CLEAN COAL TECHNOLOGY

Coproduction of Power, Fuels and Chemicals

Coproduction of Power, Fuels and Chemicals

A report on a program conducted jointly under cooperative agreements between:

- Waste Management and Processors, PTY., LLC.
- Gasification Engineering Corp./Global Energy Inc.
- Texaco Energy Systems Inc.

DEPARTMENT OF ENERGY • UNITED STATES OF AMERICA

CLEAN COAL TECHNOLOGY

Coproduction of Power, Fuels and Chemicals

Executive Summary

Coproduction of power, fuels and chemicals offers an innovative, economically advantageous means of achieving the nation's energy goals. Coproduction involves the integration of three major building blocks:

- Gasification of coal or other hydrocarbon fuels to produce synthesis gas (syngas)
- Conversion of a portion of the syngas to high-value products such as liquid fuels and chemicals
- Combustion of syngas to produce electric power.

In coproduction, the relative amounts of syngas used for power generation or converted to fuels and chemicals depend on market demands. The goal of coproduction is to fully utilize the feedstock and maximize revenue streams. By permitting operation of the gasifier at full capacity to make syngas for either power generation or fuels and chemicals production, coproduction makes more efficient use of capital than when producing power alone.

Gasification can accommodate a wide range of feedstocks, including coal and low-cost opportunity fuels such as petroleum coke, biomass, and municipal wastes. By taking advantage of both fuel flexibility and product flexibility, coproduction offers significantly improved economics compared with conventional power generation facilities.

Power production is achieved by the use of integrated gasification combined-cycle (IGCC), an advanced technology that combines modern coal gasification with gas turbine and steam turbine power generation. IGCC is one of the most efficient and cleanest of available technologies for coal-based power generation, with emissions comparable to those of natural gas-based power production.

Coproduction projects currently envisioned incorporate a number of commercially demonstrated processes for converting syngas to fuels and chemicals, including (1) Fischer-Tropsch technology to produce a range of liquid products that can supply the gasoline and diesel fuel markets, and (2) the LPMEOH™ process for manufacture of methanol, an industrial chemical in widespread use.

IGCC and conversion of syngas to liquid products have both been demonstrated successfully under the Clean Coal Technology (CCT) Program sponsored by the U.S. Department of Energy (DOE). This Program is a multi-phased effort administered by the National Energy Technology Laboratory (NETL).

Three DOE-sponsored projects are underway to develop facilities for NETL's Early Entrance Coproduction Plants (EECP). These projects are being conducted by: (1) Waste Management and Processors, PTY., LLC., (2) Gasification Engineering Corp., a Global Energy Inc. company, and (3) Texaco Energy Systems Inc. Each project involves preliminary process designs, conceptual economics, and site specific studies. If the concepts evaluated in these projects appear feasible from a technical and economic standpoint, the project teams will be positioned to prepare detailed engineering designs and obtain funding to construct and operate the EECPs.

The projects described in this report represent a major step in the development of advanced technology modules for integration into the high efficiency, near pollution-free energy concept that constitutes the core of DOE's Vision 21 Program, with a goal of achieving commercial operation by the year 2007.

Implementation of these projects will constitute a major step in the development of the advanced energy systems needed to maintain our prosperity, protect the environment, and provide energy security. The proposed plants will also result in a significant reduction in emissions of greenhouse gases, especially carbon dioxide.

Coproduction of Power, Fuels and Chemicals

Background

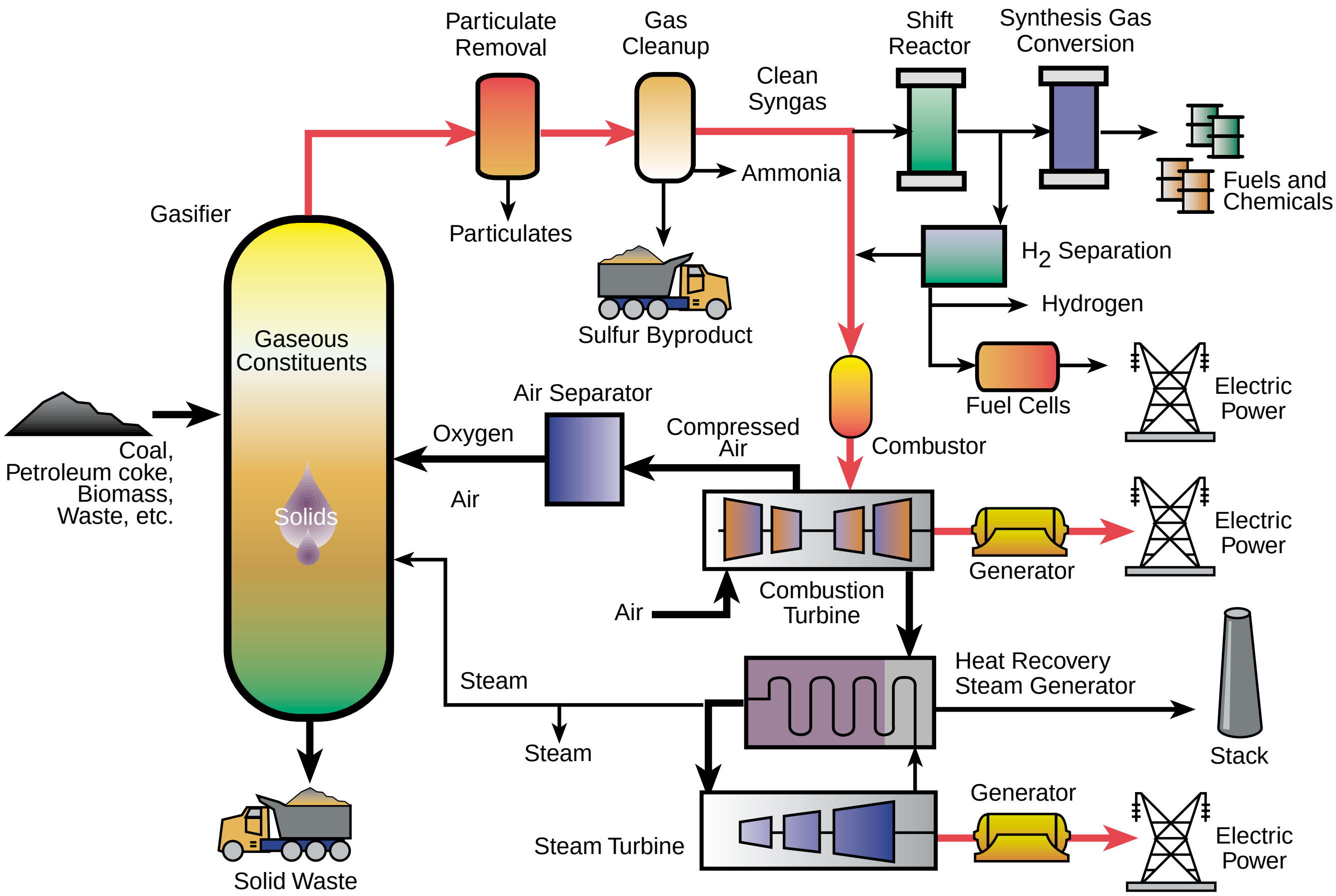
Three major challenges facing the United States are continued economic growth, environmental protection, and energy security. Achieving these objectives depends on an adequate supply of affordable energy produced in an environmentally friendly way. To prosper in the 21st century, we need 21st century technology. Our reliance on standard pulverized coal (PC) fired power plants with efficiencies in the range of 35% will not suffice. A major goal of the Department of Energy's (DOE) Clean Coal Technology (CCT) Program has been to demonstrate the cutting edge technologies the nation will need to meet our economic and environmental goals. In the United States there are several hundred years of coal reserves.

Coproduction of power, fuels and chemicals offers an innovative, economically advantageous means of achieving our energy needs. Coproduction involves the integration of three major building blocks:

- Gasification of coal or other carbonaceous materials to produce synthesis gas (syngas)
- Conversion of a portion of the syngas to high-value products such as liquid fuels and chemicals
- Combustion of syngas and unreacted syngas from the conversion processes to produce electric power in a combined-cycle system.

The relative amounts of syngas used for power generation or converted to fuels and chemicals can be varied depending on market demands.

The first two steps are referred to as Integrated Gasification Combined-Cycle (IGCC) operation. In IGCC, the fuel (usually coal) is reacted with steam and oxygen to produce syngas, which consists of hydrogen (H_2), carbon monoxide (CO), and smaller amounts of



Gasification-Based System Concepts

other gases such as carbon dioxide (CO_2), hydrogen sulfide (H_2S), ammonia (NH_3), water vapor, and methane (CH_4), with traces of other materials. This gas is cleaned of its contaminants and used for electric power production. Such a system is inherently more efficient and cleaner than conventional PC-fired systems, with efficiencies typically being above 40% and emissions reduced to the lowest levels currently achievable.

In addition to higher efficiency, gasification has many other advantages. One advantage is that H_2S and NH_3 are much more easily scrubbed from the gasifier effluent than are sulfur dioxide (SO_2) and nitrogen oxides (NOx) from the stack gas of a PC-fired boiler. Thus, IGCC plants are environmentally more friendly. Furthermore, the recovered H_2S is readily converted to sulfur or sulfuric acid, both of which are commodity chemicals with a large market. Likewise, ammonia is a commodity chemical that can easily be sold.

Another major advantage of gasification is that it can accommodate a wide variety of feedstocks, including low-cost, so-called opportunity fuels. In addition, the syngas can be converted to a broad range of useful products, such as diesel fuel, methanol, higher waxes, ammonia, and other chemicals.

In the coproduction concept, an energy complex produces not only power, but also fuels and/or chemicals. This greatly increases the flexibility of the complex and offers economic advantages compared with separate plants, one producing only power and the other only fuels or chemicals. Operation of the gasifier at full capacity to make syngas for either power generation or manufacture of higher value products such as fuels and chemicals maximizes the efficiency of capital utilization.

This report discusses in more detail some of the available options, the technologies involved, and what DOE is doing to promote them and ensure they are available as we need them.

