Multi-client Study Prospectus

Polygeneration from Coal

Integrated Power, Chemicals and Liquid Fuels

Nexant

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Contents

1.1 OVERVIEW

Nexant has published a multi-client study to analyze the technologies and economics of utilizing coal in an integrated facility that will produce both electric power, and major petrochemicals or liquid fuels. This approach used high-efficiency coal gasification and integrated downstream processes. With high prices for oil and natural gas, this type of large-scale integrated facility may offer superior investment returns, as well as a hedge against raw material supply constraints.

1.1.1 Overall Value Premise

Advanced coal gasification technologies have raised the efficiency of coal conversion far above that of conventional coal combustion, and offer the promise of economically and environmentally acceptable uses for coal in the petrochemical and fuel industries. One of the more exciting development concepts is an integrated approach to *Polygeneration from Coal*, the conversion of coal to both power and synthesis gas (syngas), which can then be converted to chemicals and/or liquid fuels. An integrated approach offers a strategy to truly maximize adding value to coal. In *Polygeneration from Coal*, the gasification of coal produces synthesis gas (syngas) that can be used partly for the generation of electricity in conventional integrated gas/steam turbine combined cycle (IGCC) systems, and partly for the concurrent production of commodity chemicals (methanol, ammonia and their derivatives such as olefins and acetic acid from methanol and fertilizers from ammonia) or liquid fuels (methanol, diesel, dimethyl ether, and gasoline).

This use of coal as both a fuel and a feedstock in a technologically advanced facility represents a modern approach to maximizing coal's potential, far beyond the way in which co-generation maximized the values of fuel in chemical facilities in the 1980s and 1990s. Thus, the concept of *Polygeneration from Coal* offers a highly flexible, highly competitive cross-sector design and implementation with a multi-faceted value premise:

- The gasifier can operate on coal or other hydrocarbon source feedstock, with superior environmental performance.
- Because the synthesis gas produced in the gasification can be shifted to/from power generation and chemicals/liquid fuels, it offers inherent peak period maximization capability for electric power and facility revenue optimization.
- Sharing the coal handling and gasification facilities between power generation and chemicals/liquid fuels production provides both with improved scale and efficiency of the capital investment and operations support.
- This integrated concept has economic potential since the syngas produced in the gasifier can have several applications:
    - Town gas for heating, cooking, etc., depending on the location of the complex

- Power generation via IGCC
  - Methanol production from hydrogen and carbon monoxide components of the syngas (supplemented by water-shift reaction)
  - Ammonia production from the hydrogen component of the syngas
  - Liquid fuel production: diesel, dimethyl ether, or gasoline
  - Hydrogen for fuel cells
  - Derivative chemicals from methanol or ammonia
  - A concentrated carbon dioxide waste stream that can be used for a number of chemical applications
- Power for sale into the chemical complex, nearby power users or a municipal power grid system

Polygeneration from Coal has considerable advantages versus conventional coal combustion, and can now be foreseen as a viable and practical replacement in countries and regions that have relied on coal combustion for power. In these and other locations, *Polygeneration from Coal* benefits from a number of fundamental attributes.

Environmentally superior: lower emissions of sulfur oxides, nitrogen oxides, and particulate matter compared to conventional pulverized coal combustion and thus allows coal utilization.

- The gasifier design produces CO_2 that is more concentrated and more easily collected and separated environmentally than conventional coal-fired furnaces
- Higher coal conversion efficiency

Polygeneration from Coal potentially provides:

- Lower costs of production than conventional feedstock/process alternatives in commercial operation as crude oil and natural gas prices may remain high or continue to rise
- Reduce exposure to uncertain energy and feedstock imports, especially in coal producing regions
- Lower costs than conventional production of power and chemicals separately

This prospectus describes the background of why this is an important and timely issue, the scope of our analysis, and the approach we used in the study. We also detail our experience and qualifications to perform the study, and how you may subscribe.

1.2 BACKGROUND

Coal can be made into useful products by a number of chemical processing approaches, but practically speaking these can be viewed as either liquefaction or gasification processes.

1.2.1 Coal Liquefaction

Coal liquefaction is typically the term used to describe the use of coal to produce liquid fuel or hydrocarbon products. The motivation to develop existing and new technologies to convert coal to liquid fuel has been largely driven by the growth in oil prices and concerns about the oil supply in recent years. Converting coal to liquid fuel could provide a means of dampening the escalation of oil prices. Not only is coal to liquid (CTL) technology an appealing option for the Unites States, but also for areas of Asia (China in particular) where there is an abundance of coal and shortage of oil.

There are two main methods of coal liquefaction that have both already been put to use in the past to varying degrees: indirect coal liquefaction and direct coal liquefaction. There are concerns involving both types of liquefaction methods. There have also been questions about the environmental aspects of coal liquefaction.

1.2.2 Direct Coal Liquefaction (DCL)

1.2.2.1 General

DCL technology was initially developed by Friedrich Bergius as a commercial process in Germany. Before World War II, seven DCL plants were in operation and five more plants were added during the war, producing more than 3 million tons of oil per year. Subsequently, the production of liquid fuel via DCL was essentially abandoned when low-cost Middle East oil became available in the early 1950s.

Because higher rank coals are less reactive, and also higher priced, processes had been developed ranging from low rank coals (lignites) to high volatility bituminous coals. Since the 1950s, DCL has not been used on a commercial scale due largely to its high capital and operating costs. In fact, until recently research in the field has been limited due to the high cost of testing out new technologies in pilot plants. There have been studies performed in the past concerning the viability of DCL. However, in recent years there have been initiatives focused on future ventures in the direct coal liquefaction field.

1.2.2.2 U.S. DOE Direct Coal Liquefaction Program

The DOE direct coal liquefaction program was in effect in the 1970s and early 1980s. It stemmed from the energy crisis that was occurring at that time and consisted mainly of large scale demonstration projects with broad industry participation. Most of the effort placed into the program was during the years of 1978 to 1983, when crude oil prices were at their highest (until the last few years).

The demonstration projects showed that DCL was a potentially feasible process with plant sizes up to 200 tons per day. The program also identified issues with such coal processing, primarily yields, product quality, and capital costs.

It was estimated that in order for the DCL technology to be economically viable, the crude oil prices would have to be above $45 per barrel. Because DCL is not yet a commercialized process, there have been no realized economic benefits from the program to date. Direct liquefaction technology is still a possible option for the future. However, in order to put this technology in use, there will likely need to be additional improvements in factors such as environmental impact and economics of the technology.

1.2.3 Indirect Coal Liquefaction (ICL)

Unlike DCL, indirect coal liquefaction (ICL) technology involves the use of an intermediate step in the production of liquid fuels. The first step of the process is the gasification of coal with oxygen to produce synthesis gas ("syngas"). There are many different types of proven gasifiers available for this part of the process.

The syngas is then cooled, purified, and rid of contaminants. The ratio of hydrogen to carbon dioxide for the syngas is adjusted with a water-shift reactor. Once the syngas is purified, the CO and H_2 are combined catalytically and converted to form a wide range of products including hydrocarbons such as synthetic gasoline or synthetic diesel, or oxygenated fuels, as well as alcohols, aldehydes, ketones, and acids.

The step required to convert the gasified coal to liquid hydrocarbons is known as the Fischer-Tropsch (F-T) process. F-T processing is a well-established commercial process and is currently a focus of many global gas-to-liquid (GTL) efforts to use "stranded" natural gas to produce synthetic liquid transportation fuels. Since F-T synthesis is based on the reaction of hydrogen and carbon monoxide (syngas), any appropriate source material that can produce syngas can be used, such as coal via gasification.

Similar to DCL, ICL processing has been restrained commercially by its high capital costs as well as high operational and maintenance costs. However, ICL is a technology that is currently in use in a number of global locations. For instance, Sasol in South Africa uses F-T technology to produce a variety of synthetic petroleum products with coal and natural gas as the feedstock.

Since coal gasification is a well-proven technology that has had many applications, its use is being extended to large-scale IGCC (integrated gasification combined cycle) power generation. In countries with large, accessible coal reserves the promise of an integrated polygeneration system is attractive as compared to conventional coal-based power generation. For example, for methanol synthesis, the cascade use of the chemical energy of syngas increases system efficiency and decreases energy loss from combustion. The efficiency of polygeneration may be as high as 55 to 60 percent as compared to about 45 percent for the supercritical-steam turbine cycle. Although high capital costs for the gasifier system can be a barrier, it is expected that technology and scale advances, and the "learning curve" will bring this cost down.

Burning coal conventionally can cause severe pollution problems, producing more carbon dioxide per unit of energy produced than other fossil fuels. In countries that burn coal for power, polygeneration's high efficiency has the potential to reduce carbon emissions, while at the same time lowering overall cost.

Moreover, with the current tightness in North American natural gas supplies and high cost incremental supplies placing a floor under the price of natural gas, the prospects for coal and/or coal gasification as a source of petrochemicals, fuel and power are becoming a much more realistic alternative. As petroleum and natural gas supplies decrease relative to total demand, prices may remain high or continue rising, making coal a more economical and competitive feedstock/raw material. But, as crude and natural gas prices have continued to rise, coal prices have remained relatively flat, as shown for the U.S. (Figure 1.1) and for China (Figure 1.2).

