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Economics of Natural Gas Upgrading

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ABSTRACT

Economics of Natural Gas Upgrading

Natural gas could be an important alternative energy source in meeting some of the market demand presently met by liquid products from crude oil. This study was initiated to analyze three energy markets to determine if greater use could be made of natural gas or natural gas derived products and if those products could be provided on an economically competitive basis. The three markets targeted for possible increases in gas use were motor fuels, power generation, and the chemical feedstocks market.

The economics of processes to convert natural gas to transportation fuels, chemical products, and power were analyzed. The economic analysis was accomplished by drawing on a variety of detailed economic studies, updating them and bringing the results to a common basis. The processes analyzed included production of methanol, MTBE, higher alcohols, gasoline, CNG, and LNG for the transportation market. Production and use of methanol and ammonia in the chemical feedstock market and use of natural gas for power generation were also assessed. Use of both high and low quality gas as a process feed stream was evaluated. The analysis also explored the impact of various gas price growth rates and process facility locations, including remote gas areas. In assessing the transportation fuels market the analysis examined production and use of both conventional and new alternative motor fuels.

OBJECTIVES

During the past decade, a gas supply surplus has existed in the United States. Future gas supply prospects have also brightened because the estimates of the potential size of undiscovered gas reserves has increased. At the same time, U.S. oil reserves and production have steadily declined and oil imports have steadily increased.

Reducing the growth in the volume of crude oil imports was an important objective of the Energy Policy Act of 1992. Natural gas could be an important alternative energy source in meeting some of the market demand presently met by liquid products from crude oil. This study was initiated to analyze three energy markets to determine if greater use could be made of natural gas or natural gas derived products and if those products could be provided on an economically competitive basis. In particular, the following three markets were targeted for possible increases in gas use:

- Transportation fuels
- Power generation
- Chemical feedstock

Gas-derived products that could potentially compete in these three markets were identified and the economics of the processes for producing those products were evaluated. The processes considered covered the range from commercial processes to those in early stages of process development. The analysis also evaluated the use of both high quality natural gas and lower quality gases containing CO_2 and N_2 levels above normal pipeline quality standards.

Analysis of Gas Derived Products in Transportation Fuels Markets

Three types of products can be produced from natural gas for use in the transportation fuels market (Exhibit 1). Natural gas is currently used in the production of MTBE, ether which is used in gasoline production both because of its high octane properties and to meet the CAA oxygen content standard required in about 1/3 of the U.S. market. There are other ethers and alcohols that could also potentially be produced from natural gas and compete in the oxygenated gasoline market. While oxygenates command a price premium compared with other gasoline components, the volumes required are limited by octane need and oxygen content requirement as specified by environmental regulations.

Natural gas can also be used to produce synthetic gasoline and diesel. In this instance the issue is the price competitiveness of gas derived gasoline and diesel vs crude oil derived products.

The final avenue of access is production of alternative transportation fuels -- primarily methanol and CNG. Even if the alternative transportation fuels can be produced at a competitive price to gasoline and diesel fuel, they face major hurdles in gaining entry and acceptance in that market. The hurdles that a new fuel faces in establishing a position in the transportation fuels market are summarized in Exhibit 2.

Ideally for most efficient operation, an alternative-fueled vehicle would be an original equipment vehicle/engine system optimized to use the specific fuel. Sometimes in the transition period when the use of the fuel is being established, existing gasoline or diesel vehicles can be converted to use an alternative fuel such as methanol or CNG. Vehicles can also be designed to use either of two fuels (bi-fueled) or a combination (flexible-fueled). These types of vehicles are designed to help the user cope with the problem of finding fuel while the distribution network and number of refueling locations for the alternative fuel is growing.