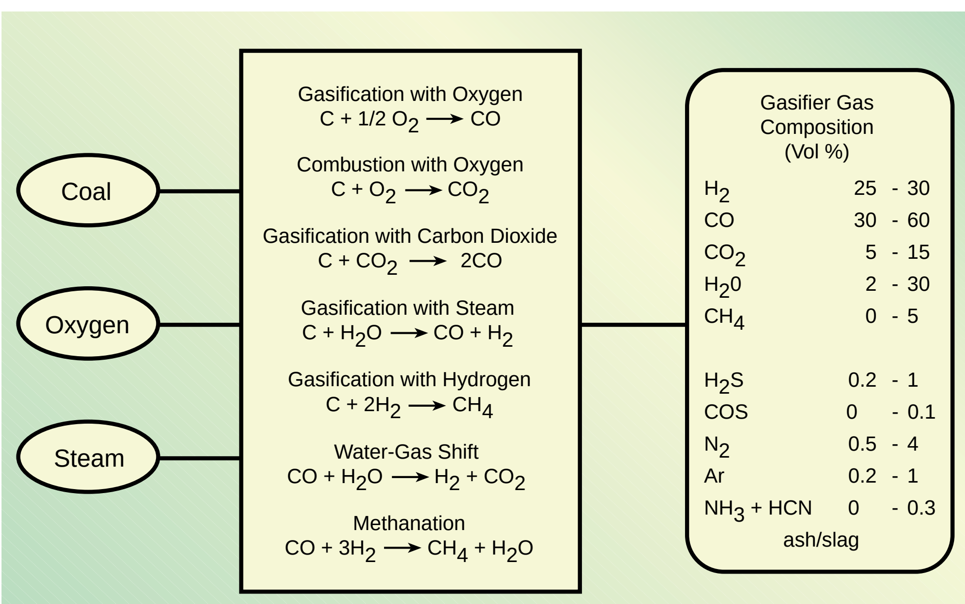
Description of Gasification and Power Generation Technology

Gasification

The first step in coproduction is gasification. Coal gasification has been practiced commercially for many years. The heart of these systems is the gasifier, which converts carbonaceous feedstock into largely gaseous components by applying heat under pressure in the presence of steam and oxygen. Partial oxidation of the feedstock provides the heat. The product is syngas, along with smaller quantities of CO_2 and CH_4.

Minerals (ash) in the feedstock separate and leave the bottom of the gasifier either as an inert glass-like slag or other marketable solid product. Only a small fraction of the ash becomes entrained in the syngas and requires removal downstream. Sulfur in the gasifier feed is reduced to H_2S, and nitrogen is reduced to NH_3. These materials, along with hydrogen chloride and entrained particles, are removed in the downstream gas cleanup system.

The syngas is used to generate electric power via a combustion turbine and produce a broad range of chemicals and clean fuels. Syngas can also be used to generate power via fuel cells or to produce hydrogen.



Gasification chemistry

Combined-Cycle Power Generation

As indicated above, the clean syngas from the gasification step is burned, in whole or in part, in a combustion turbine. This turbine drives an electric generator and an air compressor which provides air under pressure to the air separation unit to supply oxygen to the gasifier. The hot gas from the combustion turbine is sent to a heat recovery steam generator (HRSG), which produces steam for a steam turbine/generator. This combined use of combustion and steam turbines significantly boosts the overall thermal efficiency of power generation compared with single cycle operation.

Ultimately, IGCC systems will be capable of reaching efficiencies of 60% with near-zero sulfur and particulate pollution and low NOx emissions. The high process efficiency results in lower production of CO_2, which is a major greenhouse gas considered responsible for global climate change. In gasification systems, CO_2 can be readily removed from the syngas because it is present in concentrated form. This option is well suited to a variety of CO_2 sequestration schemes such as storage.

Syngas Conversion Processes

The key to coproduction is the ability to utilize syngas in applications other than power generation.

Gasification can deliver a full slate of commodity products, including hydrogen, environmentally superior transportation fuels, and chemicals. Hydrogen is a particularly attractive coproduction option, because it requires the lowest incremental investment (estimated at less than 10% of the IGCC plant cost) beyond the initial IGCC investment and has the potential to provide significant additional revenue. Hydrogen is a critical ingredient in refinery hydrocracking and desulfurization processes and is also a base raw material for ammonia production.

Coproduction options include conversion of syngas to methanol, higher alcohols, Fischer-Tropsch (F-T) liquids, waxes, and other high-value products. F-T fuels, with their zero aromatic content, high cetane number, and zero sulfur and nitrogen content, will be a valuable blending stock for diesel fuel to meet the requirements of the Clean Air Act Amendments of 1990, administered by the U.S. Environmental Protection Agency (EPA). The fuel products will also meet EPA's Tier 2 sulfur requirements for light duty vehicles of 30 ppm for gasoline and 15 ppm for diesel.

A number of commercially proven syngas conversion technologies have already been developed.

Fischer-Tropsch Process

F-T technology was initially developed, beginning in 1923, by two German scientists, Franz Fischer and Hans Tropsch, based on earlier observations by Sabatier and Senderens. The F-T process converts syngas into a mixture of mainly straight chain paraffinic and olefinic hydrocarbons. F-T synthesis takes place over a cobalt- or iron-based catalyst that promotes the reaction of CO and H_2 to form hydrocarbons and water. The hydrocarbon product includes material of varying properties from light gases (C_2-C_4) through waxes such as C_{50+} molecules. The process operates at relatively moderate temperatures (400 – 550 °F) and pressures (150 – 560 psia).

After sulfur removal, the syngas is fed to the F-T reactor. The reactor operates with a H_2/CO molar ratio typically between 1.0 and 2.0. Good heat transfer is required, because the reaction is highly exothermic, and selectivity is temperature sensitive.

Four types of F-T reactors have been developed: tubular fixed-bed, circulating fluidized bed, fixed fluidized bed, and slurry bubble column. Each type has its advantages and disadvantages.

Recently, significant amounts of operating data have been accumulated for slurry bubble column reactors, including the operation of a 5-m diameter, 2500 b/d reactor at Sasol Synfuels International (SASOL) in South Africa and the 0.6-m reactor at the DOE-owned Alternative Fuels Development Unit (AFDU) at LaPorte, Texas. The slurry reactor design has proven to be the preferred configuration, primarily because of superior temperature control.

The reaction to form paraffins is as follows:

$$2\ nH_2 + nCO = C_nH_{2n+2} + nH_2O$$

Similar reactions take place to form olefins and alcohols. The F-T product distribution typically follows the single-parameter Anderson-Schulz-Flory (ASF) equation:

$$W_n = n(1-\alpha)^2\alpha^{n-1}$$

where W_n is the weight fraction of product of carbon number n, and α is the chain growth probability. The higher the value of α, the longer the average chain length of the hydrocarbons. If α equals 0, only methane is produced. In practice, there is often a deviation from the ideal ASF distribution. The extent of this deviation varies with the nature of the catalyst and the operating conditions.

The reactor effluent is cooled to allow separation of the tail gas, condensate (naphtha and diesel fuel), wax, and process water. The majority of the tail gas is reformed and recycled through the reactor to increase the overall conversion of CO to liquid hydrocarbons. Alternatively, in the coproduction mode the tail gas can be utilized to supplement the fuel used for power production, thereby increasing overall efficiency.

F-T products are ultra-clean fuels in that they contain no sulfur or nitrogen and are virtually free of aromatics. F-T derived diesel fuel is of excellent quality, having a cetane number greater than 70. The zero-sulfur F-T naphtha can be used as a blending stock for low-sulfur gasoline production, although the naphta has a low octane. The trend in both Europe and the United States is for cleaner transportation fuels, with more stringent fuel quality and vehicle exhaust emissions regulations being promulgated by governmental bodies. This will add impetus to more widespread use of F-T products.

To meet certain fuel specifications, such as pour point and octane number, raw F-T products require additional processing. The wax can be processed in a selective hydrocracker operating under mild conditions, where some longer chain hydrocarbons are broken into shorter molecules and some isomerization occurs, thereby improving the boiling range and pour point for blending with diesel fuel.

The light naphtha can be hydrotreated to saturate the olefins and subsequently used in a refinery isomerization unit or fed to a naphtha cracker for ethylene production. The heavy naphtha also can be hydrotreated and then fed to a naphtha cracker. If a naphtha cracker is not available, this stream can be stored and used as a peaking fuel in a gas turbine to augment electricity production.

Several facilities have been built for implementing F-T technology. Most notable is the commercial operation that has been carried out successfully for many years by SASOL. This development was undertaken by South Africa to minimize its dependence on imported oil and to utilize its large reserves of coal.

The SASOL operation uses iron-based catalysts as developed in the initial German work. Other companies that operate either pilot-plant or commercial F-T facilities include two major established oil companies, Exxon-Mobil and Shell, and two relatively new companies, Rentech and Syntroleum.

Numerous patents cover F-T catalysts and process configurations. Rentech and Syntroleum hold some significant patents and have established licensing arrangements with a number of potential users of the F-T process, including major corporations.

Several companies have announced their intention to participate in commercial F-T projects. In some cases, these projects are being considered as a means of utilizing natural gas reserves that are deemed uneconomical for development or for stranded natural gas that has no access to conventional markets.

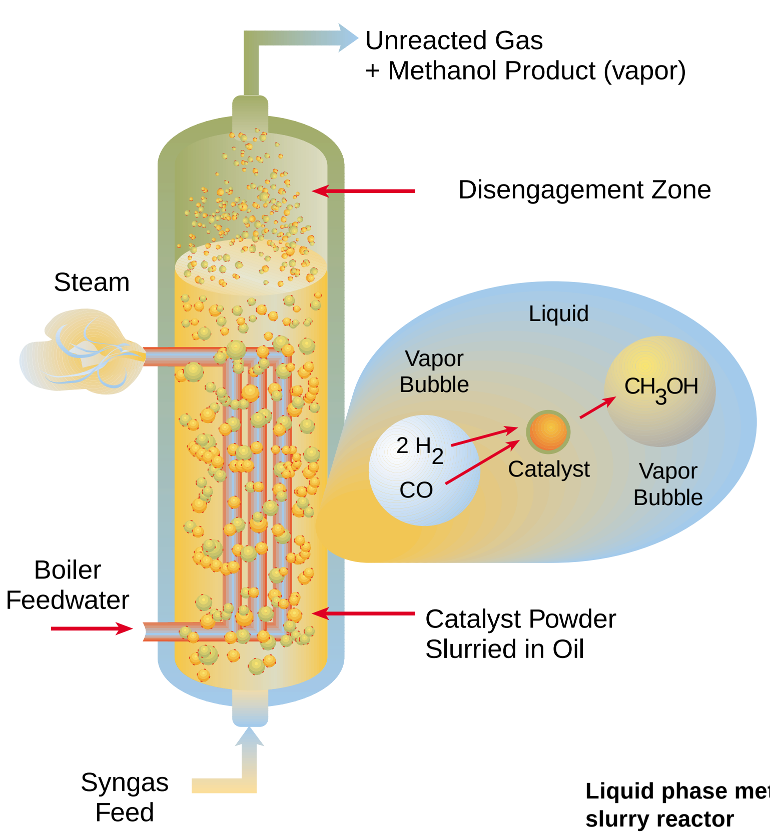
Production of Methanol

The Liquid Phase Methanol (LPMEOH™) process (described in Topical Report No. 11) integrates coal gasification with chemicals production. It was demonstrated on a commercial scale by a partnership between Air Products and Chemicals, Inc., and Eastman Chemical Company as part of the CCT Program. Application of this technology can enhance the economics and efficiency of power generation by producing a clean-burning, storable liquid (methanol) from syngas during periods of low power demand. The methanol can be used to fuel combustion turbines during peak demand.