Figure 1.1 U.S. Historical Crude/Gas/Coal Prices
(U.S. dollars per ton)

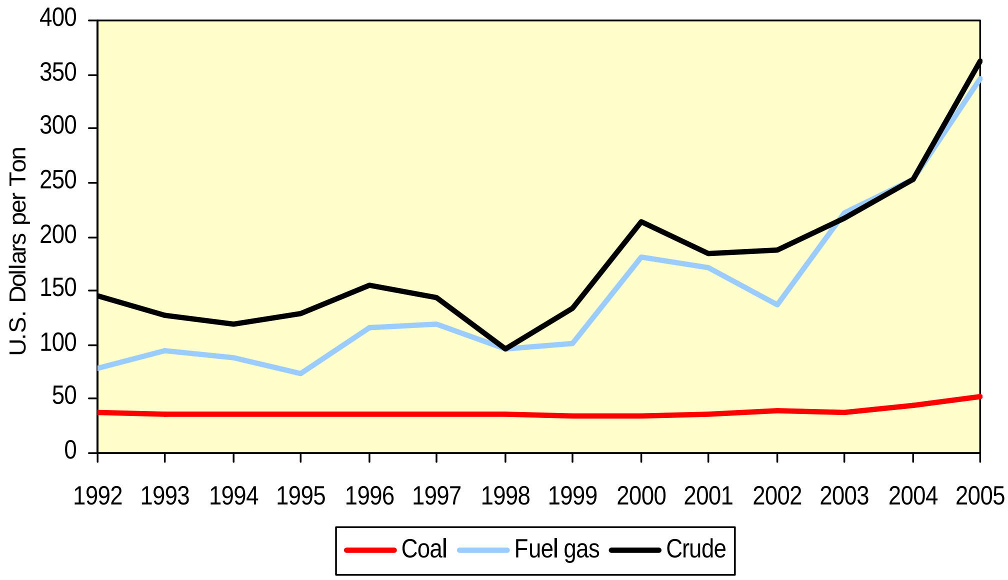

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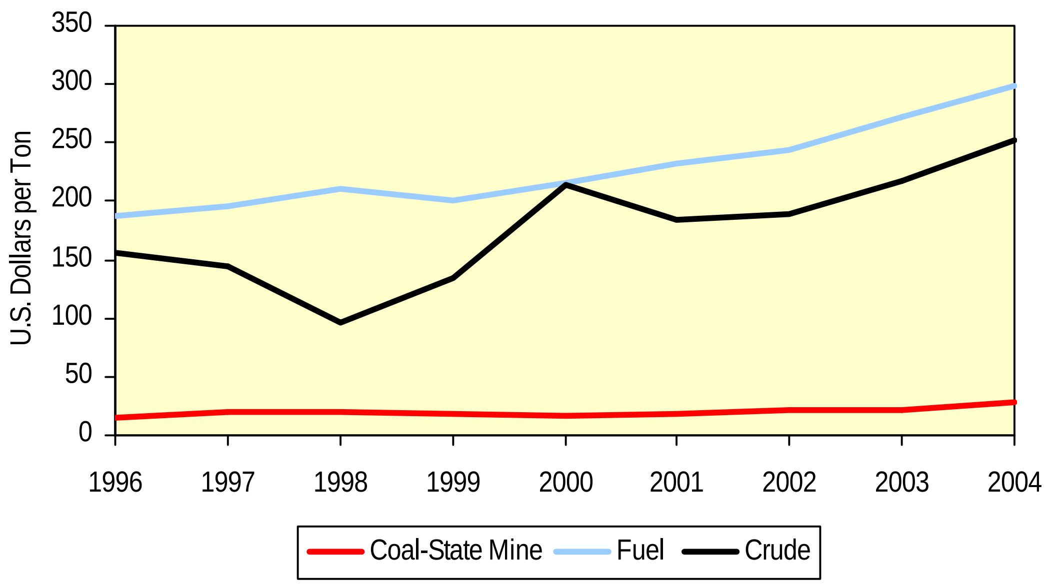
Figure 1.2 China Historical Crude/Fuel/Coal Prices
(U.S. dollars per ton)



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Thus, with crude oil and natural gas high in price, alternate production of power and fuel/petrochemicals from coal via polygeneration becomes more of a cost-effective reality.

Regions with large coal reserves, such as China, are actively examining the potential for coal polygeneration. China has the third largest coal reserves in the world, after the United States and the former Soviet Union (FSU). It can be expected that similar initiatives will follow elsewhere.

1.2.4 U.S. Energy Policy Act of 2005

The Energy Policy Act of 2005 was passed in the United States on July 29, 2005 and signed into law on August 8, 2005. The act was created in order to try to deal with growing energy supply challenges while providing tax incentives and loan guarantees for various types of energy production. The U.S. Energy Policy Act is one of many national programs worldwide that is focused on responding to the economic and supply issues present in current energy markets and supply/demand. It is of broad general relevance to *Polygeneration from Coal* due both to the very large coal reserves in the U.S. and some of the Act's provisions that benefit coal gasification.

The incentives of the Act apply to both traditional energy production and more efficient energy technologies and conservation. The Act includes many provisions and is intended to provide for a long range energy policy.

1.3 ABSTRACT OF STUDY

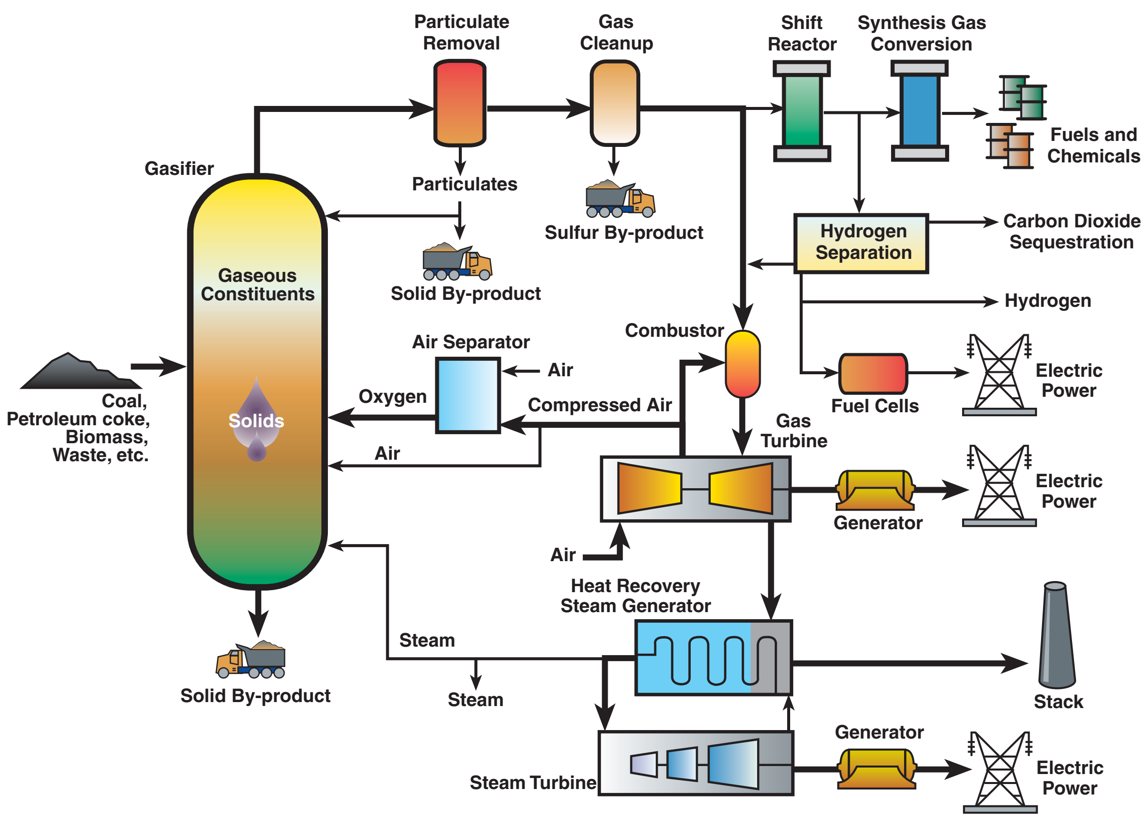
The general concept of *Polygeneration from Coal* is illustrated in Figure 1.3.

This portrays the general concept through electric power generation, and also the point at which the remainder of the synthesis gas is sent to adjacent process facilities for the production of chemicals and/or liquid fuels.

The economic attractiveness of the use of coal for *Polygeneration* of power and chemicals/fuels is dependent upon the relative prices of coal and alternate, more conventional feedstocks. In countries such as China, where coal combustion as a simple fuel is common, but is threatened by environmental issues, the conversion to *Polygeneration* can be considered a logical next step.

In other locations, where coal is abundant but not especially widely used, such as the United States, the advances in gasifier technology can be viewed as a primary driver to replace high cost natural gas, crude or ethylene feedstock, especially in light of the pattern in recent years of rapidly increasing crude oil/natural gas prices. The fundamentals of these factors have changed dramatically in the favor of coal since the mid-1900s, when coal lost its role as the basic feedstock for organic chemicals, and since the 1980s as the preferred energy input for electric power.

