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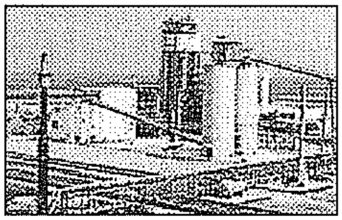
Gasification Technology R&D



Program Performance Goal:
By 2010, complete research and development for advanced power systems capable of achieving between 45 and 50 percent electrical efficiency at a capital cost of $1,600 per kilowatt (in constant 2007 dollars) or less for a coal-based plant.

MORE INFO
- How Gasification Power Plants Work
- Pioneering Gasification Power Plants
- DOE's Current Gasification Research

Coal gasification offers one of the most versatile and clean ways to convert coal into electricity, hydrogen, and other valuable energy products.

Coal gasification electric power plants are now operating commercially in the United States and in other nations, and many experts predict that coal gasification will be at the heart of future generations of clean coal technology plants.

Rather than burning coal directly, gasification (a thermo-chemical process) breaks down coal - or virtually any carbon-based feedstock - into its basic chemical constituents. In a modern gasifier, coal is typically exposed to steam and carefully controlled amounts of air or oxygen under high temperatures and pressures. Under these conditions, molecules in coal break apart, initiating chemical reactions that typically produce a mixture of carbon monoxide, hydrogen and other gaseous compounds.

Gasification, in fact, may be one of the most flexible technologies to produce clean-burning hydrogen for tomorrow's automobiles and power-generating fuel cells. Hydrogen and other coal gases can also be used to fuel power-generating turbines, or as the chemical "building blocks" for a wide range of commercial products. [> Read more about hydrogen production.]

The Energy Department's Office of Fossil Energy is working on coal gasifier advances that enhance efficiency, environmental performance, and reliability as well as expand the gasifier's flexibility to process a variety of coals and other feedstocks (including biomass and municipal/industrial wastes).

Environmental Benefits

The environmental benefits of gasification stem from the capability to achieve extremely low SOx, NOx and particulate emissions from burning coal-derived gases. Sulfur in coal, for example, is converted to hydrogen sulfide and can be captured by processes presently used in the chemical industry. In some methods, the sulfur can be extracted in either a liquid or solid form that can be sold commercially. In an Integrated Gasification Combined-Cycle (IGCC) plant, the syngas produced is virtually free of fuel-bound nitrogen. NOx from the gas turbine is limited to thermal NOx. Diluting the syngas allows for NOx emissions as low as

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15 parts per million. Selective Catalytic Reduction (SCR) can be used to reach levels comparable to firing with natural gas if required to meet more stringent emission levels. Other advanced emission control processes are being developed that could reduce NOx from hydrogen fired turbines to as low as 2 parts per million.

The Office of Fossil Energy is also exploring advanced syngas cleaning and conditioning processes that are even more effective in eliminating emissions from coal gasifiers. Multi-contaminant control processes are being developed that reduce pollutants to parts-per-billion levels and will be effective in cleaning mercury and other trace metals in addition to other impurities.

Coal gasification may offer a further environmental advantage in addressing concerns over the atmospheric buildup of greenhouse gases, such as carbon dioxide. If oxygen is used in a coal gasifier instead of air, carbon dioxide is emitted as a concentrated gas stream in syngas at high pressure. In this form, it can be captured and sequestered more easily and at lower costs. By contrast, when coal burns or is reacted in air, 79 percent of which is nitrogen, the resulting carbon dioxide is diluted and more costly to separate.

Efficiency Benefits

Efficiency gains are another benefit of coal gasification. In a typical coal combustion-based power plant, heat from burning coal is used to boil water, making steam that drives a steam turbine-generator. In some coal combustion-based power plants, only a third of the energy value of coal is actually converted into electricity.