Exhibit 1
Assessing Increased Use of Gas in the Transportation Fuels Market

TYPE OF FUEL	GAS DERIVED PRODUCTS	MARKET PENETRATION	MARKET SIZE
GASOLINE BLEND COMPONENTS	MTBE OTHER ETHERS ALCOHOLS	EASY	LIMITED BY NEED FOR OXYGENATES
GASOLINE AND DIESEL	SYNTHESIZED GASOLINE & DIESEL	EASY IF PRICE IS COMPETITIVE	LARGE
ALTERNATIVE TRANSPORTATION FUELS	METHANOL CNG	DIFFICULT	LARGE BUT HARD TO PENETRATE

Exhibit 2
Market Penetration Hurdles for Alternative Transportation Fuels

- **Building a Customer Base of Vehicles Which Can Use the Fuel**
- **Developing Infrastructure of Delivery and Refueling Facilities**
- **Gaining Consumer Acceptance of Fuel/Vehicle Systems**
  - **Cost: Vehicle cost, fuel cost, maintenance and repair cost**
  - **Convenience: Fuel availability, refueling time, refueling frequency**
  - **Performance: Start reliability, no stalling, power**
  - **Safety Perception: As safe or safer than current vehicles**

Finally, a new fuel must gain consumer acceptance, which depends on how the consumer assesses the economics, convenience, performance, safety and other factors in choosing to purchase an alternative - fuel vehicle versus a conventional fuel vehicle.

As shown in Exhibit 3, the process routes from natural gas to transportation fuels involve commercial processes such as methanol and MTBE and some processes in the research phase such as production of gasoline or diesel by direct conversion processes such as oxidative coupling or oxyhydrochlorination.

Economic Evaluation of Gas to Transportation Fuel Conversion Processes

Data was taken from a variety of previous economic studies to develop the evaluation of the natural gas to transportation fuel economics presented in this study. Only Fischer-Tropsch and oxidative coupling economic data were available from a common source. Since each source of data used somewhat different factors for determining total capital and total operating and maintenance costs, it was decided to accept certain basic data from the economic sources and calculate the rest of the economics using a consistent methodology. All cost were escalated to December 1993 using Nelson-Farrar Indexes reported in the "Oil and Gas Journal".

The current and future prices of natural gas and crude oil in the US are obviously important variables in assessing the economic competitiveness of transportation fuels derived from these two feedstocks. While US gas suppliers have been exceeding needs for the past decade and US crude production has been declining annually, most forecasts of future US energy prices predict a higher growth rate for gas prices compared to crude prices (Exhibit 4). Forecasters see US crude prices as being set in the international crude market, where surplus production capability has existed since the early 1980's. Gas prices in the US are determined in the regional North American market and are based on assessments of the economics of continuing to add future reserves. The assumption of a higher future gas price growth rate makes it more difficult for a process using a gas feed to be economically attractive versus a process using a crude feed. In their most recent energy price forecast, GRI lowered their projection of future gas prices. The GRI forecast was used as a sensitivity case in this analysis.

A summary of the economic analysis of conversion of natural gas to transportation fuels is shown in Exhibit 5. Conversion of natural gas to methanol and MTBE are commercial processes, a number of facilities have been built and are producing and selling a product into the market place at a competitive price. The cost of producing MTBE from natural gas and n-butane was evaluated and estimated to be 86 cents per gallon. Analysis of the gasoline market indicates that MTBE can command a price premium of 30-40 cents per gallon over refinery gasoline gate prices. Thus, MTBE is clearly commercially viable at current gasoline prices and should continue to be competitive in the future.

The economic analysis indicates that methanol can be produced from lower 48 U.S. gas at 44 cents per gallon (cpg). Viewing methanol as an alternative transportation fuel, the 44 cpg must be translated to equivalent gasoline basis, accounting for energy density and efficiency differences. On a gasoline-equivalent basis, methanol would be 74 cpg at the plant gate versus 68 cpg for gasoline. This is not a large differential but development of distribution and refueling infrastructure and

Exhibit 3
Natural Gas Conversion Processes

Conversion Processes to Transportation Fuels - Syngas - Methanol - Direct conversion - Compression
Commercial Scale Plants Operating - MTBE (via Methanol) - Methanol (via Syngas)
Developing Processes - Fischer-Tropsch
Research Processes - Oxidative Coupling - Higher Alcohols