Figure 1.3 Polygeneration



Source: DOE/NETL Laboratory

There are a number of important reasons for heightened interest in coal as a source of energy, liquid fuels and chemicals:

1. Energy and Feedstock Security -- The United States has very large recoverable reserves of coal, estimated at about 275 billion tons. These reserves, equivalent to 225-250 years of supply at current usage rates, have a greater "life" than for any other country.
2. Since coal reserves are generally not concentrated internationally in the same countries that have large crude oil and natural gas reserves, a shift toward coal upgrading would make the world economy less dependent on long troublesome supply chains for these large volume commodities (energy, fuels and chemicals).
3. With present oil prices, it does not appear that significant market intervention would be necessary to establish a significant coal upgrading industry in many countries. Conversely, with crude oil prices relatively low, say below $30 per barrel as in the 1990s, by most accounts coal upgrading via DCL or ICL would be optimum economically in only a few limited situations worldwide.
4. Other regions, such as Asia (especially China) and Europe, also have considerable coal reserves. These could be used to produce products to augment imports and provide a

hedge against crude supply disruptions, as shown in Table 1.1 and Figure 1.4. This is especially important in light of China's growth as an energy and chemical consumer.

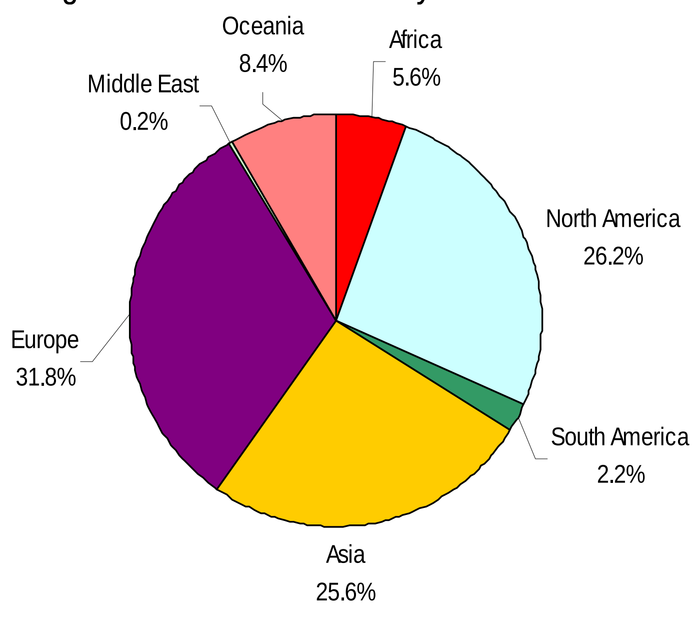
The global distribution of coal reserves is illustrated in Table 1.1 and Figure 1.4.

Table 1.1 Major Proven Coal Reserves, by Country [1]
(Billion tons)

United States	275
Russia	173
China	126
India	93
Australia	90

[1] Source: Clean-Energy U.S.

Figure 1.4 Regional Coal Reserve Share by Percent of Global Coal Resource



Compared to many other countries, developing coal-based liquid fuel and chemicals is more a important strategic issue for the Chinese government due to their reluctance to become more reliant upon imported oil. With crude oil imports exceeding 100 million tons per year and growing, the Chinese government is trying to find ways to lower the growth of imports in China's energy mix.

As recommended by the Chinese Task Force on Energy Strategies and Technologies, *"Modernization of coal is a large and necessary component of energy systems that satisfy the Three E's (Economic development, Energy security, and Environmental protection) for China's* *sustainable development. Modernization of coal refers to the use of gasification technology to produce synthetic gas for power, clean fuels for transportation and cooking, and heat for both domestic and industrial heating applications, to replace coal combustion technology and oil imports. This strategy is based on technologies that are mostly known and proven, many of which are already in use in China, largely in the chemicals sector. What is needed for successful implementation is to promote the integration of, and investment in, those technologies rather than the development of many new ones. Investments in new capacity should be directed to gasification-based systems, with an emphasis on co-production of multiple energy carriers and often chemicals as well at the same site, i.e., polygeneration. A flexible and adaptive strategy needs to be implemented step-by-step."*

For China, there are several reasons for *Polygeneration from Coal* to be successful:

- Infrastructure Availability – Existing means are in place for distribution of coal by rail and barge, as well as via mine-mouth utilization
- Cost Advantage/Stability – Coal costs less than other hydrocarbon fuels/feedstocks and is less volatile in price today. For example, steaming coal at $0.75 - $1.75 per million Btu compares favorably with natural gas at $6.00 - $10.00 per million Btu, based on recent price ranges in international markets.
- Diversity – Utilization of coal can insulate against the price and availability shock potential of oil and natural gas

Recently in China, a project has been funded by the U.S. Trade and Development Agency (USTDA) with the goal of testing the feasibility of building a new polygeneration plant. This project involves Hunnan International Technopolis Shenyang, where the company is looking into the economic parameters and technology options for the establishment of coal gasification, garbage gasification, methanol synthesis, and conversion processes for a polygeneration plant.

Interest in coal gasification has been strong in the United States as well. For example, in December 2005, the U.S. Department of Energy (DOE) announced an agreement with a coal and energy industry consortium to build a $1 billion clean-coal power plant that will reduce pressure on natural gas consumption. DOE approved FutureGen Industrial Alliance's plans for development and construction of a 275 MW power plant that will implement coal gasification technology to convert coal into highly enriched hydrogen gas, which will in turn be burned in the plant to generate electricity. Under this agreement, the FutureGen group of eight U.S., Australian and Chinese companies will contribute $250 million to the project with the U.S. government funding the rest of the balance. Once it is demonstrated that the process is viable, future projects heading towards commercialization will commence. More recently in May 2006, it was announced that twelve potential sites are being considered by the FutureGen Alliance for the first $1 billion FutureGen coal gasification project.

There has also been strong interest expressed by many other U.S. firms, as well as governmental agencies, to develop in, participate in, or facilitate coal gasification projects of various configurations. In fact, there are almost too many projects under study to keep an up-to-date list.

2.1 OVERVIEW

Nexant will review and analyze *Polygeneration from Coal* to produce electric power simultaneously with chemicals and/or liquid fuels. Since some subscribers may be interested in the production of only chemicals or fuels, but not both, the study is structured as two separate related reports ("Volumes").

2.1.1 Polygeneration of Power and Chemicals

Nexant examines the technologies for coal gasification to syngas for power plus a wide array of chemicals available from syngas:

- Methanol
- Ammonia/Urea
- Olefins/Polyolefins
- Acetic Acid
- Vinyl Chloride Monomer

This report Volume discusses the major gasification and chemical technologies, their advantages and disadvantages, and how they can be optimized for integration into the *Polygeneration* scheme. The flexibility available in balancing power and chemical production levels, environmental issues specific to this production, and other issues important to a full understanding of the technologies and costs involved were analyzed and discussed.

Nexant reviewed gasifier technologies being offered in the marketplace that are best suited to *Polygeneration with chemicals production*, those that maximize coal conversion efficiency, hydrogen/carbon monoxide ratio, and syngas production flexibility, while considering how they best integrate into downstream power and chemical production technologies.

Technologies that are integral and best suit the conversion of syngas to chemicals and downstream were reviewed and evaluated as to their applicability. This included technologies such as methanol to olefins (MTO), an emerging alternative to conventional steam cracking of conventional hydrocarbons.

2.1.2 Polygeneration of Power and Liquid Fuels

This report Volume examines how gasification technology is best suited for the production of power and liquid fuels. Syngas with the appropriate hydrogen/carbon monoxide ratio can be converted to low-sulfur diesel fuel via the Fischer-Tropsch reaction or to dimethyl ether (DME) from methanol produced from syngas. More recently, the Fischer-Tropsch reaction has been shown to be able to produce gasoline with the addition of an isomerization step.

The review discussed the major gasification and liquid fuels technologies, the designs for optimizing the various liquid fuels, and their integration into the *Polygeneration* scheme. The flexibility available in balancing power and fuels production levels, environmental issues specific to this production, and any other issues important to a full understanding of the technologies and costs involved were analyzed and discussed.

Nexant reviewed gasifier technologies being offered in the marketplace that are best suited to *Polygeneration with liquid fuels production*, those that maximize coal conversion efficiency, hydrogen/carbon monoxide ratio, and syngas production flexibility, while considering how they best integrate into downstream power and fuels production technologies.

Technologies that are integral and best suit the conversion of syngas to DME, diesel, gasoline and other fuels were reviewed and evaluated as to their applicability. This includes, but is not limited to, the following:

- Diesel
  - Fischer-Tropsch conversion
- Dimethyl ether
- Gasoline
  - Haldor Topsoe TIGAS
- Methanol

2.2 COAL GASIFICATION

For each study segment, Nexant described and reviewed the available technologies for coal gasification and investigated developments that may prove important from both cost and environmental standpoints.

With regard to commercially available technologies, we reviewed the three major types:

- Fixed-bed reactors
- Fluidized-bed reactors
- Entrained-flow reactors

We also reviewed the technologies as presented by the major licensors, such as Advantica, GE Energy, KBR, Lurgi, etc. Given the high degree of recent interest and activity in coal gasification in general and polygeneration in particular, we contacted these and other licensors for the latest developments and design improvements, as well as reviewed other information available in the public domain (i.e., non-confidential information).