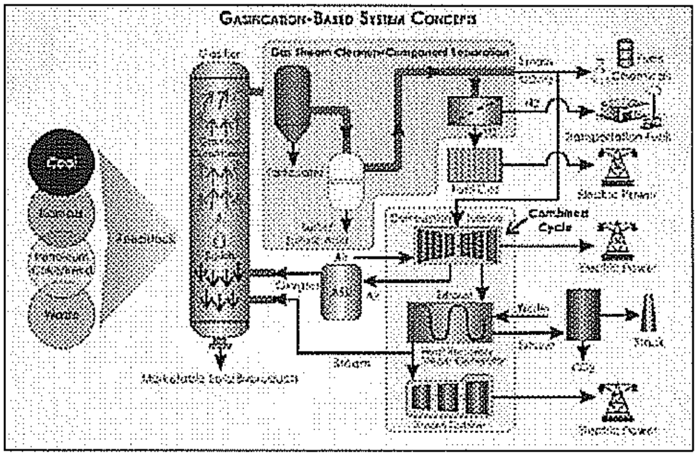
A coal gasification power plant, however, typically gets dual duty from the gases it produces. First, the coal gases, cleaned of impurities, are fired in a gas turbine - much like natural gas - to generate one source of electricity. The hot exhaust of the gas turbine, and some of the heat generated in the gasification process, are then used to generate steam for use in a steam turbine-generator. This dual source of electric power, called a "combined cycle," is much more efficient in converting coal's energy into usable electricity. The fuel efficiency of a coal gasification power plant in this type of combined cycle can potentially be boosted to 50 percent or more.

Future concepts that incorporate a fuel cell or a fuel cell-gas turbine hybrid could achieve efficiencies nearly twice today's typical coal combustion plants. If any of the remaining heat can be channeled into process steam or heat, perhaps for nearby factories or district heating plants, the overall fuel use efficiency of future gasification plants could reach 70 to 80 percent.

Higher efficiencies translate into more economical electric power and potential savings for ratepayers. A more efficient plant also uses less fuel to generate power, meaning that less carbon dioxide is produced. In fact, coal gasification power processes under development by the Energy Department could cut the formation of carbon dioxide by 40 percent or more, per unit of output, compared to today's conventional coal-burning plant.

The capability to produce electricity, hydrogen, chemicals, or various combinations while eliminating nearly all air pollutants and potentially greenhouse gas emissions makes coal gasification one of the most promising technologies for energy plants of the future.

How Coal Gasification Power Plants Work



The heart of a gasification-based system is the gasifier. A gasifier converts hydrocarbon feedstock into gaseous components by applying heat under pressure in the presence of steam.

A gasifier differs from a combustor in that the amount of air or oxygen available inside the gasifier is carefully controlled so that only a relatively small portion of the fuel burns completely. This "partial oxidation" process provides the heat. Rather than burning, most of the carbon-containing feedstock is chemically broken apart by the gasifier's heat and pressure, setting into motion chemical reactions that produce "syngas." Syngas is primarily hydrogen and carbon monoxide, but can include other gaseous constituents; the composition of which can vary depending upon the conditions in the gasifier and the type of feedstock.

Minerals components in the fuel, which don't gasify like carbon-based constituents leave the gasifier either as an inert glass-like slag or in a form useful to marketable solid products. A small fraction of the mineral matter is blown out of the gasifier as fly ash and requires removal downstream.

Sulfur impurities in the feedstock are converted to hydrogen sulfide and carbonyl sulfide, from which sulfur can be easily extracted, typically as elemental sulfur or sulfuric acid, both valuable byproducts. Nitrogen oxides, another potential pollutant, are not formed in the oxygen-deficient (reducing) environment of the gasifier; instead, ammonia is created by nitrogen-hydrogen reactions. The ammonia can be easily stripped out of the gas stream.

In Integrated Gasification Combined-Cycle (IGCC) systems, the syngas is cleaned of its hydrogen sulfide, ammonia and particulate matter and is burned as fuel in a combustion turbine (much like natural gas is burned in a turbine). The combustion turbine drives an electric generator. Exhaust heat from the combustion turbine is recovered and used to boil water, creating steam for a steam turbine-generator.

