PERP Program – New Report Alert

May 2005

Nexant's *ChemSystems* Process Evaluation/Research Planning program has published a new report, ***Coal Gasification Technologies (03/04S11)***.

Background

Gasification is a high-temperature process usually conducted at elevated pressure that converts any carbon-containing material into a mixture composed primarily of carbon monoxide and hydrogen. Since this gas is often used for the synthesis of chemicals or synthetic hydrocarbon fuels, the gas is referred to as synthesis gas or syngas. The syngas can also be used as a fuel to generate electricity or steam and as a source of hydrogen. Gasification adds value to low- or negative-value feedstocks by converting them to marketable products.

Typical feedstocks to gasification are coal; petroleum-based materials such as crude oil, coke, and high-sulfur residues; gases; and various waste materials. Dry or slurried feedstock is reacted in the gasifier with steam and oxygen in a reducing (oxygen-starved) atmosphere at a high temperature and (usually) high pressure. The resulting syngas typically contains about 85 percent of combined carbon monoxide and hydrogen, with the balance being largely carbon dioxide and methane.

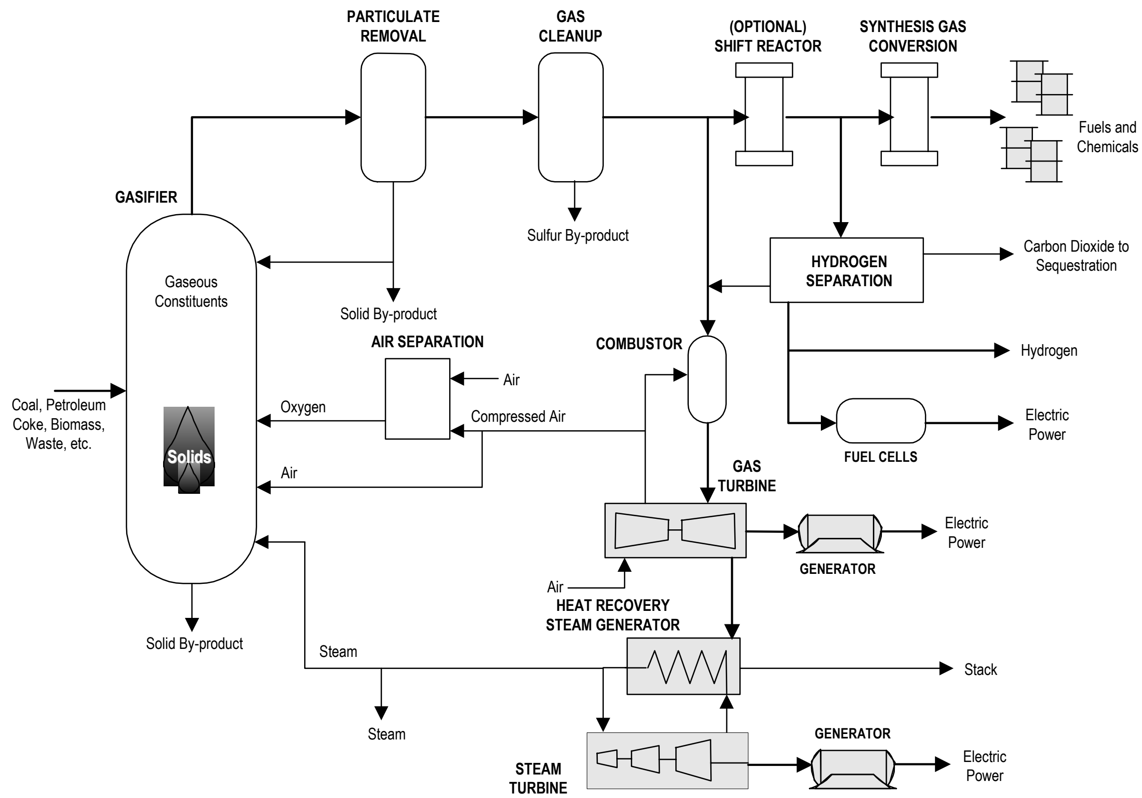
The high temperature in the gasifier converts the inorganic materials in the feedstock, such as ash and metals, into a vitrified material resembling coarse sand in texture and generally referred to as slag. This inert slag has a variety of uses in the construction and building industries.