2.3 ECONOMICS

2.3.1 Polygeneration of Power and Chemicals

Typical indicative capital cost estimates and cost of production economics were developed for the production of syngas and export power via gasification, including sensitivities for syngas/power production ratio as determined by the gasifier flexibility. Economics represent both typical U.S. Gulf Coast and China grass-roots construction.

Integrated economics for the production of chemicals from the syngas produced in the gasifier were developed, in essence a coal to chemicals and export power cost of production. The integrated economics represent world-scale, competitive capacities for the syngas derivatives, and gasifier capacities and configuration (number of gasifiers, number of trains of associated process systems/units) sized to suit the power and derivatives demand.

2.3.2 Polygeneration of Power and Liquid Fuels

Cost of production economics were developed for the production of syngas and export power via gasification, including sensitivities for syngas/power production ratio as determined by the gasifier flexibility. Economics represented both U.S. Gulf Cost and China grass-roots typical construction costs.

Integrated economics for the production of liquid fuels from the syngas produced in the gasifier were developed, in essence a coal to fuels and export power cost of production. The economics were developed for the various integrated fuel production routes, such as F-T for diesel and gasoline, methanol for DME and methanol for gasoline. The integrated economics represent world-scale, competitive capacities for the synthetic fuels, with special consideration for the likelihood of large-scale GTL (gas to liquids) plants to be built in remote, stranded gas locations. The integrated economics include gasifier capacities and configuration (number of gasifiers, number of trains of associated systems) sized to suit the power and derivatives demand.

2.4 REGIONAL ECONOMICS

Nexant developed cost of production economics for the various chemicals/derivative and fuels listed in each report on a regional basis, taking into account typical regional conditions, including:

- Cost of production estimates for 2007 and forecasts for 2010 and 2015 feedstock prices were developed for each of the products and fuels listed via polygeneration and alternate conventional routes as a means to gauge the competitiveness of the coal-based routes.
- Costs were developed for the regions/countries with major accessible coal reserves, including the United States, China, and Eastern Europe/Eurasia.
- Export economics were developed for the derivative products/fuels from these locations to the United States and Western Europe.

2.4.1 Polygeneration of Power and Chemicals

Nexant compared typical regional cost of production economics of the major traded chemical products, including:

- Methanol
- Ammonia/Urea
- Olefins/Polyolefins
- VCM
- Acetic acid

The coal-based economics for the coal-rich countries were compared to the cost of production for the same chemicals using conventional feedstock and process technology. These comparisons were used to help develop regional production and competitive dynamics, which are illustrated by comparing the delivered cost of the product to a typical import location. A typical cost of production worksheet for a coal-based gasifier (power production) is shown in Table 2.1.

Nexant developed regional costs and factors to develop the economic cases for the countries and regions involved in the production cost estimates. These estimates included all major raw materials and by-product prices, and utility and wage unit costs. ISBL (inside battery limits) and OSBL (outside battery limits) capital costs were estimated for each process on a USGC basis and were adjusted for the particular countries and locations using our technology database of construction cost location factors. Location factors for labor force size and costs (social charges) and general plant overhead were also applied.

Table 2.1 Cost of Production Estimate for: Power Process: Combined-Cycle from Coal-Derived Syngas

Plant Start-up	2Q2004			
Analysis Date	2Q2004			
Location	US Midwest			
Capacity	4.27	Million Megawatt-Hr/Yr		
Availability	93	Percent =	8146.8	Hrs/Yr
Throughput	3.97	Million MWH/Yr		

CAPITAL COST	Million U.S. $
ISBL	232.0
OSBL	40.9
Total Plant Capital	**272.9**
Other Project Costs	68.2
Total Project Investment	**341.2**
Working Capital	22.9
Total Capital Employed	**364.1**

PRODUCTION COST SUMMARY			Units Per MWH Product	Price, U.S. $ /Unit	U.S. $ Per MWH	Annual Cost, MM U.S. $
RAW MATERIALS	Syngas from Coal	MM Btu	6.35227	2.2158	14.0751	55.89
	Catalyst & Chemicals	U.S.$	1.00000	0.3277	0.3277	1.30
	TOTAL RAW MATERIALS				**14.4028**	**57.19**
BY-PRODUCT CREDITS					0.0000	0.00
	TOTAL BY-PRODUCT CREDITS				**0.0000**	**0.00**
NET RAW MATERIALS					**14.4028**	**57.19**
UTILITIES	Power (Purchased)	MWH	(0.154695)	48.0000	(7.4254)	(29.49)
	Boiler Feed Water	M Gal	(0.272098)	1.7400	(0.4735)	(1.88)
	Steam, VHP	M Lb	2.269354	15.0000	34.0403	135.18
	Steam, MP	M Lb	0.204561	12.2500	2.5059	9.95
	Steam, LP	M Lb	(0.070186)	11.5000	(0.8071)	(3.21)
	Steam, VLP	M Lb	0.019535	11.2500	0.2198	0.87
	Process Water	M Gal	0.093727	1.0200	0.0956	0.38
	Fuel	MM Btu	0.014343	7.5500	0.1083	0.43
	TOTAL UTILITIES				**28.2639**	**112.24**
NET RAW MATERIALS & UTILITIES					**42.6667**	**169.43**
VARIABLE COST					**42.6667**	**169.43**

					U.S. $ Per MWH	Annual Cost, MM U.S. $
DIRECT FIXED COSTS	Laborers,	46.0 Men	43.40 Thousand	U.S. $	0.5027	2.00
	Foremen,	10.0 Men	49.20 Thousand	U.S. $	0.1239	0.49
	Supervisors,	2.0 Men	59.50 Thousand	U.S. $	0.0300	0.12
	Maintenance, Material & Labor		2.50 % of ISBL		1.4606	5.80
	Direct Overhead		45.0 % Labor & Supervision		0.2955	1.17
	TOTAL DIRECT FIXED COSTS				**2.4126**	**9.58**
ALLOCATED FIXED COSTS	General Plant Overhead		60.0 % Direct Fixed Costs		1.4476	5.75
	Insurance, Property Tax		1.0 % Total Plant Capital		0.6873	2.73
	TOTAL ALLOCATED FIXED COSTS				**2.1349**	**8.48**
CASH COST					**47.2142**	**187.49**
Depreciation @		5.0 % for ISBL & OPC		5.0 % for OSBL	4.2957	17.06
COST OF PRODUCTION					**51.5098**	**204.55**
Return on Total Capital Employed (Incl. WC) @				10.0 Percent	9.1680	36.41
COST OF PRODUCTION + ROCE					**60.6778**	**240.96**

Note: By convention in various industries, M in MWH means million (mega), while M in MMBtu means thousands.

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2.5 COMMERCIAL EVALUATION

Nexant developed forecasts of the major product groups included in the technoeconomic evaluations. The forecasts included demand, production and trade, globally and by region, to 2020. The forecasts covered the following products:

Chemicals:

- Methanol
- Ammonia
- Olefins
- Polyolefins
- Vinyl chloride
- Acetic acid

Liquid Fuels:

- Diesel
- Dimethyl ether
- Gasoline
- Methanol

Below are shown the tables of contents for each of the two related report volumes issued as part of this multi-client study.

3.1 POLYGENERATION OF POWER AND CHEMICALS

3.2 POLYGENERATION OF POWER AND LIQUID FUELS

4.1 OVERALL APPROACH FOR THIS STUDY

The design concept of *Polygeneration from Coal*, either as chemicals or fuels production along with electric power, is based on the key concept of coal gasification, followed by a series of unit operations, designed to maximize the value-added to the products (including power), both in optimizing revenue and cost efficiencies.

We note the difference between a specific project and the generalized approach taken in the representative ("typical" for a general location, such as the USGC) analysis in this multi-client study. Of course, for a specific project a developer would need to make the selection and design of the gasifier highly dependent upon actual coal properties, including heat content, ash content, ultimate coal analysis, moisture content, and fusion temperature, among others. Similar issues would need to be taken into account to design the IGCC power generation part of a plant, as well as the liquid fuels and/or chemical section of a facility. As a result, the proportions of the respective products, including electric power output, would depend on technical issues, site specific factors, and the commercial attributes and arrangements of the project.

For the purpose of developing the typical representative economics presented in this study, Nexant selected typical technical attributes and production ratios for each of the power/chemicals and power/fuels cases, and gasifier and downstream equipment and unit operations. These "typicals" were those that we concluded could produce the product slate and that represent state-of-the-art technology as offered by the licensors and other technology holders, as produced from a typical coal assay. As a result of the economic comparisons in this study, the reader will have an understanding of the competitiveness of a typical *Polygeneration from Coal* installation versus conventional commercial technology and process routes.

In the economic analysis of the study, by crediting the power generated in a manner that reflects the value of the power as a revenue credit against the costs, the net cost of producing the chemicals or liquid fuels can be calculated. (The power value may be that of full cost plus return or forecast market price for power, as we feel appropriate to be produced from a coal-based project with similar performance and environmental attributes as the *Polygeneration from Coal* concept).

4.2 OTHER ASPECTS OF APPROACH FOR THIS STUDY

The reviews of conventional technology were based on Nexant's in-house and published information regarding process technology, augmented by contacts with licensors, engineering contractors and other experts in the industry. The reviews of developing technology were "built up" from a review of patents, public domain information, and discussions with the technology developing companies and engineering contractors.