The main uses for methanol are in the production of chemicals, such as formaldehyde, acetic acid, and other derivatives, and as a fuel. It can be dehydrated to produce olefins, a large and growing market. Demonstration of the LPMEOH™ process has increased the experience base and reduced the commercial risk for future operations, whether integrated with chemicals production or with IGCC power production. Together these technologies can fill local needs for electric power, transportation fuels, and chemicals.

Production of Higher Alcohols

In addition to methanol, alcohols having higher molecular weights, such as C_2-C_6 alcohols, can be produced from syngas. Research is underway to develop processes suitable for commercial application. Higher alcohols are candidates for inclusion in gasoline as oxygenates to reduce exhaust emissions that contribute to smog formation.



Liquid phase methanol slurry reactor

View of LPMEOH™ Demonstration Unit with building housing catalyst facilities in foreground

Production of Hydrogen and Future Fuels

Another option for coproduction is the manufacture of hydrogen from syngas. This product is part of the product slate envisioned in DOE's Vision 21 Program. Hydrogen is a critical ingredient in refinery processes, such as hydrocracking and hydrotreating, and is also a starting material for ammonia production.

Hydrogen production is being considered as an integral part of DOE's Future Fuels Program, which targets the development of clean fuels that will require major modifications to, or replacement of, the existing transportation fuels infrastructure.

It is anticipated that these future generation fuels will be obtainable from domestic natural gas, petroleum, refinery wastes, coal and other suitable carbonaceous feeds. As part of an advanced transportation system, the widespread deployment of these future fuels will enable vehicles to achieve zero to near-zero emissions of criteria pollutants and greenhouse gases.

These future fuels will be cost competitive, reliable, safe, and comparable to current fuel in efficiency and performance. They will, however, likely require some adjustment to today's consumer patterns and fueling/refueling requirements. Examples of advanced vehicle systems that will require these future fuels include diesel-electric hybrids and fuel cell powered vehicles. Future fuels will enable the Nation to meet its desire for a high-efficiency transportation system having minimum environmental impact.

Industrial Applications of Gasification

Current Status of Gasification

In today's changing world, single-purpose, single-technology power plants are limited in their ability to compete in the marketplace. Deregulation is completely restructuring the electric power industry. Competition is forcing energy suppliers to downsize, streamline operations, and merge. Gasification will be the key to providing low-cost energy for continued U.S. economic growth while, at the same time, furthering national goals to protect the environment and mitigate concerns about global climate change. Successful new energy firms will capitalize on opportunities to integrate electric power generation with industrial processes.

Energy firms that produce a variety of products, such as steam, chemicals, and fuels, are poised to capture an increasing volume of electricity sales in a deregulated environment. In a competitive energy market, systems that offer the producer reduced market risk and enhanced revenues from high-value products are essential. Gasification systems will prosper in this type of environment by offering significant hedges against market and environmental risks.

Gasification in conjunction with syngas conversion processes represents the only technology capable of coproducing power and a wide variety of commodity and premium products. A gasification facility can be built to convert virtually any carbonaceous feedstock into products such as power, steam, hydrogen, transportation fuels, and value-added chemicals.

Different technology combinations enable use of low-cost, readily available resources and waste materials in highly efficient energy conversion options. These options can be selected to meet any of a host of market applications, with modules being combined according to individual business opportunities. These versatile technology combinations will be the core of the new generation of energy plants.

Of the gasification plants that have been constructed to date, several have improved their economic viability through the sale of coproducts. In the United States, the Eastman Chemical Company's commercial plant at Kingsport, Tennessee, operated since 1983, has pioneered the use of coal gasification solely for the production of chemicals from carbon monoxide and syngas-derived methanol.

DOE, in partnership with industry, has played a crucial role in catalyzing long-term research and demonstrating advanced technologies such as IGCC, through the CCT Program. At a time when deregulation has made the power industry cautious about investment, DOE mitigates economic and technical risks by underwriting the development of novel technologies. Public/private partnerships are fostering the commercialization of gasification-based processes that will give the United States an edge in rapidly expanding global energy markets while meeting increased domestic demand for power and fuels with superior environmental protection.

The Future of Gasification-Based Energy Plants

Gasification systems are the basis of a new energy industry. The electric power industry is keenly aware that gasification is a leading candidate to provide clean and efficient baseload power when major capacity additions are needed.

Gasification has inherent characteristics that will enable major energy industries — electric power generation, petroleum refineries, chemicals and fuels industries — and energy users to remold their technology and business structures to meet future market needs and take advantage of new opportunities.

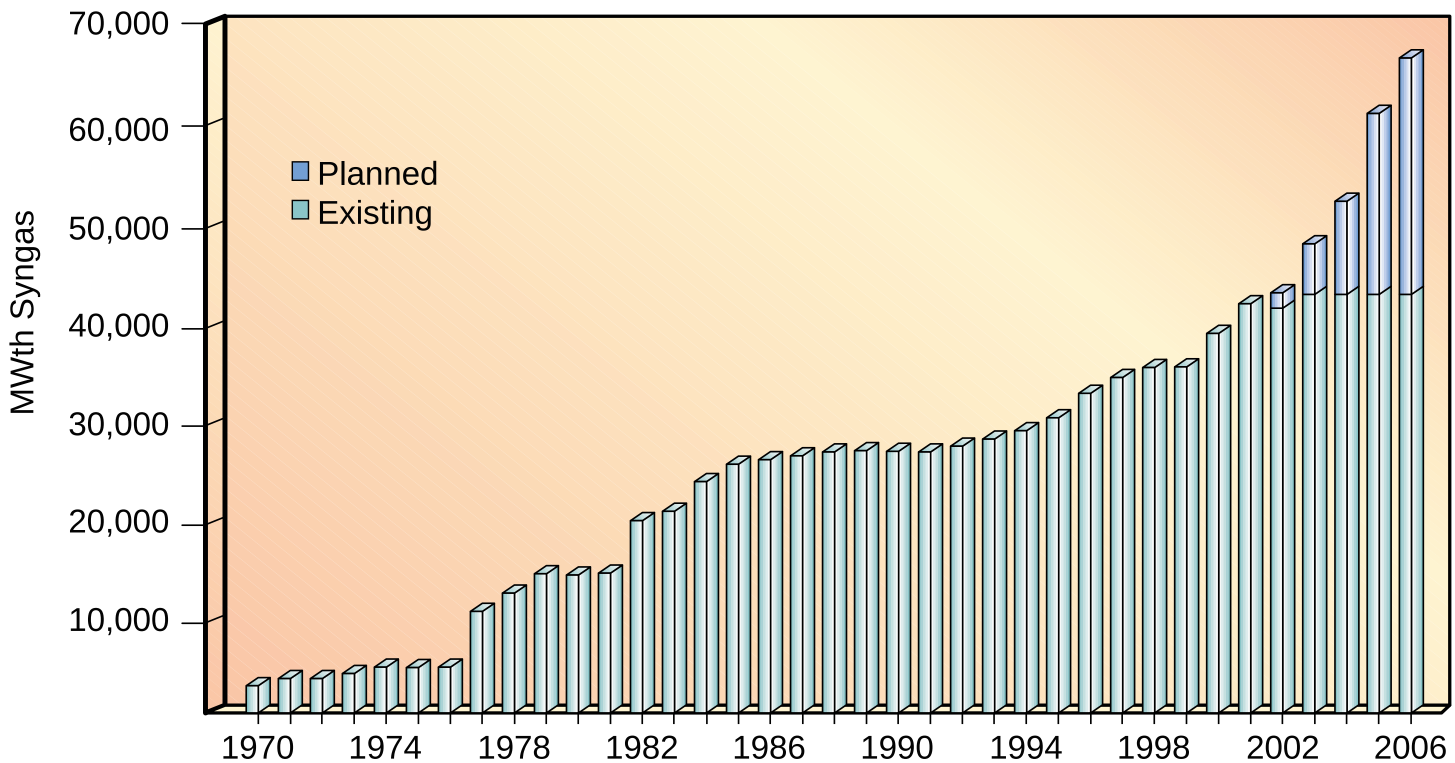
Deregulation, restructuring, and new types of cost competition are emerging along with increased environmental pressures. As a result, the boundaries of these industries and their business structures will change significantly. The inevitable result will be opportunities for lower-cost, more efficient, and less polluting energy conversion technologies. These technology options will enable structural changes in both the technology base and business interests of major energy industries as power generation evolves into more diverse coproduction modes.

The unique advantages of gasification systems have created a significant industrial applications market because of both upstream (feedstock) and downstream (product) flexibility.

In the petroleum refining industry, gasification has numerous important near-term synergistic applications. Gasifiers are used to process refinery wastes, avoiding waste disposal costs and improving the yield from increasingly sour crude oils. At the same time, electricity and steam are produced to meet refinery needs, and the excess syngas can be used to generate valuable hydrogen or fuel products that are integrated into refinery operations.

In the pulp and paper industry, black liquor produced in the pulping process can be gasified to capture its energy value for kiln operation and recover pulping chemicals for reuse. This increases process efficiency and reduces environmental impact by destroying potentially hazardous process wastes.

In the steelmaking industry, gasification can provide syngas for use both as the reactant for direct reduction and as a fuel for power generation, especially in countries where natural gas and coke are not readily available.



Cumulative worldwide gasification capacity and growth

Market Potential for Coproduction

Advantages of Coproduction

In the past, IGCC has typically been considered for baseload, high-dispatch market needs for electric power. However, there continues to be a high demand for peaking and intermediate load capacity. Combining coproduction of chemicals and power in a gasification facility allows the flexibility to maximize power generation during peak demand periods and maximize chemicals production during off-peak periods, making gasification more attractive to the existing power market. It also allows flexibility in geographical location based on local grid peak-shaving needs.

A combined power and methanol plant requires less capital than separate power and methanol processes. Locating the integrated facility near a chemical complex provides a means of improving gasification economics by ensuring full utilization of the gasifier and exploiting synergies between the processes.