The raw syngas is treated using proven commercial technologies to remove trace elements or other impurities for recovery or recycle to the gasifier. Sulfur can be recovered as marketable elemental sulfur or sulfuric acid.

If the syngas is to be used to produce electricity, it is typically used as fuel in an integrated gasification combined cycle (IGCC) power generation configuration. The combined cycle system utilizes a high-efficiency gas turbine to burn the clean syngas, with exhaust heat recovered to generate steam for use in a high-efficiency steam turbine. Both the gas turbine and the steam turbine drive electric power generators. A wide range of products, such as fuels, chemicals, fertilizers, and industrial gases, can be produced in lieu of power or in conjunction with power.

Figure 1 depicts a simplified flow chart illustrating alternative utilization options for coal-derived syngas. Various gasification and environmental cleanup technologies convert coal (or other carbon-based feedstocks), oxidant, and water to syngas for further conversion into marketable products: electricity, fuels, chemicals, steam, hydrogen, and others.

Figure 1
Gasification-Based Energy Conversion System Components



Source: "Major Environmental Aspects of Gasification-Based Power Generation Technologies", SAIC Report for DOE, December 2002

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Technology

Gasification consists of a series of controlled chemical reactions taking place at up to 1,000 psig or more and nominally 2,600^{o}F, resulting in corrosive slag and hydrogen sulfide gas as co-products. As the feedstock is exposed to rising temperature in the gasifier, devolatilization and breaking of weaker chemical bonds occur, yielding tars, oils, phenols, and hydrocarbon gases. These products generally react further to form carbon monoxide, hydrogen, and lesser quantities of carbon dioxide. The fixed carbon that remains after devolatilization is gasified through reactions with oxygen, water, carbon dioxide, and hydrogen, and these gases react further to produce the final gas mixture. The water-gas shift reaction alters the hydrogen to carbon monoxide ratio of the final gas mixture. Since no oxygen is consumed, exothermic (heat-releasing) methanation reactions increase the efficiency of gasification and the heating value of the syngas produced.

Although there are various types of coal gasification reactors, with different design and operating characteristics, all fall into one of three generic categories:

- Moving-bed reactors (also referred to as fixed-bed reactors)
- Fluidized-bed reactors
- Entrained-flow reactors

Various properties of coal impact on different parts of the gasification process. The primary property affecting the ease of conversion in gasification is the coal rank, which in turn reflects its volatile matter content, oxygen content, level of maturity, extent of aromatic ring condensation, and porosity. Reactivity varies dramatically with rank, with some low-rank coals being several orders of magnitude more reactive than high-rank coals.

When bituminous coals are heated to 300-350^{o}C, the particles tend to swell and agglomerate, producing a consolidated cake, which can disrupt gas flow patterns and lower thermal efficiency in fixed- or fluid-bed gasifiers.

For gasification technologies utilizing a slagging gasifier, slag flow behavior is an important parameter. Slag viscosity varies over several orders of magnitude for the different coals at representative gasifier temperatures.

Fouling of heat transfer surfaces can result from constituents such as chlorine, sodium, potassium, and calcium. Sulfur and chlorine contents are the coal properties most affecting corrosion.

Those gasification technologies that are predominantly used in commercial applications and have been extensively evaluated and tested are listed in Table 1.

Table 1 Gasifier Technology Suppliers

Technology Supplier	**Gasifier Type**	**Solid Fuel Feed Type**	**Oxidant**
Chevron Texaco, USA	Entrained Flow	Water Slurry	O_2
Global Energy E-GAS, USA	Entrained Flow	Water Slurry	O_2
Shell, USA/The Netherlands	Entrained Flow	N_2 Carrier/Dry	O_2
Lurgi, Germany	Moving Bed	Dry	Air
British Gas/Lurgi, Germany/UK	Moving Bed	Dry	O_2
Prenflo/Uhde, Germany	Entrained Flow	Dry	O_2
Noell/GSP, Germany	Entrained Bed	Dry	O_2
HT Winkler (HTW), RWE Rheinbraun/Uhde, Germany	Fluidized Bed	Dry	Air or O_2
KRW, USA	Fluidized Bed	Dry	Air or O_2

The ChevronTexaco (GE), E-GAS (Conoco Phillips) and Shell gasifiers are illustrated and discussed in detail, with brief descriptions only for the other listed suppliers.