Nexant used its own proprietary as well as commercial state-of-the-art software tools to develop the technology and economic estimates. We employed well established, state-of-the-art chemical process industry engineering estimating tools and principles as used by major engineering contractors.

Additional aspects of our approach for this multi-client study are as follows:

- The economic evaluations were premised as typical regional costs of production based on capital costs that were appropriate for "factored estimates".
- The economic evaluations did not reflect specific site issues, but should portray economics that are representative of the respective countries or regions as a whole.
- Commercial information and forecasts were developed from Nexant's extensive in-house databases, augmented with selected regional fieldwork.
- Market projections were developed with the aid of Nexant's Supply/Demand computer modeling systems and databases

The study was completed in June 2008.

Please visit www.chemsystems.com to authorize purchase of the study, or return the following authorization form to one of the Nexant offices.

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7.1 GENERAL

Nexant uses multidisciplinary project teams drawn from the ranks of our international staff of engineers, chemists, economists and financial professionals, and from other Nexant groups to respond to the requirements of each assignment. Most of the staff of consultants possesses credentials in both scientific and commercial disciplines plus substantial industrial experience. The collective talents of our staff strategically located and closely linked throughout the world, result in valuable insights gained through a variety of perspectives.

ChemSystems is an international consultancy that is now part of Nexant, Inc., and is dedicated to assisting businesses within the global energy, chemical, plastics and process industries by providing incisive, objective, results-oriented management consulting. Over three decades of significant activity translate into an effective base of knowledge and resources for addressing the complex dynamics of specialized marketplaces. By assisting companies in developing and reviewing their business strategies, in planning and implementing new projects and products, diversification and divestiture endeavors and other management initiatives, Nexant helps clients increase the value of their businesses. Additionally we advise financial firms, vendors, utilities, government agencies and others interested in issues and trends affecting industry segments and individual companies. Whether identifying opportunities, managing change or confronting competitive challenges, we adhere to the highest ethical and professional standards.

ChemSystems, founded in 1965, was originally an independent, management-owned consultancy. IBM acquired it in 1998, and from early 1998 until August, 2001 ChemSystems was a part of IBM Global Services and IBM’s Chemical and Petroleum group. Effective September 1, 2001, the ChemSystems unit of IBM was acquired by Nexant, Inc. Nexant, Inc. is an independent industry-expert consulting firm, spun off from Bechtel over six years ago, that provides technology solutions and experienced-based technical and management consulting services to electric utilities, energy and power producers, chemical companies, oil and gas companies, governments, and energy/chemical end-users worldwide. All of the staff and intellectual capital of ChemSystems was acquired by Nexant, Inc. Thus, Nexant, Inc., with ChemSystems as part of its Chemicals and Petroleum Division, continues to maintain fully-integrated operations in White Plains, New York; London, England; San Francisco, California; Washington, D.C. and Bangkok, Thailand. Other business unit offices are located in Boulder, CO and Phoenix, AZ, and satellite business or project offices are located in Tokyo, Beijing, Seoul, and Houston. We also work with representatives throughout the world.

From major multinationals to locally-based firms and governmental entities, our clients look to us for expert judgment in solving compelling business and technical problems and in making critical decisions. The acquisition of ChemSystems by Nexant, Inc., enhanced ChemSystems’ ability to successfully serve its clients via the use of complementary methodologies and technologies, which are used to provide services to clients and allow us to provide more complete and effective consulting.

Nexant's clients include most of the world's leading oil and chemical companies, financial institutions, and many national and regional governments. Nexant, Inc. is active in most of the industrialized countries of the world, as well as in most of the developing areas including the Middle East, Africa, and East and Southeast Asia.

Major annual programs are:

- Process Evaluation/Research Planning (PERP)
- ChemSystems Online (CSOL)/Petroleum and Petrochemical Economics (PPE) – United States, Western Europe and Asia

The PERP service covers technology, commercial trends, and economics applicable to the chemical industry. The program has more than 50 subscribers, including most of the major international chemical companies. Many of the processes to be analyzed in this multiclient have been assessed in the PERP program.

CSOL/PPE covers the market and manufacturing economics for major petrochemicals.

Over the past five years, the program has been completely overhauled and upgraded. The models and databases that run the analysis have been replaced with a start-of-the-art industry simulation program that has taken the 30 years of industry knowledge and experience of our consultants and enhanced it to a proved new level of forecasting expertise.

The CSOL simulation model is used to generate the PPE reports and also an internet serviced brand ChemSystems Online, which provides global data, analysis and forecasts of:

- Plant capacities
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- Consumption
- Supply/demand and trade
- Profitability analysis
- Forecast
- Price forecast
- Techno-economic analysis

A subscription to ChemSystems Online includes both written reports (the PPE program) on the petroleum and petrochemical industry and internet access to all data analysis and forecasts. Your subscription may be tailored to meet your specific company requirements and the fees reflect the value brought to your business. Insightful analysis and a reliable forecasting methodology provide the means to significantly improve your business performance though better investment decisions and improved competitive position.

7.2 SUMMARY OF NEXANT'S PROJECTS RELATED TO COAL

- SYNTHETIC FUEL CAPITAL AND PRODUCTION COSTS -- Nexant performed this study for the U.S. Department of Energy (DOE) as input to their assessment of the costs and benefits of flexible and alternative fuel use in the U.S. transportation sector. Nexant reviewed state-of-the-art coal liquefaction technology and developed production cost estimates for producing synthetic crude and then upgrading the syncrude to a gasoline product.

- CHEMICALS FROM COAL AND SHALE FEEDSTOCKS -- Recognizing the eventual importance of coal and shale resources in replacing gas and petroleum, this study examined the various technologies that could be used to produce feedstocks and chemicals. Three separate potential implementation cases were treated in detail: Economic, By-product, and "National Need." The production of synthetic fuels, olefins and aromatics and their derivatives from coal and shale were projected through the year 2000. A large number of patent references and flowsheets are included in the study, which also reviewed the chemical implications of synthetic fuels programs in the United States and elsewhere. There is also a section on utilization of U.S. tar sands resources.

- SYNTHESIS GAS (FUTURE SOURCES) -- This report reviewed the technology for production of synthesis gas (H_2, CO mixtures) from a number of sources. Most emphasis was devoted to coal and biomass (municipal solid waste and wood) gasification and new gasification technology. The report discussed downstream processing requirements and examined coal and biomass properties and their impact upon gasifier design. The economics of producing industrial fuel gas (gasifier effluent after acid gas removal) via different routes were compared to the direct use of natural gas and low sulfur fuel oil.

- HYDROGEN-SYNTHESIS GAS STUDY -- Nexant completed a multiclient study on the production of hydrogen and synthesis gas from heavy oils and coal. The objective of this study was to analyze the effects on the U.S. natural gas shortage on that portion of the petrochemical industry dependent upon natural gas as a feedstock, with particular emphasis on ammonia, methanol, and hydrogen-based chemicals. The study included a section on comparative costs for all hydrocarbon feedstocks from natural gas to coal.

- WEST GERMAN COAL RESEARCH AND DEVELOPMENT / COAL GASIFICATION -- West German companies have undertaken a massive effort to update their technologies to meet motor fuels and chemical requirements from indigenous and imported coals. An unusually productive marriage of government and private money, deployed in pilot plants located in chemical and energy complexes, is steadily advancing the state-of-the-art in West Germany. Promising United States technologies are also being considered and improved. This study reviewed and analyzed the individual programs for their merit and impact on synthetic fuels and coal-based chemicals projects in the industrialized countries.

- EVALUATION OF COAL-BASED AMMONIA/METHANOL PROJECT -- Nexant developed the overall facilities concept and developed capital cost estimates for this project. Lurgi and Koppers-Totzek gasifiers were studied in detail. Internal steam and power balances were developed and the optimal synthesis gas processing sequence was developed.

- EVALUATION OF COAL/NATURAL GAS BASED METHANOL/POWER -- Nexant developed the overall facilities concept and capital cost estimates for an integrated complex employing "second generation" coal gasification, steam/methane reforming and combined cycle power generation technologies for the co-production of methanol and power. Relative coal and natural gas consumption was based on producing a stoichiometrically balanced methanol synthesis gas from coal-based hydrogen deficient and natural gas based carbon deficient synthesis gases.

- COAL TAR CHEMICALS -- In response to a Japanese company's request for an analysis of coal tar chemicals, Nexant conducted a study of U.S. and West European markets/applications and evaluated the technology for four basic coal tar chemicals and specific hydrogenated derivatives. The compounds studied included tetralin, biphenyl, acenaphthene, and phenanthrene and hydrogenated derivatives of acenaphthene and phenanthrene. The technology review covered all aspects of the chemistry of these materials as well as all applications and developments worldwide.

- IMPACT OF COAL CONVERSION PLANTS ON AROMATICS -- For a U.S. chemical company, Nexant assessed the economic feasibility of aromatics recovery from by-products streams of coal gasification and coal liquefaction plants. Production technology and economics were provided for benzene, toluene, phenol, cresol, xylenol, and coal derived naphtha.

- SMOKELESS FUELS FROM COAL -- For a specialty fuel producer, Nexant identified and characterized methods for producing smokeless briquettes that met international standards and identified potential binders that could be used with existing equipment to produce smokeless briquettes that could be used for export. Binders studied included: coal tar pitch, petroleum resin, coal and starch.