Market Drivers

Continued growth in gasification is being driven by a number of factors:

- Market forces are replacing government regulations, thus placing increased emphasis on economic performance.
- Environmental standards are becoming increasingly stringent, and greenhouse gas emissions are of growing concern.
- Demand is increasing for cleaner transportation fuels, which require more hydrogen to produce.
- Demand is escalating for chemicals both in the United States and in other coal-dependent areas such as Asia.
- Costs for solid waste and sewage sludge disposal are continuing to escalate, increasing the incentive to use them as opportunity feedstocks.
- Interest is increasing in the use of renewables, such as biomass, to address global climate change concerns.
- Utilities, independent power producers, and refiners, who have grown increasingly dependent on the volatile natural gas market, are seeking to diversify their fuel supply mix.

Competition Within Energy Markets

During the coming years, competition among various power systems and fuel resources will continue. Natural gas has been readily available and relatively inexpensive, leading to growth in natural-gas-based power systems. However, as gas becomes more expensive, lower-cost energy resource options such as coal and alternative fuels become increasingly viable choices. Gasification will then prove to be ideally suited for providing efficient power generation and syngas manufacture.

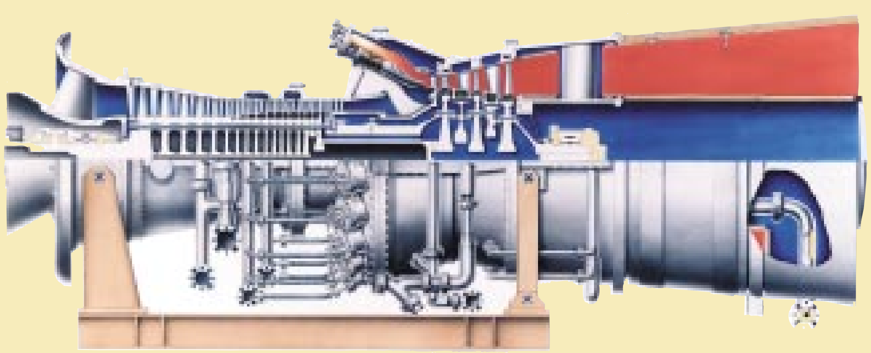
The capital cost for a natural gas combined-cycle power plant is currently about one-half the cost of a coal-based IGCC plant. IGCC is capital intensive and needs economies of scale and fuel cost advantages to be an attractive investment. However, gasification costs can be lowered through integration with downstream applications such as fuels and chemicals production. Gasifiers can (1) operate on low-cost opportunity feedstocks; (2) be used to convert hazardous waste into useful products, reducing or eliminating waste disposal costs; and (3) coproduce power, steam, and high-value products for use within the host plant or for export.

DOE has studied the economics of coproduction, demonstrating the advantage of multiple revenue streams, i.e. from sale of electric power, liquid fuels, and chemicals. In one scenario, it is assumed that the power generated by coproduction is sold at the same price as that generated by natural gas combined-cycle. Thus, the price of natural gas sets the cost of power and establishes a benchmark for economic comparison. In addition, liquid fuels are valued at an assumed premium of \$8/barrel over the reference world oil price of \$21/barrel in 2010 as predicted by the U.S. Energy Information Agency. Based on a fixed return on equity (ROE) of 15% and a coal price of \$30/ton,

Gasification Projects in the CCT Program

Through the DOE CCT Program, coal gasification has been successfully demonstrated on a commercial scale. The CCT Program, a cost-shared effort with private industry, provides an effective approach to moving new technologies from bench scale to the marketplace. Coal gasification projects conducted under the CCT Program include:

- The Tampa Electric Company IGCC project (described in Topical Report No. 19) is a greenfield facility built in Polk County, Florida. The plant uses a Texaco oxygen-blown entrained flow gasifier integrated with a General Electric 7F gas turbine and steam cycle in a combined-cycle plant. The plant also has integrated air separation and cold gas cleanup systems. The plant has accumulated over 27,000 hours of operation, producing 250 MWe at over 75% stream factor. Overall plant availability averages over 90%. Carbon burnout exceeds 95%, and emissions of SO_2, NOx, and particulates are well below the regulatory limits set for the plant site. This facility was the winner of the 1997 Powerplant of the Year Award presented by *Power* Magazine.
- The Wabash River Coal Gasification Repowering Project (described in Topical Report No. 20) involves repowering a 1950s steam turbine with an advanced gasification system. This project, now completed, was a joint venture between PSI Energy and Global Energy Inc. (formerly Destec). The Wabash River plant hosts the world's largest commercially operating single-train gasification system. The conventional coal boiler was replaced by an oxygen-blown, two-stage entrained gasifier and a gas cleanup system. A General Electric gas turbine was installed to make a combined-cycle power plant. Net power production of 262 MWe was achieved during the four-year demonstration period. During that period, total operating hours exceeded 15,000, and the unit continues to operate successfully. Overall thermal efficiency approached 40%, at up to 77% plant availability. Environmental performance was excellent, with SO_2 emissions of 0.1 lb/million Btu and NOx emissions of 0.15 lb/million Btu. This plant was winner of *Power* Magazine's 1996 Powerplant of the Year Award. The Tampa and Wabash River IGCC plants are the two cleanest coal-based power plants in the world.
- The Kentucky Pioneer Energy IGCC Demonstration Project, involving a 540 MWe (net) IGCC unit, will be conducted by Kentucky Pioneer Energy, LLC, a subsidiary of Global Energy Inc. This plant, which will be the largest power producer of the IGCC demonstration projects, features use of the BGL (formerly British Gas/Lurgi) slagging fixed-bed gasification system coupled with both a combined-cycle power plant and a 2 MWe molten carbonate fuel cell (MCFC). The fuel cell will generate power from a portion of the syngas. The project will use a Midwestern high-sulfur bituminous coal, as well as coal fines and renewable feedstocks such as biomass and refuse derived fuels (RDF). The slagging gasifier produces a non-leaching, glass-like slag that can be marketed as a usable by-product. Production of F-T liquids from a portion of the syngas is an option that will be considered. Projected overall thermal efficiency is 48%.



General Electric model MS 7001FA gas turbine

IGCC is competitive with natural gas at about \$3.75/million Btu. For comparison, by generating additional revenue, coproduction attains the same ROE at a lower natural gas price of about \$3.25/million Btu. These figures illustrate the improved profitability of coproduction.

Global Acceptance of Gasification

The stage is set for gasification to play a major part in domestic and global energy markets. In addition to coal-based utility applications, gasification has been used in the conversion of petroleum coke, residual oil, and biomass to power, steam, and chemicals. Currently, coal is the feedstock for 44% of the syngas capacity worldwide. Petroleum and petroleum coke provide an additional 42%, and other resources provide the remainder. Biomass constitutes only a fraction of a percent of all gasification feedstocks. With emphasis on reducing fuel costs, waste disposal costs, and CO_2 emissions, a number of projects will soon use biomass as gasifier feed.

By the year 2015, it is anticipated that gasification-based technologies will have gained global acceptance and, as a result, will have penetrated worldwide power generation markets, achieved more widespread use in the petroleum refining industry, and been widely deployed in the fuels and chemicals market. Gasification-based processes will be the technology of choice because of their low cost and superior environmental performance and because their modularity of design and fuel flexibility provide easy integration with other processes.

Commercial guarantees and financing will be readily available, minimizing the need for government incentives. This ease of access will result in increased use of domestic resources, improving U.S. industrial competitiveness and enhancing U.S. energy security.

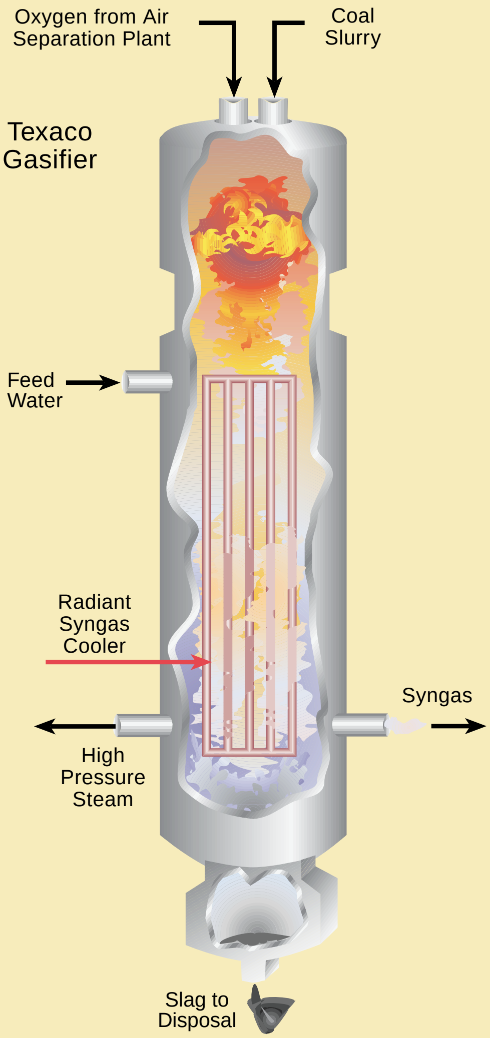
Tampa Electric Company IGCC Project

Wabash River Coal Gasification Repowering Project

Coal Gasification

Coal gasification has been in use for many years. Primitive coal gasification provided town gas worldwide more than 100 years ago, and a gasification industry produced coal-based transportation fuels for Germany during World War II.

Advanced gasification technology development began in the U.S. in the 1960s, the stimuli being (1) the desire for development of coal-based replacements for natural gas and oil due to shortages and price increases, and (2) the need for more efficient, clean coal-based power plants. Modern gasification technology is the result of the response of U.S. government and industry to these needs. Such systems use advanced pressurized coal gasifiers to produce a fuel for gas turbine-based electric power generation; the gas turbine exhaust produces steam to generate additional electricity.



The first commercial scale use of coal gasification in the United States was the Cool Water Project in California, which was based on Texaco technology. The Cool Water Project, which received major support from the U.S. Synthetic Fuels Corporation, Southern California Edison Company, EPRI (formerly the Electric Power Research Institute), and others, was instrumental in proving the feasibility of coal gasification and demonstrating their exceptionally low emissions.

Today, coal gasification is seeing increasing use. In the United States, Texaco gasifiers are utilized in commercial operation at the Eastman Chemical plant in Kingsport, Tennessee to produce synthesis gas for production of methanol and a wide range of other chemicals. The Dakota Gasification plant in North Dakota uses Lurgi gasifiers to produce synthetic natural gas and chemicals.