Integrated Gasification Combined Cycle (IGCC) power systems use a gasifier to convert a carbon-based feedstock into syngas that is cleaned of particulates, sulfur, and other contaminants and is then combusted in a high-efficiency combustion turbine which drives an electrical generator. Heat from the combustion turbine exhaust gas is recovered to generate steam for subsequent use in a steam turbine/generator.

The major system components for a coal-fed IGCC plant, along with required auxiliary components, are discussed in the report. The current commercial IGCC status and potential advances to IGCC technology are likewise discussed.

Figure 2 shows some of the many co-product options for utilization of syngas from gasification, besides the generation of electric power. The myriad of possibilities includes:

- Syngas for generation of power and steam
- Syngas for Fischer-Tropsch hydrocarbon liquids as refinery/petrochemical feedstocks, transportation fuels, alpha olefins, waxes, etc.
- Carbon monoxide separated from syngas for use in the production of chemicals
- Hydrogen separated from syngas for use in hydrogenation processes, fuel cell energy source, ammonia production.
- Syngas for methanol production leading to fuel and chemical end uses.

The LPMEOH™ process is an effective technology for converting a portion of the hydrogen and carbon monoxide in an IGCC electric power plant's coal-derived syngas to methanol. The process is quite flexible in being able to handle wide variation in syngas composition. The process can be designed to operate in a continuous, baseload manner, converting syngas from oversized gasifiers or from a spare gasifier. Alternatively, the process can be designed to operate only during periods of off-peak electrical demand to allow the gasifiers to continue to operate at full rate. In either baseload or cycling operation, once-through partial conversion of between 20 and 40 percent of the hydrogen and carbon monoxide in the IGCC power plant's syngas is optimal on an economic basis.

One of the key advantages of the LPMEOH process is that it can process carbon monoxide-rich gas without ratio adjustment on a once-through basis. The LPMEOH process differs from conventional gas-phase methanol technology (fixed beds of catalyst pellets) in its use of an inert hydrocarbon oil as a reaction medium and heat sink and a powdered catalyst. The slurry reactor can thus achieve high syngas conversion per pass, due to its capability to remove heat and maintain a uniform temperature throughout the reactor. A second differentiating feature of the LPMEOH reactor is its ability to tolerate sharp transient changes in operating conditions, due to the thermal moderation provided by the liquid inventory in the reactor. A third differentiating feature of the LPMEOH process is the high quality of the methanol product produced directly from syngas rich in carbon oxides.