Exhibit 4
Forecasts of U.S. Oil and Natural Gas Prices
(Prices in 1994$)

	PRICE IN			GROWTH RATE
FORECAST	1993	2000	2010	93-2010
1994 DOE OUTLOOK				
GAS ($/MCF)	1.79	2.48	3.56	4.1%
OIL ($/BBL)	18.65	21.25	28.88	2.6%
1995 DOE OUTLOOK				
GAS ($/MCF)	2.02	2.29	3.37	3.1%
OIL ($/BBL)	16.12	19.13	24.12	2.4%
1995 GRI FORECAST				
GAS ($/MCF)	2.06	2.53	2.71	1.6%
OIL ($/BBL)	16.42	18.58	20.54	1.3%

Exhibit 5
Comparative Economics of Gas
To Transportation Fuel Processes

Process	Liquid Phase Methanol	UOP - MTBE	IFP Higher Alcohol	Fischer-Tropsch	Oxidative Coupling	Delivered CNG
Product	Methanol	MTBE	C1-C6 Alcohol	Gasoline or Diesel	Gasoline	CNG
Costs (cpg) Feed	24	51	36	52	52	28
Other Operating	7	17	22	28	43	11
Capital	12	14	43	58	67	6
Total	44	86	120	137	169	48
Equiv. Gasoline (cpg)	74	NA	NA	137	169	48
Competing Fuels	Gasoline	Octane Blend Comp'nts	Gasoline Blend Comp'nts	Gasoline	Gasoline	Deliv'd Gasoline
Competing Fuel Price (cpg)	68	98	68-98	68	68	84

gaining consumer acceptance are major obstacles on the path to commercial success for methanol.

The demonstrated processes are processes which have been built at commercial scale and for which cost and technical feasibility have been demonstrated. Conversion of natural gas to liquids using Fischer-Tropsch is placed in this category. There are no operating Fischer-Tropsch gas-to-liquid plants, but there are commercial Fischer-Tropsch units for converting syngas from coal gasification and there are commercial units for generating syngas from natural gas. The estimated cost of producing liquid fuels from natural gas using a Fischer-Tropsch process is 1.37$/gallon. This is double the current production cost of gasoline. If gas prices rise faster than crude, the gap between cost of producing Fischer-Tropsch liquids and gasoline would only widen. The economic hope for a Fischer-Tropsch process using natural gas may lie with utilizing remote gas resources.

The processes that are in a research and development phase include a process to produce higher alcohols from natural gas and oxidative coupling, a direct methane to gasoline process. Using conversion and selectivity assumptions for oxidative coupling previously used in a Bechtel analysis, the cost of producing a gasoline product would be $1.69/gallon. This cost is far above current gasoline prices. Moreover, review of a variety of oxidative coupling research results indicates that the conversion and selectivity used in the economic analysis is beyond those which have practically been achieved.

Several processes have and continue to be studied to convert natural gas to C_1-C_6 alcohols. In this study, economics were developed for the IFP process and the estimated cost of the product was $1.20/gallon. While the higher alcohols merit a market price premium over gasoline, the IFP alcohol product consists of 50-70% methanol and 16-23% ethanol in the product. Because of such poor selectivity to higher alcohols the process does not look economically attractive. In this process, as in the case of oxidative coupling, the question is, is there sufficient reason to believe that a major process improvement is achievable that can justify further R&D expenditures.

Economics and Use of Gas in Chemical Feestock and Power Generation Markets

The use of natural gas in chemical feedstock and in power generation applications is established. This study has analyzed the market for chemical products to assess demand growth and the potential for increased gas usage. Likewise, the issue of increased natural gas use in the power sector was addressed. In each of these applications, use of low quality natural gas (LQNG) was compared with use of high quality natural gas.

The principal uses of natural gas in the chemical feedstock market are in the production of ammonia, methanol and hydrogen (Exhibit 6). The most promising growth area for increased gas usage is in methanol production. U.S. methanol consumption in 1991 was 1.68 billion gallons and in 1995 it is expected to reach 2.75 billion gallons. This growth is primarily attributable to the increased use of methanol to produce MTBE for use in making oxygenated and reformulated gasoline. The high rate of methanol demand growth will diminish after 1995. Use of methanol as a direct transportation fuel is an uncertain factor in assessing longer term demand growth prospects.