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The use of these two types of turbines - a combustion turbine and a steam turbine - in combination, known as a "combined cycle," is one reason why gasification-based power systems can achieve high power generation efficiencies. Currently, commercially available gasification-based systems can operate at around 40% efficiencies; in the future, some IGCC systems may be able to achieve efficiencies approaching 60% with the deployment of advanced high pressure solid oxide fuel cells. (A conventional coal-based boiler plant, by contrast, employs only a steam turbine-generator and is typically limited to 33-40% efficiencies.)

Higher efficiencies mean that less fuel is used to generate the rated power, resulting in better economics (which can mean lower costs to ratepayers) and the formation of fewer greenhouse gases (a 60%-efficient gasification power plant can cut the formation of carbon dioxide by 40% compared to a typical coal combustion plant).

All or part of the clean syngas can also be used in other ways:

- As chemical "building blocks" to produce a broad range of higher-value liquid or gaseous fuels and chemicals (using processes well established in today's chemical industry);
- As a fuel producer for highly efficient fuel cells or perhaps in the future, hydrogen turbines and fuel cell-turbine hybrid systems;
- As a source of hydrogen that can be separated from the gas stream and used as a fuel (for example, in the hydrogen-powered Freedom Car initiative) or as a feedstock for refineries (which use the hydrogen to upgrade petroleum products).

Another advantage of gasification-based energy systems is that when oxygen is used in the gasifier (rather than air), the carbon dioxide produced by the process is in a concentrated gas stream, making it easier and less expensive to separate and capture. Once the carbon dioxide is captured, it can be sequestered - that is, prevented from escaping to the atmosphere, where it could otherwise potentially contribute to the "greenhouse effect."

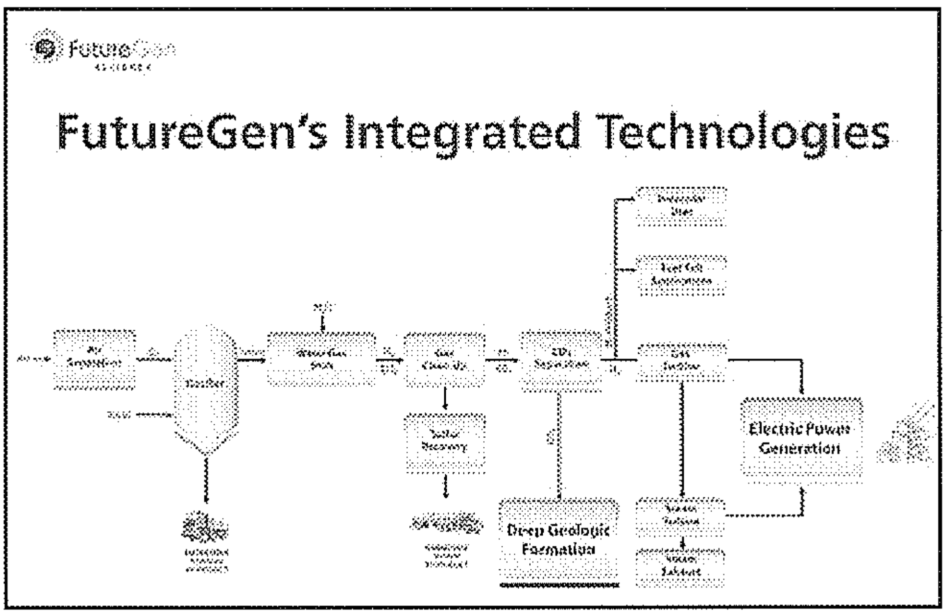
FutureGen ALLIANCE

FutureGen Technology

Technology Overview

FutureGen is the first facility of its kind to combine and test several cutting-edge technologies in a single plant, including coal gasification, emissions controls, hydrogen production, electricity generation, and carbon dioxide capture and storage (CCS). The diagram below illustrates how these technologies fit together to create a near-zero emissions power plant.

Coal gasification is the core technology behind FutureGen. A gasifier will be used to convert coal into a gas of mostly hydrogen and carbon monoxide. The carbon monoxide is reacted with steam to produce additional hydrogen and carbon dioxide.