Overseas, a major chemical and transportation fuel industry exists in The Republic of South Africa, mostly based upon an advanced version of the early German gasification technology. Several German gasifiers are commercially available. Texaco gasifiers are in commercial operation, or planned, in the People's Republic of China and other nations. In Germany, methanol is produced via coal gasification in a facility operated by Sekundarrohstoff Verwertungszentrum Schwarze Pumpe GmbH (SVZ). The SVZ facility, which has been operated for decades near Berlin, is now the largest recycling center in Europe.

Gas turbines for power generation have been one of the spinoffs of jet aircraft engine development. Initially utilized by utilities for peaking purposes, their reliability, efficiency and capacity have improved to the extent that they now also provide intermediate and baseload electric power. It is projected that coal gasification and gas turbines will make significant contributions to future power generation

Today's systems are efficient because of major improvements that have taken place in gasification and gas turbine technologies, and a high degree of system integration that efficiently recovers and uses waste heat.

Gas cleanup in a gasification-based power plant is relatively inexpensive compared with flue gas cleanup in conventional coal-fired steam power plants, for several reasons: (1) smaller equipment is required because a much smaller volume of gas is cleaned, and (2) the contaminants are removed in a reduced state (H_2S and NH_3) rather than in an oxidized state (SO_2 and NOx). This results from the fact that contaminants are removed from the pressurized fuel gas before combustion. In contrast, the volume of flue gas from a coal-steam power plant is much greater because of the presence of nitrogen diluent from the air and because the flue gas is cleaned at atmospheric pressure.

Atmospheric emissions are very low due to the use of proven technologies for highly effective removal of sulfur and other contaminants from the syngas. Advancements being demonstrated in the CCT Program are expected to result in still higher efficiencies.

Early Entrance Coproduction Plants

Among its many benefits, coproduction can lead to a reduction in oil imports by producing significant quantities of ultra-clean fuels from domestic resources with minimum emissions. However, private investors and process developers are hesitant to invest in coproduction plants until technical, economic, and integration risks are acceptable.

DOE has adopted an Early Entrance Coproduction Plant (EECP) strategy to mitigate these risks. This strategy initially involves feasibility studies of several coproduction configurations assuming a variety of feedstocks at a number of plant locations. Three EECP feasibility studies have been initiated. Each study involves design of a unique facility capable of coproducing a combination of electric power, heat, fuels, and chemicals from syngas derived either from coal alone or from a combination of coal and other feedstocks.

Each EECP study will pursue a different coproduction strategy, conduct research and development to address technical issues, and culminate in a preliminary design of a precommercial facility. If the strategies appear feasible, each project team will have sufficient information to proceed with a detailed engineering design and obtain private funding to construct and operate an EECP.

These EECP conceptual plants would be small-scale commercial facilities that are intended to demonstrate successful operation of integrated technologies. They would be constructed adjacent to existing facilities and be capable of processing multiple feedstocks and delivering more than one product. They would be built by industrial consortia in partnership with State and Federal governments. Once successful operation has shown the risks to be acceptable, future commercial plants would not require Federal funds.

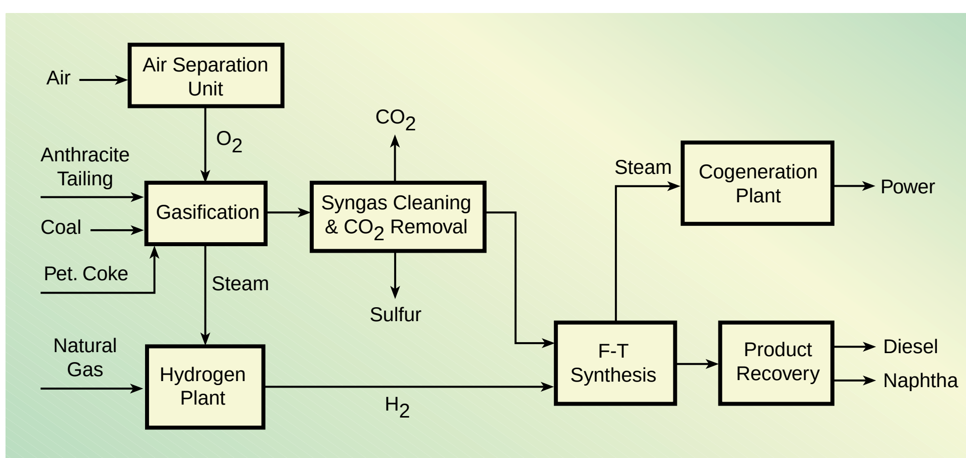
The three EECP studies currently underway are described in the following sections.

Waste Management and Processors Project

The Waste Management and Processors EECP project involves converting high-ash coal residue into premium transportation fuels and electricity. Coal waste not only provides a low-cost feedstock, but its use also benefits the environment by reclaiming land and eliminating a potential pollution problem. The proposed plant location is at the Gilberton Power Plant cogeneration facility, Gilberton, Pennsylvania.

The prime contractor is Waste Management and Processors, PTY., LLC., (WMPI) of Gilberton, Pennsylvania. The WMPI team includes Nexant (a Bechtel Technology and Consulting company), a global engineering and construction company; Texaco Global Gas and Power, an integrated energy company with an international presence in coal gasification; and SASOL Technology Ltd., a leader in F-T process technology.

This EECP would take full advantage of the existing infrastructure at Gilberton, thereby minimizing cost while providing immediate local environmental benefits by reclaiming coal wastes, which include large ponds filled with anthracite waste derived from on-site coal cleaning operations.



Waste Management and Processors process flow diagram

Operation of the proposed EECP will reduce many of the technical risks that are inherent with first-of-a-kind plants. Of major concern are the waste coal gasification process and its integration with the F-T system.

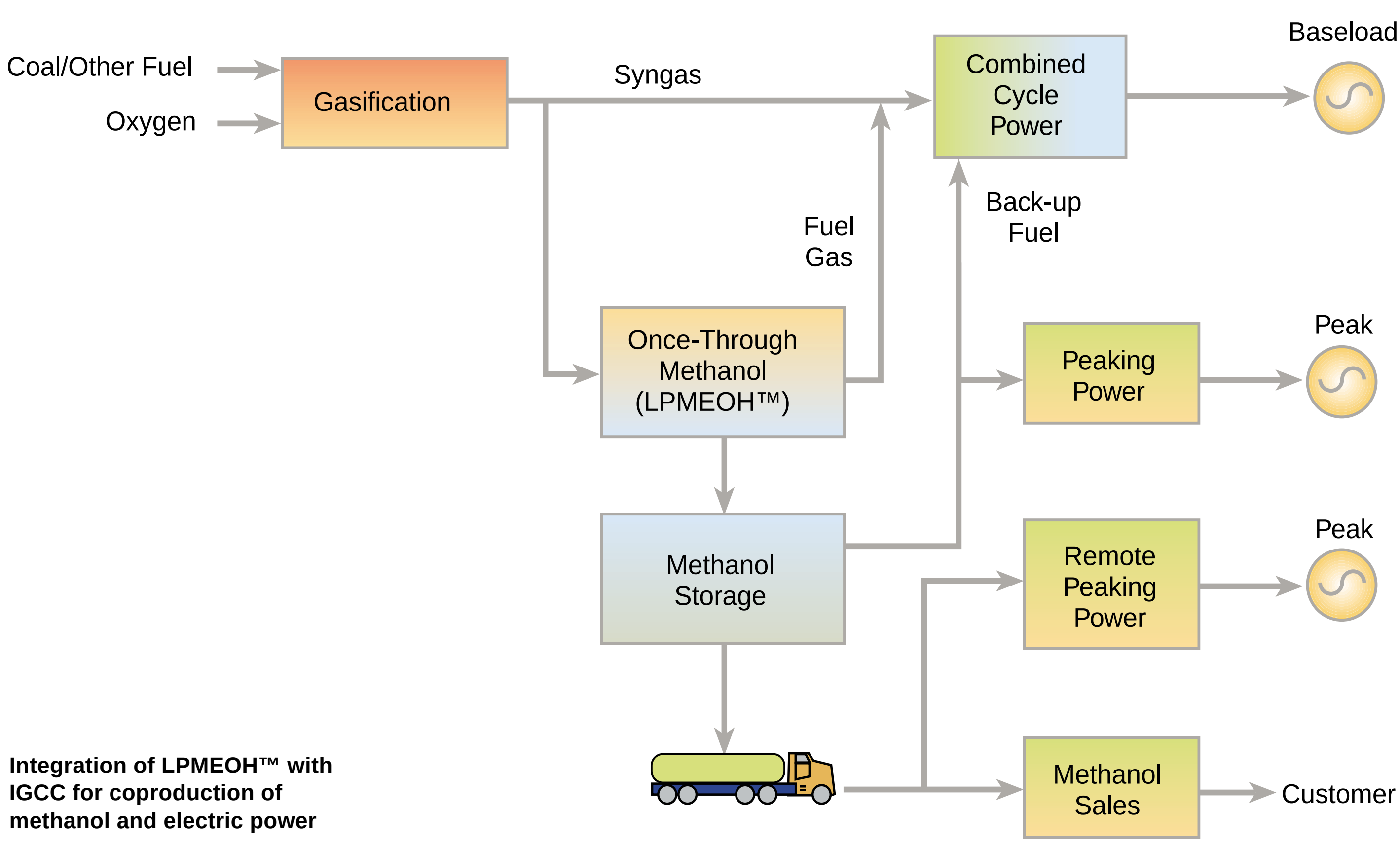
Integrated Methanol and Power Production from Clean Coal Technologies (IMPPCCT) Project

This project will evaluate coproduction of power and chemicals from a plant fueled with coal and other carbon-based feedstocks. The prime contractor is Gasification Engineering, a subsidiary of Global Energy Inc., which recently purchased the Dow/Destec gasification technology from Dynegy and renamed it E-GAS™. Team members are Air Products & Chemicals, Inc., Dow Chemical Company, Dow Corning Corporation, Methanex Corporation, and Siemens Westinghouse.

Global Energy will supply its IGCC technology expertise, and Air Products will provide experience from its LPMEOH™ process, which produces methanol from coal-derived syngas. Both of these technologies have been successfully demonstrated on a commercial scale in CCT projects.

Dow Chemical and Dow Corning will provide a customer's perspective for the methanol product and also offer some potential host sites for future commercial scale plants. Methanex will add its global expertise in producing and marketing chemical-grade methanol, and Siemens Westinghouse will lend its power generation experience in advanced turbine systems, specifically "G" model turbines.