- MARKETING ASSESSMENTS OF COAL PRODUCTS/BY-PRODUCTS -- Nexant, under contract to Tri-State Synfuels Company (a partnership between Texas Eastern Synfuels Inc. and Texas Gas Synfuel Corporation) examined in detail the marketability of products from a Lurgi/Fischer-Tropsch coal-based facility being considered for Henderson, Kentucky. The coal conversion facility was being evaluated by Tri-State under a cooperative funding agreement with the U.S. Department of Energy. The products from the plant included high Btu substitute natural gas (SNG) liquid transportation and heating fuels, and a wide range of chemical products and by-products. Nexant analyzed the general eight-state region surrounding the proposed plant. Recommendations and observations were made relating to possible changes in the originally envisioned slate of products that might improve the project's revenue generation capability. Future product prices and values were forecast, based on Nexant's prevailing long-term prognosis of energy, petroleum and petrochemical demands. Nexant performed two similar market analysis studies for New York Power Authority (NYPA). One involved a proposed 600 MW coal gasification combined cycle power plant considered for the Buffalo area. Nexant analyzed current and future markets for the fuels and chemicals (including synthesis gas derivatives) that could be manufactured in the complex. The second study was for a coal gasification plant being evaluated by NYPA for the South Bronx. Products considered for this plant included medium-Btu gas (and potential products) steam, sulfur, carbon dioxide and industrial gases (oxygen, nitrogen and argon).

- VALUE OF COED PROCESS COAL-DERIVED LIQUIDS IN A PETROLEUM REFINERY -- This study analyzed the value of liquids produced in a plant designed to make synthetic crude oil from coal.
- VALUE OF LIQUIDS PRODUCED FROM COAL IN A COG (COAL, OIL GAS) REFINERY -- This study, for the Pittsburgh & Midway Coal Mining Company, determined the value of coal-derived liquids in petroleum refineries.
- COAL-METHANOL SLURRY PREFEASIBILITY STUDY -- This study analyzed the economic viability of using coal-methanol slurry fuels in Malaysia.
- COAL-LIQUID MIXTURE -- Assistance was provided to the U.S. Synthetic Fuels Corp., on oil, water and methanol coal mixture technologies, economics and markets in regard to defining the scope for a planned solicitation.
- COAL MINE ASSETS APPRAISAL -- Certain coal mining equipment (mobile and fixed) and systems were evaluated and appraised in support of a lease financing.
- EVALUATION OF COAL TO SYNTHETIC GASOLINE PROJECT -- This project compared the attractiveness of gasoline production from coal derived methanol via the Mobil MTG (methanol-to-gasoline) process, to the economics of direct coal liquefaction as well as coal based methyl fuel production.
- CHEMICALS FROM COAL AND SHALE -- This study was performed under an RANN grant by the Office of Energy R&D Policy, NSF. The objectives of this study were: estimate feedstock demands for major organic chemicals through the year 2000; gauge the probable timing as to when chemical feedstock demands will constitute an unreasonably large fraction of conventional hydrocarbon sources; identify the potential technologies for (a) transformation of coal and shale building blocks to primary organic chemical building blocks or feedstocks, and (b) synthesis of current "petrochemicals" from such coal and shale-derived building blocks; define research and development strategies and a related program to assure that any conversion of the organic chemical industry to coal and shale would be based upon available and the most economically possible technology.
- SYNTHESIS GAS FOR CHEMICALS -- This multiclient report dealt with the applicability of emerging synthesis gas based routes to chemicals compared to traditional production methods. The synthesis gas based routes were analyzed based on the economics of large-scale production of synthesis gas from coal.

7.3 ADDITIONAL BACKGROUND ON PRODUCING CHEMICALS OR LIQUID FUELS FROM COAL

Coal can be made into useful products by a number of chemical processing approaches, but practically speaking these can be viewed as either liquefaction or gasification processes.

7.3.1 Coal Liquefaction

Coal liquefaction is typically the term used to describe the use of coal to produce liquid fuel or hydrocarbon products. The motivation to develop existing and new technologies to convert coal to liquid fuel has been largely driven by the growth in oil prices and concerns about the oil supply in recent years. Converting coal to liquid fuel could provide a means of dampening the escalation of oil prices. Not only is coal to liquid (CTL) technology an appealing option for the Unites States but also for parts of Asia (China in particular) where there is an abundance of coal and shortage of oil.

There exist two main methods of coal liquefaction that have already been put to use in the past to varying degrees: indirect coal liquefaction and direct coal liquefaction. There have been many speculations and comparisons concerning the two methods of liquefaction and their relative effectiveness, as well as their fundamental economics versus conventional supply.

There are concerns involving both types of liquefaction methods. One major challenge is the hydrogen/carbon ratio. There have also been questions about the environmental safety of coal liquefaction.

7.3.2 Direct Coal Liquefaction (DCL)

7.3.2.1 General

The method of DCL was found by Friedrich Bergius as a commercial process in Germany. Before World War II, seven DCL plants were in operation and five more plants were added during the war producing more than 3 million tonnes of oil per year. The production of liquid fuel via DCL was abandoned when low-cost Middle East oil became available in the early 1950s.

DCL would typically involve first converting coal into a partially refined synthetic fuel material, and then further refining the product into synthetic gasoline and diesel as well as LPG. With DCL, a coal-oil slurry feed containing up to about one-half coal is heated to moderately high temperatures in a high pressured hydrogen atmosphere for about an hour. A variety of suitable catalysts are used to promote the conversion of coal to liquid products. The gasoline-like and diesel-like products are recovered from the partially refined synthetic fuel by distillation. Hydrogen is added to the mixture to 1) increase the hydrogen/carbon ratio and 2) reduce the oxygen, sulfur, and nitrogen in the coal feedstock. The addition of hydrogen increases the energy need and thus increases the cost of DCL. However, it is critical to remove the oxygen, sulfur and nitrogen so that hydrocarbon fuels can be obtained (oxygen removal) and poisoning of cracking catalysts can be prevented (sulfur and nitrogen removal).

In the DCL process, one ton of coal yields about one-half ton of liquids. Because higher rank coals are less reactive, and also perhaps because they are typically higher priced in the market, processes have been developed for low rank coals (lignites) to high volatile bituminous coals.

Currently, DCL is not being used on a commercial scale due largely to its high capital and operating costs. In fact, research in the field has been limited due to the high cost of testing out a new technology in a pilot plant. There have been studies performed in the past concerning the viability of DCL. However, in the recent years there have been talks of many future ventures in the direct coal liquefaction field.

7.3.2.2 US DOE Direct Coal Liquefaction Program

The DOE Direct Coal Liquefaction (DCL) program was in effect in the 1970s and early 1980s. It stemmed from the energy crisis that was occurring at that time and consisted mainly of large scale demonstration projects with broad industry participation. The goal of this program was to try to show that directly converting coal to liquid fuels was not only viable alternative to acquiring liquid fuels but also the best-available technology. This presumption is largely dependent on the fact that U.S. has ample amounts of coals reserve and the price of coal remained relatively modest.

In addition to the DCL program, there was a smaller program, involving less industry involvement and more focused on a fundamental R&D process, also with the goal of researching DCL processes that lasted through the 1980s into the 1990s but was ultimately shut down by 2000 due to budget reductions. Consequentially, most of the effort placed into the program was during the years of 1978 to 1983, where the price of crude oil prices was highest.

In the DOE DCL program, the technology studied involved adding hydrogen to coal in solvent slurry at high temperatures and pressures. This process proved to be unsuccessful and after the OPEC embargo in 1973 and 1974, different process techniques were investigated on a small scale, leading way to three “second-generation processes” being performed on a large scale basis. These included the SRC-II (solvent-refined coal) in Tacoma, Washington, EDS (Exxon donor solvent) in Baytown, Texas, and H-Coal (single-reactor hydrogenation) in Catlettsburg, Kentucky.

The DOE provided 65 percent of the funding for the demonstrations and 83 percent for the smaller R&D program that followed the large scale demonstrations. The total amount contributed by DOE added up to approximately $2.3 billion, with the industry contributing $1.15 billion. Between the years 1978 and 1982, the DOE budgeted approximately $2 billion for direct liquefaction technology demonstrations while industry contribution amounted to over $1 billion. The demonstrations were technically successful but were never commercialized because there was no increase in oil price that had been projected to occur during the 1970s.

The companies that participated in these studies included mainly major oil companies (Exxon, Mobil, Chevron, Amoco, Conoco, Gulf, and others) and companies in the electric power industry (notably EPRI and Southern Co). The U.S. coal industry did not contribute to the budget of the program. When the demonstrations ended in 1983, the DOE budget dropped quite sharply and continued to decrease for the next 5 years and increased over the following 4 years only to steadily decline to termination over the following 8 years until 1999.

In the mid-1990s, the only remaining coal to liquid plant still in operation was the multistage coal liquefaction unit operated by Hydrocarbon Research, Inc. (later called Hydrocarbon Technologies, Inc - HRI/ HTI).

The demonstration projects showed that DCL was a feasible process with plant sizes up to 200 tons/day. There were successful operations of process equipment including emulated bed reactors, letdown valves, de-ashers, and preheaters that showed scale up was a viable option. Also resulting from the program was the identification of the problems that came along with coal processing. The processes resulted in low yields, poor product quality, and high capital costs.