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The carbon dioxide will be separated from the hydrogen and permanently stored in deep geologic formations thousands of feet below the earth's surface. This technology is known as carbon sequestration.

The hydrogen created from the gasification and carbon dioxide separation process will be used primarily to power a combustion turbine that will generate electricity. Steam heated by the combustion turbine exhaust drives a second turbine to generate additional electricity. This dual-turbine system used to create electricity from gasified coal is known as Integrated Gasification Combined Cycle (IGCC) technology.

Depending on the final technologies selected, FutureGen will produce either slag or ash from the non-combustible portion of the coal and a sulfur byproduct from captured hydrogen sulfide. Each of these byproducts may have commercial value depending on local market conditions. Additionally, the hydrogen used to produce electricity could also be used to power fuel cell vehicles of the future or as a feedstock for other industries.

Read more about coal gasification and carbon sequestration.

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FutureGen™ ALLIANCE

Frequently Asked Questions

FutureGen Management, Budget, and Oversight

- What is the role of the FutureGen Industrial Alliance, Inc versus the US Department of Energy?
  FutureGen is a public-private partnership between the U.S. Department of Energy (DOE) and the FutureGen Industrial Alliance, Inc, a non-profit consortium of leading international energy companies. The Alliance is responsible for design, construction, and operation of the facility. DOE is responsible for independent oversight and coordinating participation of international governments. Alliance member companies are dedicating nearly $400 million toward the project's cost and bring valuable technical expertise and power plant engineering and construction experience to this effort.
- How much money are each of the Alliance members investing in FutureGen?
  The Alliance members will be contributing nearly $400 million toward the project over its lifetime. Currently, there are twelve members of the Alliance and each member contributes equally.
- How much of the cost for FutureGen is being spent on construction versus other activities?
  The cost is estimated at $1.5 billion dollars, with the vast majority going toward design and construction of the plant and the balance going toward carbon capture and sequestration and other aspects of the facility. We will have a more detailed estimate of the actual cost and breakdown by activity when the preliminary plant design is completed.
- Is there a chance that the FutureGen facility will be sold after the start-up period?
  The non-profit Alliance will bring a long-term perspective to FutureGen even though only four years of operation are required as part of the formal partnership with DOE. Because this is a $1.5 billion project, the Alliance sees the power plant as an important commercial-scale research and development (R&D) platform for testing cutting-edge technologies for coal-based power generation. The goal of the Alliance members is that FutureGen becomes a self-sustaining R&D facility.
- What happens at the end of the power plant's operating period?
  While the long-term business model for operating the plant is still being developed, the Alliance expects to operate and continue to improve coal technology at this power plant for as long as possible. Companies that build power plants typically expect the plant to operate for 30 to 50 years.
- Does the Alliance plan to build more than one FutureGen?
  The Alliance was formed to build and operate FutureGen as a first-of-its-kind power plant at which coal companies, utilities, and governments can learn about near-zero emission power generation. The goal of the FutureGen project is that the designs proven through the project will be replicated by utilities and power plant developers throughout the world.

Plant Operations

- FutureGen is described as a near-zero emissions plant. What will the actual emissions be?
  The first-of-its-kind FutureGen plant will integrate advanced technologies for coal gasification, electricity production, emissions control, CO_2 capture and permanent storage, and hydrogen production at a commercial scale. During normal operations, emissions will be as low as, if not lower than virtually any other coal plant in the world. However it should be noted that there may be criteria emissions, such as NO_x, SO_2, and particulates, when the plant is starting up and shutting down. An important element of the FutureGen project is to develop during its operation and testing, new and innovative ways to minimize emissions during these transient events.
- Are there any targets in terms of plant efficiency? How will FutureGen's efficiency differ from a traditional coal plant?
  There are not yet explicit efficiency targets, but the Alliance wants it to be as high as possible. While IGCC plants have higher efficiency than existing coal plants, adding CO_2 capture to the process will reduce the

overall efficiency. Part of the learning that will come from operating this first-of-its-kind facility is whether electricity production combined with CO_2 capture and sequestration can be done efficiently and cost effectively. It is also important to note that FutureGen will be a commercial-scale R&D facility that will operate on a variety of coal types on varying power production regimes, so efficiency metrics in the traditional sense are not necessarily relevant.