If the concept proves to be economically feasible, the team will develop an engineering design package for a plant to be built at the Wabash River site near Terre Haute, Indiana. Existing contracts call for sale of syngas to the adjacent power generation facility during periods of peak demand. Methanol is the co-product of choice, and the LPMEOH™ process is particularly suit-



Integration of LPMEOH™ with IGCC for coproduction of methanol and electric power

able for ramping up in a relatively short period of time, an advantage when operating during non-peak periods.

Texaco Energy Systems Inc. Project

The Texaco EECP project combines Texaco's coal gasification expertise with Rentech's F-T technology to produce electric power, high-quality transportation fuels, and chemicals from coal and/or petroleum coke. Joining Texaco are Brown & Root Services, a division of Kellogg Brown & Root, Inc.; GE Power Systems; Praxair, Inc.; and Rentech, Inc.. This study is intended to determine the best configuration for commercial implementation of the integrated technology. If the concept proves economically feasible, an engineering design package will be developed for a plant to be built at one of several potential sites.

The proposed plant is designed to handle a wide variety of feedstocks and is capable of making multiple products depending on market conditions.

The project involves technical and economic studies of several process options, including syngas composition, F-T product upgrading, wastewater treatment, catalyst/wax separation, acid gas removal, tail gas utilization, and site selection.

Distinctive Features of IGCC

IGCC takes a fundamentally different approach from power producing processes that involve only combustion. IGCC generates a clean, medium-Btu syngas, with essentially complete removal of several potential air pollutants prior to combustion. As a result, atmospheric emissions of these pollutants are very low.

The higher efficiency of IGCC power plants results in lower coal consumption, thereby leading to lower emissions of CO_2, a major greenhouse gas. Less coal use also results in less ash requiring disposal.

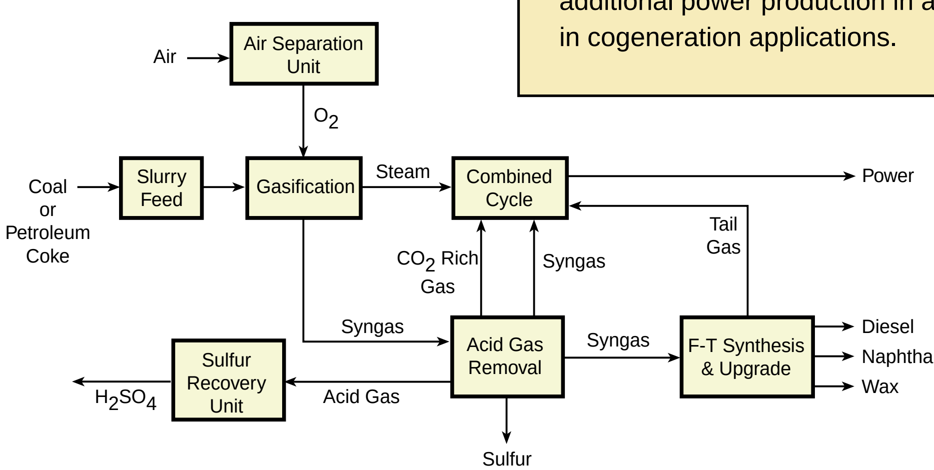
Gasification can be used with virtually any carbon-based feedstock. Water use is lower than conventional coal-based generation because gas turbine units require no cooling water, an especially important consideration in areas of limited water resources.

Combined-cycle units can be operated on other feedstocks, such as natural gas or fuel oil, before the gasifier is constructed, thereby providing early power. The size of gas turbine units can be chosen to meet specific power requirements. Ability to operate on multiple fuels also permits continued operation of the gas turbine unit if the gasifier island is shut down for maintenance or repairs, or if warranted by changes in fuel costs.

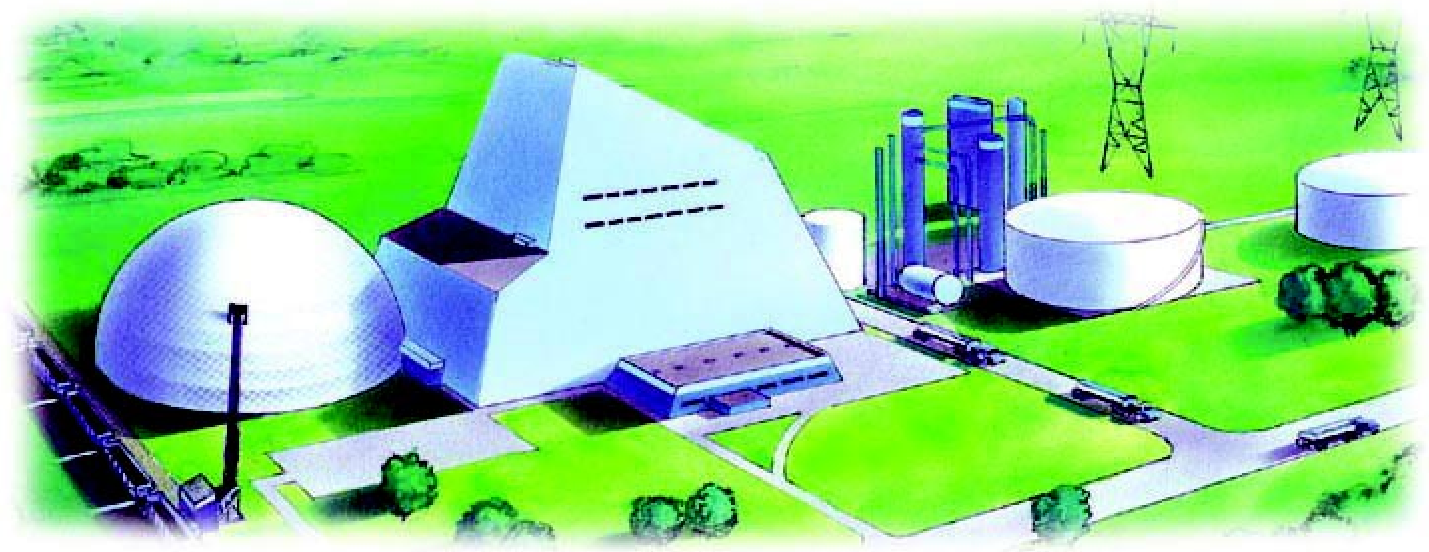
An additional benefit of IGCC is product flexibility, permitting production of alternatives such as chemicals or transportation fuels. Market forces, which are replacing regulatory structures, have resulted in expanded IGCC applications. As a result of both feedstock and product flexibility, traditional steam-powered electricity generation using single feedstocks is being supplanted by more versatile integrated technologies.

IGCC power plants use plentiful and relatively inexpensive coal as their fuel. In the United States there are several hundred years of coal reserves, and use of coal helps to reduce dependence on foreign oil.

In a typical IGCC plant, the syngas is cleaned for removal of particulates and trace contaminants. Sulfur is recovered as hydrogen sulfide and converted to elemental sulfur in a standard Claus plant. The clean syngas is utilized as fuel for electricity generation in a high-efficiency combustion turbine generator. Hot combustion turbine exhaust gas is used to produce high-pressure, high-temperature steam in a heat recovery steam generator for additional power production in a steam turbine or for use as thermal energy in cogeneration applications.



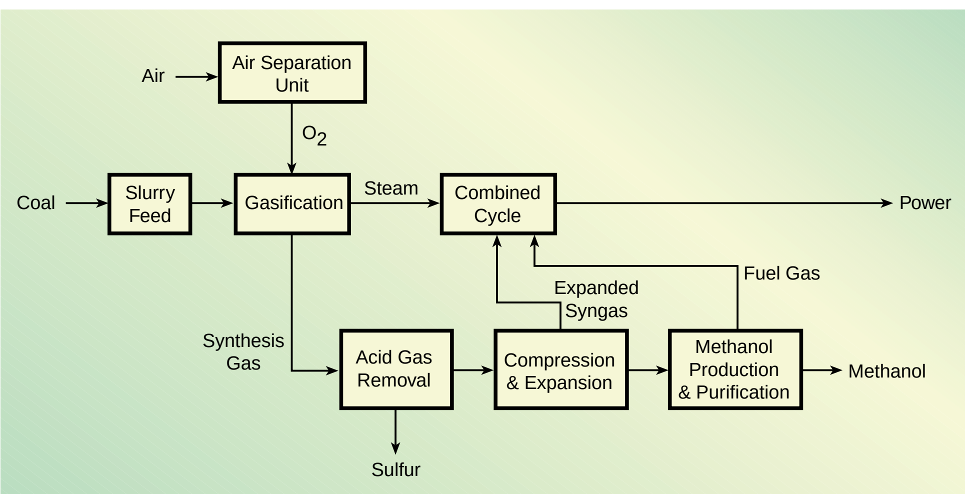
Texaco Energy Systems process flow diagram



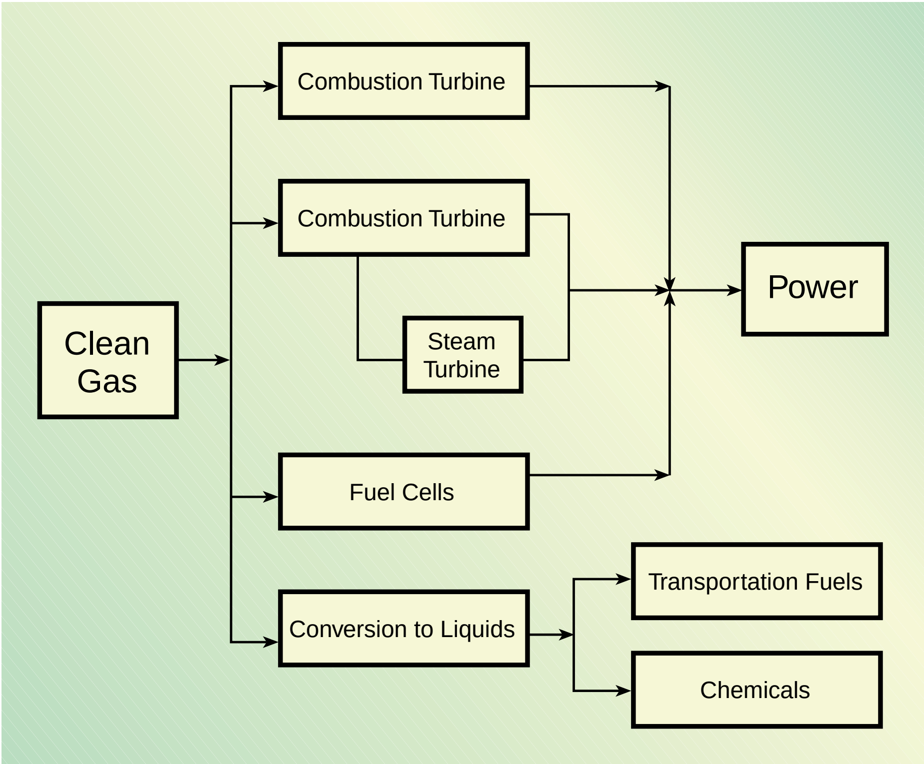
Vision 21

Ultimately, gasification will be the cornerstone technology for a new generation of energy plants for the 21st century, the Vision 21 energy systems. These will be highly efficient systems coproducing low-cost electric power, transportation fuels, and high-value chemicals, all tailored to the energy demands of the geographic area where they are located. Gasification-based technologies, with their feedstock and product flexibility coupled with high efficiency and ultra-low emissions, constitute the core of the Vision 21 concept.