Exhibit 6
Use of Natural Gas as a Chemical Feedstock

% of Total Natural Gas Consumed as Feedstock	Material Produced	Product Use	US Market Growth
60	Ammonia	Fertilizer	Very Low
22	Hydrogen & Other	Oil Refining	Moderate
18	Methanol	Transportation Fuels & Chemicals	High

Ammonia production currently accounts for 60% of the natural gas use as a chemical feedstock. U.S. demand for ammonia, however, has been stagnant and there has been a continuing threat of competition from imports from low gas price regions around the world. There appears to be little chance of ammonia production capacity growth in the U.S. and hence little opportunity for increased natural gas use.

The process economics are summarized in Exhibit 7. As can be seen, using high quality gas, methanol can be produced at a price well below the current market price, but the market is currently very tight. More importantly, future prices are expected to support an acceptable return on investment. On the other hand, ammonia prices, which are currently high, still do not cover the return to capital. Market growth and U.S. facility economics provide a consistently bleak outlook for increasing natural gas use for ammonia production.

Use of gas is increasing as a fuel for power generation due to favorable economics.

Economics of LQNG

In all of these cases, use of low quality natural gas (LQNG) as a feed was compared with the use of high quality gas. The low quality gas considered contained 13% N_2. A high nitrogen gas was analyzed because it is upgrading a low quality natural gas to a high quality gas. In the methanol case, assuming that the methanol product would sell at the same price when using the LQNG feed as when using high quality gas, the value of the LQNG as a feed would be 2.26$/MMBTU compared to 2.43 $/MMBTU for the high quality gas. For the ammonia case, the value is 2.24 $/MMBTU compared to the 2.43 $/MMBTU, and in the combined-cycle case, the LQNG is valued at 2.32 $/MMBTU. That is a range of 11-24 ¢/MMBTU lower value for the LQNG compared to high quality natural gas. Those values compare very favorably to the cost of upgrading the LQNG via nitrogen rejection which would place a value of only 1.71 $/MMBTU on the LQNG. These results make direct use of LQNG appear to be the path to pursue. There is, however, an important element of the economics not considered -- the transportation of LQNG to the production facility, or transport of the product to the customer.

Exhibit 7
Economic Comparison of Natural Gas in
Chemical and Power Processes

Process	Liquid Phase Methanol (LPMEOH)		Ammonia		Combined Cycle		Cryogenic Nitrogen Production
Product	Methanol		Ammonia		Electric Power		High Quality Natural Gas
Type of Natural Gas Feed	High Quality	Low Quality	High Quality	Low Quality	High Quality	Low Quality	Low Quality
Costs ($/per unit product)							
Name of Unit	Gallon	Gallon	Short Ton	Short Ton	kWh	kWh	10^6 Btu
Feed	0.24	0.24	50	46	0.019	0.018	1.58
Other Operating	0.07	0.07	80	83	0.005	0.006	0.31
Capital	0.12	0.12	57	59	0.011	0.012	0.24
TOTAL	0.44	0.44	240	240	0.037	0.037	2.43
Value of Natural Gas Feed, $/$10^6$ Btu	2.43	2.26[1]	2.43	2.24[1]	2.43	2.32[1]	1.71[1]
Market Price Range of Product, 10/93-10/94, $/Unit	0.46 to 1.40		104 to 232		0.046 to 0.052		2.43

[1]Assumes that product will have the same equivalent price as if produced from high quality natural gas.

In the case of power, it is expensive to transport power, if it can not be marketed locally. In the case of ammonia, there is no need for new production facilities. For methanol, the product is needed on the Gulf Coast and little high N_2 gas production is located in that region.

Thus, while the economics for LQNG look favorable, there are limited opportunities because of market and production facilities locations.