- Will the price of electricity from FutureGen be higher?
  Because FutureGen is a first-of-a-kind facility integrating both coal gasification technology and carbon dioxide capture, the cost to produce electricity will be higher than it would be from a traditional facility without these added technologies. By demonstrating how to operate a plant with these integrated technologies for the first time, we expect FutureGen will help many companies provide electricity from similar plants at a competitive cost in the future.

  The Alliance is operating as a non-profit for purposes of demonstrating the technology. All revenue from the sale of power or any marketable byproducts will be returned to the non-profit.
- At what point do you decide what technology FutureGen will use and what if better technology is available after those decisions are made?
  During calendar year 2008, the Alliance will solicit bids from equipment providers and will make equipment selections before year-end. Technology development is a continuous improvement process. After FutureGen is built there will be ample opportunities to incorporate additional innovations in future commercial versions of the plant once we have demonstrated the basic concepts.
- How much water will the power plant use on a daily basis?
  Preliminary estimates are that the plant will require 2500 gallons of water per minute.
- Where would the water come from and how will it be used in the plant? Will there be any wastewater effluent?
  Each of the site proposals has identified their recommended water supply. There may be some wastewater effluent. Any water discharged from the plant will be in compliance with the EPA standards for wastewater purity.

Coal Feedstock

- What kind of coal will FutureGen use?
  FutureGen has been designed to operate at its best using either of two primary types of coal: bituminous (e.g. Ill#6, Pit#8) and subbituminous (e.g. Powder River Basin). However, the plant is being designed to operate on other coals such as lignite. The Alliance plans to test a wide variety of coals during its operation, to better understand how these coals perform in near-zero emission gasification operations.
- Would the Alliance test feedstocks from local plants other than coal (e.g. biofuels)?
  The objective of FutureGen is to demonstrate the viability of producing power from coal with near-zero emissions. Initially we plan to test both Eastern and Western coals. While we would not rule out the possibility of a test campaign using other types of feedstock, this is currently outside of the scope of FutureGen.

Carbon Sequestration and Monitoring

- How do you know that the geologic structure of the Candidate Sites is suitable and safe for CO_2 storage? Are there concerns regarding geologic faults?
  An international panel of independent experts in geology and carbon sequestration assessed the 12 sites initially proposed to the FutureGen Alliance. Over 100 extremely stringent criteria were used to narrow these 12 sites to four that were considered most suitable from both a subsurface and surface power plant siting perspective. All four of the short-listed Candidate Sites passed this rigorous assessment. Of these four sites, one will be selected for the project.

  Our initial screen suggests there are no faults that cut through the target formation and overlying caprock near any of the Candidate Sites. We will continue to evaluate seismic and drilling information collected by the local task forces and the State Geological Surveys. After selecting a site, the FutureGen Alliance will perform additional site-specific testing including in-depth seismic and drilling studies before FutureGen is constructed and CO_2 is injected into the ground.

- What type of formations will FutureGen use for CO_2 storage?

  Deep-saline formations, at depths greater than 3,000 feet, are being proposed as the target formation for CO_2 storage. The Department of Energy and the FutureGen Alliance are both interested in deep-saline formations because the CO_2 storage capacity of these formations is large, making them a long-term viable solution. Also, many existing large CO_2 point sources are within close proximity to deep saline formations. While CO_2 storage in depleted oil wells has been widely used for enhanced oil recovery (EOR) since the 1970s - and is well understood - EOR opportunities are much less prevalent than deep-saline reservoirs. Because the FutureGen Alliance wants to ensure that this project is broadly replicable around the U.S. and the world, it is important to demonstrate CO_2 storage in this widely occurring type of geologic formation.

- How will the CO_2 be delivered to the storage area? Will it be in a gaseous state?