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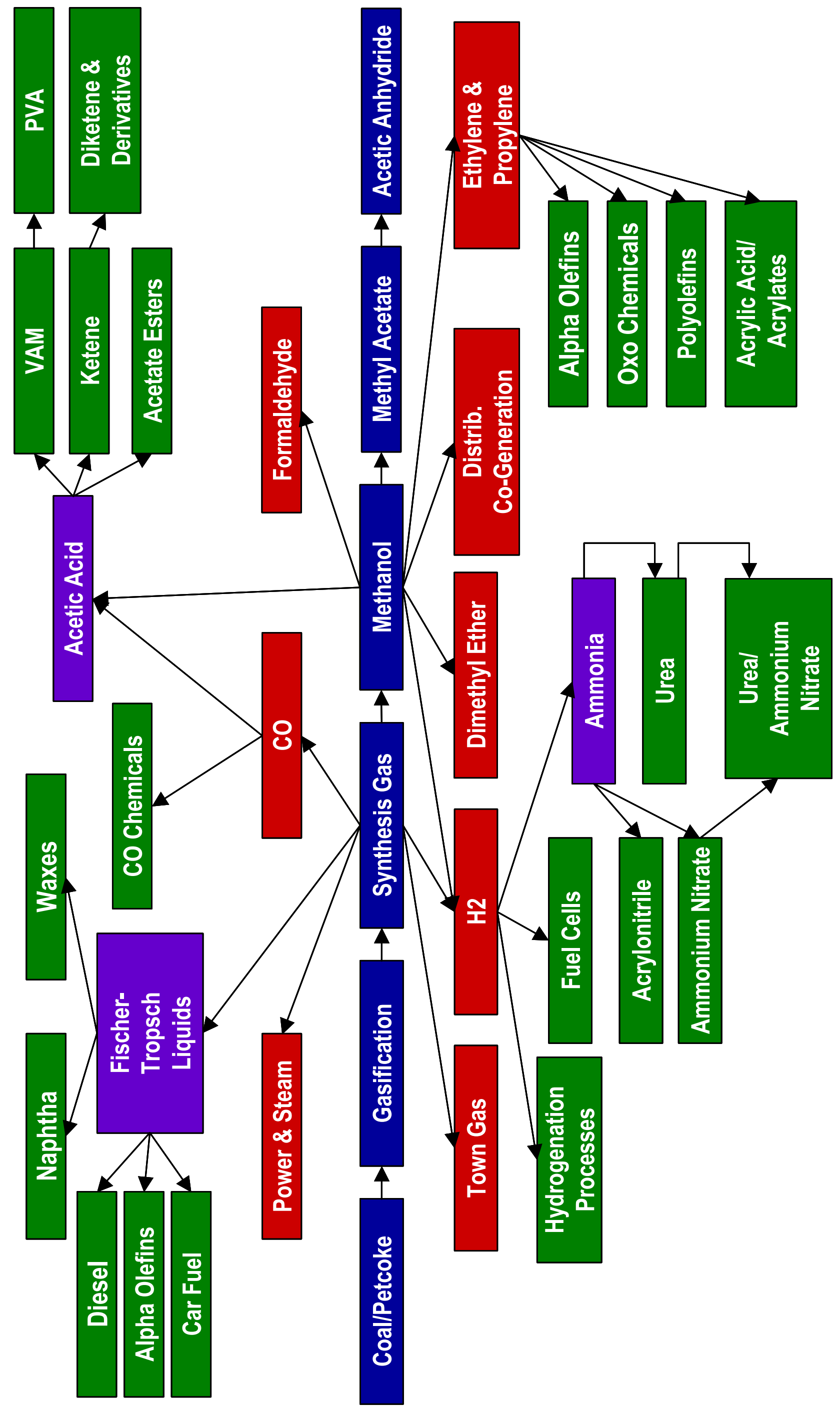
Figure 2 Co-Production Potential of Gasification



Source: "Eastman Gasification Overview", Eastman Gasification Services Company, July 19, 2004 (with modifications and additions)

Economics

A report figure presents a stacked bar chart showing the comparative methanol costs from co-production from coal (gasification followed by liquid-phase synthesis) and from steam methane reforming (followed by gas-phase synthesis). Economics for both processes are illustrated at 815 metric tons per day (MT/D). Economics for the SMR-based process are also provided for a U.S. Midwest location and a Middle East location, both at 5,000 MT/D capacity.

Even allowing for shipping from the Middle East to the U.S. Gulf Coast, methanol based on low cost natural gas in the Middle East can be made available at less than half the cost of U.S.-based methanol from natural gas.

At 815 MT/D capacity, the coal-based process compares favorably with methanol imported from the Middle East. This result reflects the economy of scale in the gasification operation and the choice of a simple, once-through methanol synthesis tailored to use the coal-derived syngas with its high carbon monoxide-to-hydrogen ratio without further adjustment. A report figure depicts methanol cost of production by the coal-based and natural gas-based processes as a function of changes in feedstock prices. Methanol cost is much more sensitive to changes in natural gas price than to changes in coal price.

Commercial Status

Worldwide, there has been a growth in gasification capacity of about 2.8 percent per year over the last three years. Over the 2001-2004 period, coal feed has become more popular, compared to petroleum residuals, and chemicals and Fischer-Tropsch liquids have become more preferred as products, compared to electric power.

Methanol supply and demand history and projections for eight different regions and the world from 2001 to 2015 are presented.

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