It was estimated that in order for the DCL technology to be economically viable, the crude oil prices would have to be above $45/bbl. If environmental concerns were to be taken into consideration, this price would further increase. The improvement in economics over H-Coal is due to the following: (1) controlled precipitation that developed that eliminated the need for an expensive filtering step; (2) recycled product liquid used to slurry the feed coal bypassed around the solids removal unit therefore increasing the efficiency of the process; (3) catalytic reactors were added in series to improve control of the liquefaction chemistry; (4) improved catalysts were developed; and (5) less complex reactors were developed.

Because DCL is not a commercialized process, there are no realized economic benefits as of yet. Direct liquefaction technology is still a possible option for the future. However, in order to put this technology in use, there will need to be additional improvements in sectors such as environmental impact and economics of the technology.

7.3.2.3 Indirect Coal Liquefaction (ICL)

Unlike DCL, indirect coal liquefaction (ICL) technology involves the use of an intermediate step in the production of liquid fuels. The first step of the process is the gasification of coal in oxygen to produce synthesis gas (syngas). There are many different types of gasifiers available for this part of the process. The syngas is then cooled, purified, and rid of contaminants. The ratio of hydrogen to carbon dioxide for the syngas is adjusted with a water-shift reactor.

Once the syngas is purified, the CO and H_2 is combined catalytically and converted to form a wide range of products including hydrocarbons such as synthetic gasoline or synthetic diesel, or oxygenated fuels, as well as alcohols, aldehydes, ketones, acids.

The step required to convert the gasified coal to liquid hydrocarbons is known as the Fischer-Tropsch process. F-T process is a well established commercial process and is currently a focus of many global gas-to-liquid (GTL) efforts to use “stranded” natural gas to produce synthetic liquid transportation fuels. The F-T process was developed in Germany by researchers Franz Fischer and Hans Tropsch in the 1920s. It was used during WWII by Germany and Japan where there was a lack of petroleum but an abundance of coal. Since then, there have been many modifications to the original process. The original process is presented by the following simplified reactions in which methane is partially combusted and then is reacted to form the saturated liquid hydrocarbon products. The second reaction is the F-T synthesis:

$$CH_4 + \frac{1}{2} O_2 \rightarrow 2H_2 + CO$$

$$(2n + 1) H_2 + nCO \rightarrow C_nH_{2n+2} + nH_2O$$

Using metal catalysts, such as iron or cobalt, the carbon monoxide and hydrogen in syngas is converted into liquid hydrocarbons of various compositions. Since F-T synthesis is based on the reaction of hydrogen and carbon monoxide (syngas), any appropriate source material that can produce the requisite syngas can be used, such as coal via gasification (or partial oxidation of many petroleum liquids).

Similar to DCL, the ICL process has been held back commercially by its high capital costs as well as high operation and maintenance costs. However, ICL is a technology that is currently in use in a number of global locations. Sasol in South Africa uses the F-T process to produce a variety of synthetic petroleum products with coal and natural gas as the feedstock.

Coal gasification is a well-proven technology that has had many applications ranging from the earliest uses of coal gas for heating and lighting in urban areas ("town gas"), progressing to the production of synthetic fuels, such as liquid hydrocarbons and synthetic natural gas (SNG) chemicals, and most recently to large-scale IGCC (integrated gasification combined cycle) power generation.

In countries with large, accessible coal reserves the promise of an integrated polygeneration system is attractive as compared to conventional coal-based power generation. For example, for methanol synthesis, the cascade use of the chemical energy of syngas increases system efficiency and decreases energy loss from combustion. The efficiency of polygeneration may be as high as 55 to 60 percent as compared to about 45 percent for the supercritical-steam turbine cycle. Though high capital cost for the gasifier system can be a barrier, it is expected that technology and scale advances will bring this cost down.

Burning coal conventionally can cause severe pollution problems, with more carbon dioxide than other fossil fuels. In countries that burn coal for power, polygeneration has the potential to reduce carbon emissions, while at the same time lowering overall cost. Unlike the combustion of coal, with its inherently low efficiency and high levels of pollution, advanced gasification technologies can convert over 95 percent of coal fuel into syngas, producing power and substituting for natural gas or crude oil in the production of chemicals and/or fuels.

Moreover, with the current tightness in North American natural gas supplies and high cost incremental supplies placing a floor under the price of natural gas, the prospects for coal and/or coal gasification as a source of petrochemicals, fuel and power are becoming a much more realistic alternative. As petroleum and natural gas supplies decrease relative to demand, prices are expected to continue rising, making coal a more economic and competitive feedstock. But, as crude and natural gas prices have risen substantially in recent years, coal prices have remained relatively flat. This change in pricing relationships has made alternate production of power and fuels/petrochemicals from coal via polygeneration more of a cost-effective reality that may be ready for large scale implementation.

Regions with large coal reserves, such as China, are actively examining the potential for coal polygeneration. China has the third largest coal reserves in the world, after the United States and the former Soviet Union (FSU). It can be expected that similar initiatives will follow elsewhere.

7.4 BACKGROUND ON PRODUCING POWER VIA COAL IGCC

Power generation and emission control systems regarding gasification and integrated gasification combined cycle (IGCC) power plants continue to evolve significantly. These changes are primarily resulting from changes in market relationships and drivers, as well as regulatory requirements. A snapshot of conditions in this changing industry in early/mid 2006 per the NETL/DOE listing showed 24 coal-fired power plant projects being studied or planned using gasification technology.

IGCC and pulverized coal (PC) fired boilers are the primary competing technologies for coal-based power generation. However, fluidized bed combustion is another technology that is available to the industry. Development and implementation of the IGCC approach continues to especially evolve. There are only a few gasification installations using coal to make electric power as the primary product, and it is commonly understood that many have experienced technical and commercial challenges that are not uncommon to the start-up of new technologies.

Existing IGCC plants use bituminous coals as their energy/raw material input. Relatively little research or commercial work has been done to investigate gasification of low rank coals. Advanced technologies are under development, such as ultra-supercritical PC technology, and new technologies to further improve IGCC performance, but their timing for successful commercialization probably cannot be well anticipated with confidence. There are some issues about the long-term performance that is likely to be achieved for IGCC applications regarding some of the emission control technologies that might reasonably be designed into an IGCC project. Nevertheless, companies in energy and related industry segments are faced with responding now to critical challenges, such as those from high oil and gas prices, environmental pressures, and growing demand for electric power, liquid fuels and chemicals.

Regarding efficiencies, and subject to the caveat of limited comparable data available for comparison, it appears that IGCC plants have significantly better thermal performance than PC power generation plants using conventional and completely demonstrated and proven technologies (subcritical and supercritical). However, new ultra-supercritical PC plants may equal or exceed IGCC in thermal performance, on all coals except the low rank (lignite) types. On the other hand, global commercial operating experience with ultra-supercritical PC power generation plants is limited.

A key issue regarding the environmental performance of IGCC installations is whether to install selective catalytic reduction (SCR) technology to reduce NOx from syngas-fired turbines at IGCC plants. Industry has been reluctant to install SCR units because of the effects on operations, capital costs and operating costs.

Other important issues with regard to IGCCs are the inclusion (or not) of a spare gasifier train, which appears necessary to achieve operational availability of 85 percent or higher, i.e., the level of availability typically available with PC plants (at least the subcritical and supercritical type). Nevertheless, the currently available carbon management technologies for IGCC are estimated to be much more cost effective than the available technologies for removing CO_2 from PC plant flue gases. This aspect is a definite advantage for IGCC facilities, but in a practical sense the advantage can only be incentivizes realized in the market if there is a regulatory requirement of some kind that forces or otherwise strongly incentivizes CO_2 capture and sequestration.

Another advantage of IGCC is that sulfur is more easily removed from an IGCC plant's effluent gas. This results since gasifiers operate in condition of low oxygen content, and as a result the sulfur in the coal converts into H_2S, rather than into SO_2 as in a PC boiler's flue gas. The H_2S is intrinsically more easily removed than the SO_2 from these two types of power generation approaches, since H_2S removal is a common and well-proven process that is performed in many refining and natural gas facilities (admittedly not as commonly with synthesis gas).

It appears in general that an IGCC power generating facility has more characteristics similar to a chemical plant than does a PC power plant. Further, and essentially due to this, IGCC power plants appear to intrinsically have more technical and site-specific differences (design alternatives, and therefore process and equipment type alternatives) than would PC plants. For instance, the type of gasifier can differ (moving bed, fluidized bed and entrained flow) as can the use of the source of oxygen (air or oxygen).

7.5 U.S. ENERGY POLICY ACT OF 2005

The U.S. Energy Policy Act is one of many national programs worldwide that is focused on responding to the economic and supply issues present in current energy markets and supply/demand. It is of broad general relevance to *Polygeneration from Coal* due to the very large coal reserves in the U.S., and is summarized below:

The Energy Policy Act of 2005 was passed in the United States on July 29, 2005 and signed into law on August 8, 2005. The act was created in order to try to deal with the growing energy problems while providing tax incentives and loan guarantees for various type of energy production.