  A pipeline will be used, most likely 10-16" in diameter, to deliver the CO_2 from the plant to the permanent storage area. (One of the Candidate Sites would not require a pipeline because the storage area is at the plant.) At the plant, the CO_2 will be compressed into a dense liquid-like state known as a supercritical fluid, which is like a liquid, before being transported for injection into the ground. It will then be delivered to the target storage formation at a depth greater than 3,000 feet, where the formation pressure will allow it to remain in a supercritical form.

- What pressure does the CO_2 have to be maintained at to remain a supercritical fluid? Are you concerned that the CO_2 will push the brine out and up to the surface?

  CO_2 can be maintained as a supercritical fluid at temperatures and pressures above its critical point, 31.1oC (88.0oF), and 73.8 bar (1070 psi). The geologic formations being considered for the volume of CO_2 that will be stored under the FutureGen project are large and regionally extensive. These factors will ensure that the injected CO_2 will simply increase the pressure in the formation, like adding air to a tire. The system will be engineered to ensure that pressures remain high enough to keep the CO_2 supercritical, but low enough to avoid damaging the caprock, which provides an impermeable barrier above the target storage formation.

- What kind of problems do you expect with CO_2 in a liquid state?

  We don't expect any issues with the CO_2 as a fluid. There is a lot of experience in the oil industry with transporting and injecting supercritical CO_2. Pipelines and wells can be engineered to handle the pressures necessary to keep CO_2 in this form using current technology.

- How much CO_2 will be injected each year?

  It is estimated that a minimum of 1 million and up to 2.5 million metric tons of CO_2 will be injected per year. As a result, the FutureGen Alliance is looking for sites that have the capacity to hold at least 50 million metric tonnes of CO_2. The capacities of the four CO_2 storage sites being proposed are all significantly greater than this amount.

- How do you know when you have hit the saturation point for CO_2 storage in the deep-saline formation?

  Injecting CO_2 will increase the pressure in the formation. We will do a thorough characterization of the selected site to determine how much pressure the caprock, or primary seal, can safely hold. Once we know how much pressure the caprock can safely hold, we can determine how much CO_2 can be safely injected. Currently, we estimate that the capacity of each of the four candidate sites is significantly greater then what is being proposed for injection.

- How do you ensure that the gas plume will remain in the area it is placed and not migrate into other places?

  The local FutureGen teams and State Geological Surveys at each site are providing initial information about the subsurface to help the FutureGen Alliance select the most appropriate site. When a final site is selected, the Alliance will complete a thorough characterization of the site before anything is injected. This will include detailed modeling and field studies. After the CO_2 is injected, we will monitor the CO_2 plume by conducting periodic surveys and continuous monitoring with state-of-the-art equipment to verify that the

CO_2 stays contained in the storage formation, as anticipated.

- How does the Alliance know that the CO_2 storage area will not interfere with groundwater?
  Groundwater suitable for drinking is much shallower than the depths of the proposed target formations for CO_2 storage. The Candidate Sites have from 1300 to more than 5000 feet of rock separating the two, as well as multiple impermeable seals or caprocks between the target formation and overlying formations with potable water resources. The storage formations selected are not a source of drinking water as defined by EPA established salinity levels. Salinity levels in these saline formations are, in some cases, 10 times greater than that of ocean water.
- Is it possible that the CO_2 that is captured could be used to support enhanced oil recovery (EOR)?
  EOR has been practiced for decades and is well understood by the oil industry. However, depleted oil wells are much less prevalent than deep-saline formations. FutureGen targets CO_2 storage in these more-widely occurring deep-saline formations to help demonstrate its replicability around the world. Once minimum annual targets for CO_2 storage are met (i.e., > 1 million tonnes per year), it is possible that some excess CO_2 could be used for other applications, such as EOR.

Employment

- How many jobs will be created by FutureGen?
  Preliminary estimates suggest peak construction employment of 600-700 workers, and a permanent workforce of over 100 during the operational phase of the project. Experience has shown that each new job created from such a project typically also creates 1-2 additional spin-off jobs.