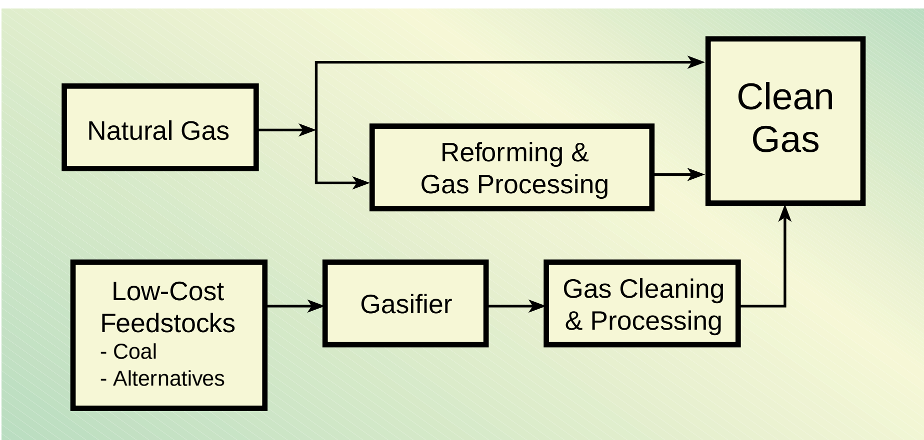
Vision 21 is DOE's strategy for advancing the research and development of technologies critical to creating the integrated energy systems of the future. R&D by DOE and its industry partners will focus on issues that are key to improving the efficiency, versatility, and cost-effectiveness of gasification-based processes and systems, and to furthering synergies between gasification and other advanced energy and environmental control technologies.



IMPPCCT process flow diagram



Clean gas is used as a feedstock for coproduction, including power generation and conversion to transportation fuels and chemicals.



Clean gas for use as coproduction feedstock can be obtained from relatively expensive natural gas or from lower cost materials such as coal or waste streams by gasification. In gasification, the lower cost feedstock can more than offset the higher capital cost.

Development Facilities

DOE owns and finances several dedicated development facilities. These facilities are used to demonstrate technology feasibility, system integration, component scale-up, product improvement, feedstock testing, advanced gasifier designs, and advanced gas separation concepts. Each facility provides opportunities to partner with industry in technology research, development, and demonstration.

Southern Company Services operates the Power Systems Development Facility at Wilsonville, Alabama (www.psdf.southernco.com), which is a multi-module test facility for evaluating power system components, including hot-gas particulate control devices, using fuel gas produced by a 38-ton/day transport gasifier. Engineering-scale testing and development of gasification processes, components, and equipment, as well as testing of devices to remove contaminants, are conducted with industrial partners.

At the Alternative Fuels Development Unit, operated by Air Products & Chemicals, Inc. at LaPorte, Texas (www.airproducts.com), researchers are demonstrating low-cost methods of making liquid fuels and chemicals from a range of syngas compositions derived from a wide variety of feedstocks. This unit is large enough to generate engineering performance data for the slurry-phase reactor system and to make products for use in application demonstrations.

Using a 150,000-cubic-foot/hour syngas generator at the Gas Processing Development Unit in Morgantown, West Virginia (www.netl.doe.gov), NETL researchers test new, attrition-resistant sorbents in fluidized-bed and transport-bed reactors. Working with contractors and industrial partners, these researchers can develop information and evaluate processes, sorbents, and catalysts in support of larger-scale testing in other units or in CCT projects.

Conclusions

The objective of coproduction is to maximize the recovery of energy and products from a wide range of fuels, including coal and low-cost opportunity feedstocks such as petroleum coke, biomass, and municipal wastes. Coproduction of power, heat, fuels and chemicals from syngas offers the potential of significantly improved economics compared with generating only power.

The concept of producing a varied slate of products along with electric power is a departure from conventional practice in which these functions are accomplished in separate facilities. Coproduction takes advantage of synergies between syngas utilization processes and power production to meet changing market demand.

Three EECP projects are underway to develop advanced technology modules that can be integrated into an ultra-high efficiency, near pollution-free energy facility as envisioned in DOE's Vision 21 Program. The intended result is to mitigate technical risks and achieve integrated coproduction in facilities that will be operational by 2007.

The implementation of these projects will constitute a major step in the development of the advanced energy systems needed to maintain our prosperity, protect the environment, and provide national energy security. The proposed plants will also result in a major reduction in greenhouse gas emissions compared with conventional coal-fired power generation.

Advantages of Gasification

Clean environment

Gasification-based plants can meet all projected environmental regulations, solving the compliance problems of both electric power generators and liquid fuel producers. Because they operate at a higher efficiency than conventional fossil-fueled power plants, these systems emit less CO_2 per unit of energy, and emissions of SO_2 and NOx, gases linked to acid rain, are a small fraction of allowable limits. Water requirements are less than half that of a pulverized coal plant with flue gas scrubbing. Gas turbines require no cooling water, an especially important consideration in areas of limited water resources.

Feedstock flexibility

Gasifiers have the flexibility to handle a variety of feedstocks. In addition to coal, feedstocks can include petroleum coke, refinery wastes, biomass, municipal solid waste, tires, plastics, hazardous wastes and chemicals, and sewage sludge. These alternative feedstocks are typically low in cost, sometimes even demanding a disposal fee. Not only do these low-cost feeds improve economics, but marketable products are created from waste streams, thus decreasing disposal costs and minimizing environmental concerns.

Product flexibility

The coproduction option helps reduce business risk by allowing a company to choose the plant configuration that best suits market demands, producing goods that have the highest value to that particular business. System efficiencies are enhanced to more than 50% when transportation fuels are produced and to 80% when coproduct steam is used directly in industrial applications.

Attractive plant economics

Gasification utilizes low-cost feedstocks while delivering high-value products. Through modularity and phased construction, capital expenditures can be distributed over time to meet financing requirements. Repowering can make use of existing plant infrastructure to reduce up-front expenditures. By-products are marketable. Continued operating experience can further reduce capital and operating costs, thereby increasing economic competitiveness.

Ease of integration with other advanced technologies

As advanced technologies for gasification, turbines, fuel cells, gas separation, gas cleaning, and syngas conversion become available, they can be readily integrated to improve overall efficiency.

In addition, both coproduction and coal gasification with gas cleaning can be readily added to existing natural gas combined-cycle plants.

The DOE Transportation Fuels & Chemicals Program

The need for liquid fuels is projected to be a critical element in this Nation's energy future in the 21st century. The objective of the Program is to develop, in partnership with industry and other government organizations, environmentally superior fuel technologies based on the conversion of coal-derived syngas. These technologies will help the U.S. meet increasingly stringent vehicle emission standards to reduce pollution from the transportation sector. For intermediate term deployment, the Program is focusing on the three Early Entrance Coproduction Plant projects that are co-sponsored with the Gasification Technologies Program and described in this document. To provide the foundation for fuel conversion technologies that will be deployed longer-term, the Program is supporting research in critical process system science, including the development of iron-based catalysts, reactor design and reaction chemistry.

Bibliography

W.R. Brown and F.S. Frenduto, "Fuel and Power Coproduction -- The Integrated Gasification/ Liquid Phase Methanol (LPMEOH™) Demonstration Project," *First Annual Clean Coal Technology Conference* (Cleveland OH), September 1992.

P. Amick and J. Cook, "The Wabash River Coal Gasification Repowering Project -- Program Update," *Second Annual Clean Coal Technology Conference* (Atlanta GA), September 1993.

D.E. Pless, "Tampa Electric Company: Integrated Gasification Combined-Cycle System," *Second Annual Clean Coal Technology Conference* (Atlanta GA), September 1993.

D.E. Pless, "Tampa Electric Company Integrated Gasification Combined Cycle Project -- Current Status," *Third Annual Clean Coal Technology Conference* (Chicago IL), September 1994.

W.R. Brown and R.B. Moore, "Flexible Electric Power Generation: The Integrated Gasification/Liquid Phase Methanol (LPMEOH™) Demonstration Project," *Third Annual Clean Coal Technology Conference* (Chicago IL), September 1994.

D.E. Pless, "Status Update -- Polk Power Station," *Fourth Annual Clean Coal Technology Conference* (Denver CO), September 1995.

E.S. Schaub, V.E. Stein, E.C. Heydorn, and E.R. Osterstock, "An Update on Liquid Phase Methanol (LPMEOH™) Technology and the Kingsport Demonstration Project," *Fourth Annual Clean Coal Technology Conference* (Denver CO), September 1995.

E.J. Troxclair and J. Stultz, "Wabash River Coal Gasification Repowering Project -- First Year Operation Experience," *Fifth Annual Clean Coal Technology Conference* (Tampa FL), January 1997.

D.P. Drown et al., "Fuel and Power Coproduction – The Integrated Gasification/ Liquid Phase Methanol (LPMEOH™) Project at Kingsport," *Fifth Annual Clean Coal Technology Conference* (Tampa FL), January 1997.

C.G. Keeler and J. Stultz, "Operating Experience at the Wabash River Coal Gasification Repowering Project," *Sixth Clean Coal Technology Conference* (Reno NV), April 1998.

J.E. McDaniel and C.A. Shelnut, "Tampa Electric Company Polk Power Station IGCC Project -- Project Status," *Sixth Clean Coal Technology Conference* (Reno NV), May 1998.

E.C. Heydorn, V.E. Stein, P.J.A. Tijm, B.T. Street, and R.M. Kornosky, "Commercial Scale Demonstration of the Liquid Phase Methanol (LPMEOH™) Process: Initial Operating Experience," *Sixth Clean Coal Technology Conference* (Reno NV), May 1998.

"Economic Analysis: LPMEOH™ Process as an Add-on to Integrated Gasification Combined Cycle (IGCC) for Coproduction," prepared by Air Products and Chemicals, Inc., for U.S. Department of Energy, 1998.