The incentives of the Act were for both traditional energy production and more efficient energy technologies and conservation. The Act covered many provisions and was intended to provide for a long range energy policy. Some major provisions of the Act include the following:

- Provides an Energy Tax Incentives Act of 2005 Commercial Building Deduction for improvements in energy efficiency building
- Provides a tax credit of up to $3,400 for owners of hybrid vehicles
- Authorizes loan guarantees for "innovative technologies" that would avoid creating greenhouse gases
- Increases the amount of biofuel that is required to be mixed with gasoline sold in the United States to three times the amount that is currently required (7.5 billion gallons by 2012)

- Looks to increase coal as an energy source while also reducing air pollution. This would be done through contributing $200 million annually for clean coal initiatives with advanced payment of royalties from coal mines and requiring an assessment of coal resources on federal lands that are not national parks
- Permits subsidies for wind energy as well as other alternative energy producers
- Includes ocean energy sources including wave power and tidal power for the first time as separately identified renewable technologies
- Authorizes $50 million annually over the life of the bill for a biomass grant program
- Contains several provisions with the goal to make geothermal energy a more competitive source of electricity against fossil fuels
- Requires the Department of Energy to performs studies on existing natural energy resources such as wind, solar, waves and tides
- Provides tax breaks for those making energy conservation improvements to their homes
- Provides subsidies for oil companies
- Sets federal reliability standards regulating the electrical grid (done in response to the Blackout of 2003)
- Certain nuclear-specific provisions

In order for the above provisions to have any affect where funding is required, there has to be money actually appropriated to the program. The tax breaks provided by the Act in certain energy areas/activities are as follows:

- $4.3 billion for nuclear power
- $2.8 billion for fossil fuel production
- $2.7 billion to extend the renewable electricity production credit
- $1.6 billion in tax incentives for investments in clean coal facilities
- $1.3 billion for conservation and energy efficiency
- $1.3 billion for alternative motor vehicles and fuels (such as ethanol, methane, liquefied natural gas, propane)

7.6 RECENT EVENTS OF INTEREST TO POLYGENERATION FROM COAL

7.6.1 China

In 2004, China announced the discovery of new coal reserves estimated at 1.4 billion tons in Wenshui County in the Shanxi Province of Northern China. Along with China's other large coal reserves, this illustrates that developing coal-based liquid fuel and chemicals is more a strategic issue for the Chinese government due to their reluctance to become more reliant upon imported oil. With crude oil imports exceeding 100 million tons per year and growing, the Chinese government is trying to find ways to lower imports in China's energy mix.

As recommended by the Task Force on Energy Strategies and Technologies, "*Modernization of coal is a large and necessary component of energy systems that satisfy the Three E's (Economic development, Energy security, and Environmental protection) for China's sustainable development. Modernization of coal refers to the use of gasification technology to produce synthetic gas for power, clean fuels for transportation and cooking, and heat for both domestic and industrial heating applications, to replace coal combustion technology and oil imports. This strategy is based on technologies that are mostly known and proven, many of which are already in use in China, largely in the chemicals sector. What is needed for successful implementation is to promote the integration of, and investment in, those technologies rather than the development of many new ones. Investments in new capacity should be directed to gasification-based systems, with an emphasis on co-production of multiple energy carriers and often chemicals as well at the same site, i.e., polygeneration. A flexible and adaptive strategy needs to be implemented step-by-step.*"

For China, there are several reasons for polygeneration from coal to be successful:

- Infrastructure Availability – Existing means are in place for distribution of coal by rail and barge, as well as via mine-mouth utilization
- Cost Advantage/Stability – Coal costs less than other hydrocarbon fuels/feedstocks and has a long history of being less volatile in price. For example, steaming coal at $0.75 - $1.75 per million Btu compares favorably with natural gas at $5.00 - $10.00 per million Btu in many global markets over the last few years.
- Diversity – Utilization of coal can insulate sectors and economies against the price and availability shock potential of oil and natural gas

Recently in China, a project has been funded by the U.S. Trade and Development Agency (USTDA) with the goal of testing the feasibility of building a new polygeneration plant. This project involves Hunnan International Technopolis Shenyang, where the company is looking into the economic parameters and technology options for the establishment of coal gasification, garbage gasification, methanol synthesis, and conversion processes for polygeneration plants.

Likewise, there are multiple reasons for the choice of gasification (ICL) as the means to utilize coal, compared to its direct use as a combustion fuel, including environmental, current and improving cost competitiveness, and feedstock flexibility (gasifiers can operate on a wide variety of feedstocks).

7.6.2 Technology Vendor News

There have been significant developments in the last few years regarding interest in gasification technologies and projects. A sample of pertinent events and news items is as follows:

- In 2004 GE Energy acquired ChevronTexaco's gasification technology, which had been licensed for use in the chemicals, electric power and hydrogen producing industries for more than 50 years. In acquiring ChevronTexaco's coal gasification technology business, GE Energy broadens its gasification plant offerings and expands its ability to provide coal-fired generation that produces fewer air pollutants than conventional coal combustion. Continuing its focus in this area, GE, one of the leading gasification licensors, is actively working on a "reference" plant IGCC engineering package to offer to prospective buyers.

- In May, 2004, ConocoPhillips announced the signing of a worldwide alliance agreement with Fluor to facilitate the development, design and construction of new projects utilizing its E-Gas technology. Through the alliance, ConocoPhillips and Fluor are partnering to provide project development and turnkey support for engineering, procurement, construction, operation and maintenance for solid fuel gasification facilities in both the chemical and energy segments.
- Royal Dutch Shell continues to be very active in coal technologies with numerous projects in China. Also, in mid-2006, Shell teamed up with the Anglo American mining firm to develop and exploit clean coal technologies, such as at Anglo's Monash project in Australia, in which their plan is to use drying and gasification technologies to produce synthetic diesel fuel from brown coal.
- Industry participants are working on a "user design basis specification" for IGCC plants (based on the three entrained-flow technology vendors – Shell, ConocoPhillips and GE, as well as KBR's "transport" gasifier).
- Lurgi continues to be active in gasification technology, and has reportedly over 100 of its gasifiers operating worldwide, with numerous new projects under development. (Lurgi is said to have the historical distinction of having the first recorded known patent for gasification, in 1887).

7.6.3 U.S. News and Events

7.6.3.1 FutureGen

In December 2005, the U.S. Department of Energy (DOE) announced an agreement with a coal and energy industry consortium to build a $1 billion clean-coal power plant that will reduce pressure on natural gas consumption.

DOE approved FutureGen Industrial Alliance plans for development and construction of a 275 MW power plant that will implement coal gasification technology to convert coal into highly enriched hydrogen gas, which will in turn be burned in the plant to generate electricity.

Under this agreement, the FutureGen group of eight US, Australian and Chinese companies will contribute $250 million to the project with the U.S. government funding the rest of the balance. Once it is demonstrated that the process is viable, future projects heading towards commercialization will commence.

More recently in May 2006, it was announced that twelve potential sites are being considered by the FutureGen Alliance for the first $1 billion FutureGen coal gasification project. Due for commissioning in 2012, the power plant will be designed to generate electricity, hydrogen, and chemical feedstocks from coal. To deal with the environmental issues, FutureGen Alliance claims that initially as high as 90 percent of the entire carbon dioxide obtained from the plant will be captured. Additionally, they claim that air pollutants will be almost totally eliminated and solid wastes will be able to be converted to functional commercial products. The final site out of the twelve will be chosen in autumn of 2007. There has also been interest expressed from Eastman Chemical and Sasol to participate in polygeneration projects.

7.6.3.2 Rentech

Also in May 2006, Rentech Inc. announced that it has completed the purchase of Royster-Clark Nitrogen Inc. from Royster-Clark Inc., a wholly owned subsidiary of Agrium Inc., for approximately $70 million. This purchase includes an 830 tonnes/day ammonia fertilizer facility located in East Dubuque, IL, inventories of the plant, and working capital. Rentech has plans to replace REMC's natural gas fed ammonia fertilizer plant with a poly-generation facility using clean coal gasification technology to produce Rentech's ultra-clean diesel fuel, fertilizer and electricity from coal. Upon completion, Rentech's plant will be the first commercial scale application of Rentech's proprietary process to produce ultra clean fuels in the United States.

The facility will be converted in phases taking approximately three to four years and about $800 million to complete. Because the facility is designed to be replicable and scalable, Rentech plans to develop multiple future CTL sites to initiate domestic CTL commercialization.

7.6.3.3 U.S. DOE Loan Guarantees

In August 2006, the U.S. DOE published policy guidelines that DOE intends to use with the first solicitation of proposals for loan guarantees for Eligible Projects under Title XVII of the Energy Policy Act of 2005. Polygeneration from Coal appears applicable to a number of the ten "eligible" project categories, such as advanced fossil energy technology, carbon capture technologies, efficient electrical power generation, and pollution control equipment.

7.6.3.4 Xcel Energy

In August 2006, Xcel Energy announced it has committed $3.5 million for preliminary development of a new coal-based IGCC power plant in Colorado, and capturing the carbon dioxide and injecting it underground for permanent sequestration.

7.6.3.5 Illinois State Plan

In August 2006, Governor Rod Blogajevich announced a long-term energy plan for Illinois. The plan includes building up to ten new coal gasification plants, essentially for polygeneration, and also a plan for carbon capture and sequestration.

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