Byproducts and Waste Products

- Will FutureGen produce ash and slag byproducts of commercial value?
  There is a high likelihood that the ash and slag byproduct will have commercial value.
- Could FutureGen be a hydrogen source for a nearby company? Will it produce high-quality hydrogen?
  The FutureGen plant has the potential to generate high-quality hydrogen, but the primary intention is to use this hydrogen for power production and onsite research. Small commercial quantities may be sold primarily for demonstration purposes.

Facilities Similar to FutureGen

- Are there other IGCC plants currently operating in the US?
  There are currently just two commercial-scale IGCC plants operating in the US today. Both were developed in partnership with the US Department of Energy as part of a government-industry cost-sharing program. Tampa Electric's Polk Power Station in Florida is a 250-MW power plant, which began operation in 1997. The Wabash River Coal Gasification Repowering Project outside of Terre Haute, Indiana began full-scale operations in 1995. The Wabash plant supplies 262 MW of electricity to the grid.
- What kind of coal are the Tampa and Wabash IGCC facilities using?
  Primarily bituminous coal and petroleum coke. Although, you would need to check with the operators of the plants to get more details.
- How is FutureGen different from the other two IGCC plants operating in the U.S. today?
  FutureGen is the first facility to integrate advanced technologies for coal gasification, electricity production, emissions control, CO_2 capture and permanent storage, and hydrogen production at a commercial scale. In addition to power production, which is the primary objective of the Wabash River and Tampa Electric plants, research and development will play an important role in of the operations plan for FutureGen. FutureGen will serve as a "living laboratory" for researchers to test and validate novel technologies.
- What is the difference in operating cost between an IGCC plant and the integrated technology the FutureGen plant will have with IGCC and carbon sequestration?
  Because this is a first-of-its-kind plant, and we are still in the conceptual design phase, we do not yet know how much more it will cost to add carbon sequestration. A primary goal of the project is to observe the

operating performance of the integrated technologies in order to better understand the cost differential and determine under what conditions cost and performance may be optimized for a fully integrated IGCC-carbon capture facility.

- Are there any power plants that use hydrogen to power turbines today?
  There are no other utility-scale turbines powered by hydrogen. FutureGen is proposing the use of a hydrogen syngas turbine. The turbine used by FutureGen will move industry more rapidly down a technology pathway toward a high efficiency, direct hydrogen-powered turbine.

Research and Technology Transfer Opportunities

- Will there be a visitor's or education center at the FutureGen facility?
  Yes, the Alliance currently plans to have a visitor's or education center.
- Will FutureGen technology be transferable to existing coal plants?
  FutureGen will advance a number of technologies that could be applicable to the existing fleet of coal plants. Insights from carbon injection and storage systems will be particularly applicable to existing plants. Lessons learned from the carbon capture process may also be important; however, because FutureGen will capture the carbon pre-combustion and existing plants would capture the carbon post-combustion, the technology will be implemented differently. In addition to FutureGen, technology development for the existing fleet of plants is also the focus of other research programs supported by the DOE.
- Is the Alliance required to share the technology and any intellectual property?
  DOE regulations require a significant amount of this information to be made public. It is the intent of the Alliance to make public as much information as possible about the operations of the plant during the first four years of operation. Most of the intellectual property employed in FutureGen is expected to be owned by the suppliers of the novel equipment (e.g. gasifiers) that are incorporated into the plant.

Site Selection Process

- How will the final site be selected?
  During 2006 the FutureGen Industrial Alliance, Inc received twelve proposals submitted through an open, competitive site selection process. A team of renowned U.S. and international scientists and engineers reviewed the proposals against a set of nearly 100 peer-reviewed, publicly-vetted criteria. These criteria reflected the environmental, technical, regulatory, and financial goals of the project. Based on a thorough evaluation, the Alliance selected four candidate sites for further review.
  In early 2007, the Alliance began a process of additional due diligence and negotiations with each of the four candidate site proposers. The final site will be selected as a result of the negotiations with the proposers based on which site provides the maximum overall value to the FutureGen project.

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