando Utilities Commission and Southern Power Company. It will gasify sub-bituminous coal and generate 285 megawatts (MW) of electricity (net) at a heat rate of 8,400 Btu/kWh (40.6% efficiency – higher heating value basis). The transport gasifier offers a simpler and more robust method for generating power from coal than other alternatives. The Demonstration Plant will use state-of the-art emission controls and will be the cleanest, most efficient coal-fired power plant technology in the world. Future units based on the plant design will be 600 MW-class units running at efficiencies near 41.5 %. This project is a continuation of successful work conducted at the Power Systems Development Facility (PSDF).

Commercialization and Deployment Activities
• The gasification technology is under development with several recent proof-of-concept greenfield and repowering installations. Existing plants may be repowered with higher-efficiency coal technologies at or below the price of the natural gas combined-cycle plants. Where natural gas is not available (a considerable portion of the United States and a major portion of the international market) or if gas costs stay above $4/mmbtu, high-efficiency coal plants will be the lowest-cost choice. • Internationally, where natural gas is not available, the market share for coal is expected to be much higher. **Market Context** • The market for new or repowered capacity from now until 2020 is estimated to be as much as 400 GW in the United States and more than that internationally. Domestically, the primary competition for this technology profile is expected to be natural gas combined cycle.

2.1.3 DISTRIBUTED GENERATION/FUEL CELLS

Technology Description

Fuel Cell Hybrid Cycles



Direct Fuel Cell Turbine Cycle

Indirect Fuel Cell Turbine Cycle

The ultimate goal of this technology is to develop fuel cell and/or hybrid systems that use natural gas or hydrogen (from coal, natural gas, or other sources) for highly efficient power generation. This also includes standalone applications of small to medium gas turbine systems, as well as advanced turbine systems for cogeneration application. Near-zero CO_2 emissions could be achieved with the integration of CO_2 capture.

System Concepts

- Hybrid systems that combine fuel cells and gas turbines to create a high-efficiency power module with near-zero emissions for central power or grid support applications.
- Unique fuel cell turbine hybrid cycles that incorporate intercoolers, humidified air cycles, and high-pressure ratios to achieve the highest efficiency.
- High-efficiency coproduction (electricity and hydrogen) energy systems, utilizing waste heat for making hydrogen from natural gas.
- Integration in the long term of CO_2 capture technologies with all of the above systems.
- Integration of fuel cells with other heat engines (reciprocating engines, Stirling engines, etc.) to create highly efficient and clean power modules.
- Fuel cell systems, including high- and low-temperature units.

Representative Technologies

- Low- and high-temperature fuel cells.
- Optimized gas turbines with higher-pressure ratios, intercoolers, oil-less bearings.
- Smart control systems.
- Hydrogen separation membranes.
- Natural gas reforming.
- CO_2 capture.
- Membrane separators for air, hydrogen, and CO_2.
- Ultra-high temperature steam turbines.

Technology Status/Applications

- Two different fuel cell turbine hybrid power systems (300 kW) have been designed, built, and operated (Siemens Westinghouse and FuelCell Energy Inc.). Both prototype systems logged more than 6,000 hours of operation each and achieved efficiencies of approximately 52% with near-zero emissions.

- The Solid State Energy Conversion Alliance (SECA) is in the fourth year of an eight-year program to develop low-cost (< $400 / kW) fuel cell modules for stand-alone and hybrid applications.
- High-temperature fuel cells – such as molten carbonate and tubular solid oxide – are engaged in commercial-scale demonstration tests, but not yet competitively on the market.
- Various elements of high-performance cycles need to be developed to integrate long-term CO_2 capture, membrane separation, optimized turbines, low-cost high-performance SECA fuel cells, and ultra-high temperature steam turbines need extensive development.

Current Research, Development, and Demonstration

RD&D Goals

- By 2010, demonstrate a gas-aggregated FC module larger than 250 kW that can run on coal syngas, while also reducing the costs of the Solid-State Energy Conversion Alliance fuel cell power system to $400/kW.
- By 2012-2015, the program aims to (1) demonstrate a megawatt-class hybrid system at FutureGen with an overall system efficiency of 50% on coal syngas, (2) demonstrate integrated fuel cell and turbine systems achieving efficiencies of 55% on coal; and (3) integrate optimized turbine systems into zero-emission power plants.

RD&D Challenges

- Low-cost, high-performance materials.
- Pressurization
- Scale up
- Aggregation
- Simpler manufacturing process and materials in fuel cells to lower costs.
- Grid interconnection.
- Fuel cell turbine control system for steady-state and dynamic operation.
- Developing new components required by long-term cycles integrating CO_2 capture.

RD&D Activities

- High-temperature fuel cell performance advancement for FCT hybrid application.
- Systems integration and controls for hybrid FCT application.
- Hybrid systems and component demonstration.
- Low-cost fuel cell systems.
- Develop hydrogen separation, transport, and storage.
- Develop methods for CO_2 sequestration and/or capture.
- Develop high-performance materials, catalysts, and processes for reforming methane.
- Develop membranes for separation of air, hydrogen, and CO_2.

Recent Progress

- Siemens-Westinghouse has demonstrated a nominal 300 kW fuel cell turbine direct-cycle hybrid for more than 3,000 hours and achieved an electrical efficiency of 53%.
- FuelCell Energy Inc. (FCE) has demonstrated a nominal 300 kW fuel cell turbine indirect cycle hybrid for more than 6,000 hours and achieved an electrical efficiency of 52%. FCE is currently building a fully integrated version of their 300 kW hybrid.

Commercialization and Deployment Activities

- Fuel cells are becoming viable in niche applications, and increased production rates are expected to lower capital costs.
- About 300 fuel cell units (mostly 200-kW size) have been installed worldwide.
- Currently, there are six industrial teams in the SECA program developing low-cost (< $400/kW) solid oxide fuel cell technology. The SECA program is supported by a significant core technology program to resolve technical issues. Three of the six SECA industry team have shown significant interest in developing fuel cell turbine hybrid products.
- Energy losses and cost are expected to decline with system refinements.