Topical Report No. 11, "Commercial-Scale Demonstration of the Liquid Phase Methanol (LPMEOH™) Process," U.S. DOE, April 1999

S.L. Douglas, "Wabash River in its Fourth Year of Commercial Operation," *Seventh Clean Coal Technology Conference* (Knoxville TN), June 1999.

J.E. McDaniel and C.A. Shelnut, "Tampa Electric Company Polk Power Station IGCC Project -- Project Status," *Seventh Clean Coal Technology Conference* (Knoxville TN), June 1999.

B.W. Diamond, E.C. Heydorn, P.J.A. Tijm, B.T. Street, and R.M. Kornosky, "Commercial- Scale Demonstration of the Liquid Phase Methanol (LPMEOH™) Process: Operating Experience Update," *Seventh Clean Coal Technology Conference* (Knoxville TN), June 1999.

U.S. Department of Energy, Energy Information Administration, "Annual Energy Outlook 2000 with Projections to 2020," December 1999.

U.S. Department of Energy and the Gasification Council, "Gasification – Worldwide Use and Acceptance," January 2000.

"Merchant Power Projects Push for Competitive Edge," *Power*, pp. 32-39, January/ February 2000.

Topical Report No. 19, "The Tampa Electric Integrated Gasification Combined-Cycle Project, An Update" U.S. DOE, July 2000.

Topical Report No. 20, "The Wabash River Coal Gasification Repowering Project, An Update," U.S. DOE, August 2000.

P. Amick, R. Geosits, S. Kramer, J. Rockey, and S. Tam, "IGCC Plant Performance & Cost Optimization Study," *Seventeenth Annual Pittsburgh Coal Conference* (Pittsburgh PA), September 2000.

D. Gray and G. Tomlinson, "Potential of Gasification in the U.S. Refining Industry," *Seventeenth Annual Pittsburgh Coal Conference* (Pittsburgh PA), September 2000.

D.E. Benedict and D. Strickland, "The Wabash River Integrated Methanol and Power Production from Clean Coal Technologies (IMPPCCT) Project," *Seventeenth Annual Pittsburgh Coal Conference* (Pittsburgh PA), September 2000.

R.A. Bailey, "The Kentucky Pioneer Energy Project," *Seventeenth Annual Pittsburgh Coal Conference* (Pittsburgh PA), September 2000.

L. Shah and C. Schrader, "DOE Early Entrance Co-production Plant Update," *Seventeenth Annual Pittsburgh Coal Conference* (Pittsburgh PA), September 2000.

C. Schrader and L. Shah, "Texaco Gasification and Fischer-Tropsch (TGFT) Process," *Seventeenth Annual Pittsburgh Coal Conference* (Pittsburgh PA), September 2000.

R.M. Hinkle, A. O'Neill, M. Bradaic, and S.S. Tam, "A Roadmap for Evaluating Gasification Investments in International Markets," *Seventeenth Annual Pittsburgh Coal Conference* (Pittsburgh PA), September 2000.

U.S. Department of Energy, Clean Coal Technology Demonstration Program -- Program Update, April 2001.

The DOE Gasification Technologies Program

As public and private R&D funding becomes increasingly limited, DOE has implemented an aggressive outreach program to partner with those who have a stake in the outcome of gasification R&D, including power generators, industrial firms, financial institutions, environmental groups, legislators, and taxpayers. DOE will educate stakeholders on the technical, economic, and environmental benefits of gasification systems, coordinating activities with other Federal, State, and local agencies and organizations. Formation of multinational partnerships, consortia, and user groups will ensure coordinated research and commercialization activities for gasification-based technologies.

To meet energy market demands and facilitate global commercial acceptance of gasification-based technologies, the DOE Gasification Technologies Program strategy emphasizes increased efficiencies, cost reduction, feedstock and product flexibility, near-zero emissions of pollutants, and reduction of CO_2.

DOE sponsors R&D contracts with industry, academia, nonprofit institutions, and government laboratories to achieve gasification technology development goals.

- Research on advanced gasifier designs has the potential to reduce capital and O&M costs, improve thermal efficiency, and expand the use of alternative feedstocks.
- Refractory materials research and instrument development are being pursued to improve gasifier performance, operational control, and reliability.
- Fluid dynamic data and advanced computational fluid dynamic models support improvements to the gasifier.
- Use of biomass and municipal waste as gasifier feedstocks for power and coproduction applications is undergoing evaluation.
- Novel technologies for gas cleaning and conditioning are undergoing development to reduce capital and operating costs. New technologies are needed to supply ultra-clean gas for fuel cell and catalytic conversion of synthesis gas to improve efficiency, enable effective CO_2 separation, and minimize consumables and waste products.
- Advanced membranes and concepts to provide lower cost separation of oxygen from air are being developed. These have the potential for very significant improvement in economics.
- Research in advanced gas separation technologies for concentrating syngas constituents targets capital and operating cost reductions, improved plant efficiency, and concentration and capture of CO_2. Investigations include hydrogen and CO_2 separation technologies capable of operating at high temperatures and pressures and in the presence of contaminants.
- Technologies to generate value-added products to minimize waste disposal and improve process economics are undergoing evaluation. Improving the quality of the ash and sulfur by-products not only enhances plant revenues, but also uses resources more effectively.

The Clean Coal Technology Program

The Clean Coal Technology (CCT) Demonstration Program, sponsored by the U.S. Department of Energy (DOE) and administered by the National Energy Technology Laboratory (NETL), has been conducted since 1985 to develop innovative, environmentally friendly coal utilization processes for the world energy marketplace.

The CCT Program, which is co-funded by industry and government, involves a series of commercial-scale demonstration projects that provide data for design, construction, operation, and technical/economic evaluation of full-scale applications. The goal of the CCT Program is to enhance the utilization of coal as a major energy source.

The CCT Program has also opened a channel to policy-making bodies by providing data from cutting-edge technologies to aid in formulating regulatory decisions. DOE and the participants in several CCT projects have provided the Environmental Protection Agency (EPA) with data to help establish targets for nitrogen oxide (NOx) emissions from coal-fired boilers subject to compliance under the 1990 Clean Air Act Amendments (CAAA).

Coal gasification systems demonstrated on a commercial scale in the CCT Program include:

- The Tampa Electric Integrated Gasification Combined-Cycle Project, which uses the Texaco gasification technology
- The Wabash River Coal Gasification Repowering Project, which uses Global Energy's E-GAS™ technology

An additional CCT project recently authorized, the Kentucky Pioneer Energy Project, involves gasification of a variety of feedstocks including low-grade coal and municipal solid waste, using BGL gasification technology.

To Receive Additional Information

To be placed on the Department of Energy's distribution list for future information on the Clean Coal Technology Program, the demonstration projects it is financing, or other Fossil Energy Programs, please contact:

Robert C. Porter
Director, Office of Communication
U.S. Department of Energy, FE-5
1000 Independence Ave SW
Washington DC 20585
(202) 586-6503
(202) 586-5146 fax
robert.porter@hq.doe.gov

Otis Mills, Jr.
Public Information Office
U.S. Department of Energy
National Energy Technology Laboratory
P.O. Box 10940
Pittsburgh PA 15236-0940
(412) 386-5890
(412) 386-6195 fax
mills@netl.doe.gov

This report is available on the Internet at U.S. DOE, Office of Fossil Energy's website: www.fe.doe.gov, and on the Clean Coal Technology Compendium website: www.lanl.doe.gov/projects/cctc

Contacts for CCT Projects and U.S. DOE CCT Program

Participant Contacts

John W. Rich, Jr.
Waste Managment and Processors, PTY., LLC.
Main Street
Gilberton PA 17934
(570) 874-1602
(570) 874-2625 fax
jwrich@ultracleanfuels.com

Doug Strickland
Gasification Engineering Corp.
444 West Sandford Avenue
West Terre Haute IN 47885
(812) 535-6082
(812) 535-6101 fax
dtstrickland@globalenergyinc.com

John H. Anderson
Texaco Energy Systems, Inc.
1111 Bagby
Houston TX 77002
(713) 752-4754
(713) 752-4681 fax
anderjh@texaco.com

U.S. Department of Energy Contacts

Stewart Clayton
U.S. Department of Energy, FE-22
Germantown MD 20874-1290
(301) 903-9429
(301) 903-2713 fax
stewart.clayton@hq.doe.gov

Victor Der
Director, Office of Power Systems
U.S. Department of Energy, FE-24
Germantown MD 20874-1290
(301) 903-2700
(301) 903-2713 fax
victor.der@hq.doe.gov

C. Lowell Miller
Director, Coal Fuels & Industrial Systems
U.S. Department of Energy, FE-24
Germantown MD 20874-1290
(301) 903-9451
(301) 903-2238 fax
lowell.miller@hq.doe.gov

Edward Schmetz
U.S. Department of Energy, FE-24
Germantown MD 20874-1290
(301) 903-3931
(301) 903-2238 fax
edward.schmetz@hq.doe.gov

Gary J. Stiegel
Product Manager, Gasification Technologies
National Energy Technology Laboratory
P.O. Box 10940
Pittsburgh PA 15236-0940
(412) 386-4499
(412) 386-4822 fax
gary.stiegel@netl.doe.gov

John C. Winslow
Product Manager, Transportation Fuels and Chemicals
National Energy Technology Laboratory
P.O. Box 10940
Pittsburgh PA 15236-0940
(412) 386-6072
(412) 386-4822 fax
john.winslow@netl.doe.gov

List of Acronyms and Abbreviations

b/d .... barrels/day
Btu .... British thermal unit
CAAA .... Clean Air Act Amendments of 1990
CCT .... Clean Coal Technology
CH_4 .... methane
CO .... carbon monoxide
CO_2 .... carbon dioxide
DOE .... U.S. Department of Energy
EECP .... early entrance coproduction plants
EPA .... U.S. Environmental Protection Agency
EPRI .... formerly the Electric Power Research Institute
F-T .... Fischer-Tropsch
H_2 .... hydrogen
H_2S .... hydrogen sulfide
IGCC .... integrated gasification combined-cycle
kWh .... kilowatt hour
LPMEOH™ .... Liquid Phase Methanol
MCFC .... molten carbonate fuel cell
MWe .... megawatts of electric power
MWth .... megawatts of thermal power (1 MWth = 3.413 x 10^6 Btu/hr)
NETL .... National Energy Technology Laboratory
NH_3 .... ammonia
NOx .... nitrogen oxides
O_2 .... oxygen
psia .... pressure, pounds per square inch (absolute)
RDF .... refuse derived fuels
R&D .... research & development
ROE .... return on equity
SO_2 .... sulfur dioxide
syngas .... synthesis gas
WMPI .... Waste Management and Processors, Inc.