Improving Process Economics and Market Potential

The economic analysis serves two purposes. First, it provides, as we have seen, the relative cost of providing products using competing process options. Secondly, it establishes sensitivity of the production costs to changes in the cost of feed, reductions in capital cost, or improvements in conversion rates or selectivity.

Some of the sensitivity analysis cases for Fischer-Tropsch (FT) are displayed in Exhibit 8. The exhibit shows that use of a slurry reactor reduces product cost 2$/Bbl. The GRI price growth vs the DOE price forecast would reduce the initial product cost by 4.60 $/Bbl. Large differences are achieved if the technology is employed in a remote gas area where facility construction cost are comparable to the US. With gas prices at 50 ¢/MMBTU product could be produced at 36 $/Bbl and, if plant size were scaled up 4 times, then price could be reduced to 25 $/Bbl.

The indirect conversion processes, such as FT and methanol production are high capital cost processes compared to crude oil conversion processes and as shown in Exhibit 9, the syngas generation step represents 70% of the facility cost. Thus, if improvement could be found in this step, the impact would be significant. While syngas production is viewed as an established process, there are still opportunities for new approaches such as membrane reactor systems.

In the case of the direct conversion processes, poor conversion and selectivity have been the barrier to achieving competitive process schemes. For these processes, marginal improvement will not suffice, new concepts with the <u>potential</u> to break through the yield barriers are needed if these processes are to achieve eventual success.

Summary

Achieving greater use of natural gas as an alternative transportation fuel is an uncertain prospect. The US government has set a target of displacing 30 percent of the crude derived fuels for light duty vehicle with non-crude-derived by 2010. CNG has very attractive economics as we have seen but the potential growth on new motor vehicles to 30% faces both political uncertainties in terms of long term commitment to this case and also the obstacles of developing a delivery system infrastructure, refueling technology, refueling outlets, and final consumer acceptance.

Those who deal with the "dismal science" of economics are often viewed as negative people, more focused on the pitfalls, than on the promises. Clearly, the objective of this effort was to provide insights into the more promising vs the less promising in allocating our R&D dollar and efforts. I do hope that we have achieved some degree of success in meeting that objective.

Exhibit 8
Fischer-Tropsch Process Economics Sensitivity Analysis

CASE	SYNGAS PROCESS	TYPE FT REACTOR	PLANT LOCATION	CAPACITY MB/D	GAS PRICE: $/MMBTU		UNIT COST OF PRODUCT: $/BARREL			
					INITIAL	GWTH RATE	FEED	O&M	CAP CHRG	PLT GATE
1	PARTIAL OXIDATION	ARGE FIXED-BED	GULF COAST	14,500	2.43	3.1	21.68	11.91	24.53	59.61
2	PARTIAL OXIDATION	FT SLURRY	GULF COAST	14,500	2.43	3.1	20.92	11.88	22.56	56.84
3	PARTIAL OXIDATION	FT SLURRY	GULF COAST	14,500	2.43	1.6	20.92	11.88	22.56	54.04
4	PARTIAL OXIDATION	FOUR RX SLURRY	GULF COAST	58,000	2.43	3.1	20.92	7.47	15.05	45.67
5	PARTIAL OXIDATION	FT SLURRY	ASIA	14,500	0.50	0	4.30	11.88	22.07	35.95
6	PARTIAL OXIDATION	FT SLURRY	ASIA	14,500	0.00	0	0.00	11.88	21.94	31.81
7	PARTIAL OXIDATION	FT SLURRY	ASIA	58,000	0.50	0	4.30	11.88	14.86	25.03

Exhibit 9

LPMEOH Process

PROCESS STEPS

- **Production of synthesis gas**
- **Methanol synthesis in a three stage reactor (1600 psia, 482°F)**
- **Thermal efficiency approximately 64%**

ECONOMICS

	$/Bbl Methanol	
Natural Gas Feed	10.08	
Maintenance	2.74	
Capital Charge	4.91	
Total	18.65	44 cpg

STATUS

- **Commercial process - mature**

POTENTIAL FOR IMPROVEMENT

- **Syngas step is 70% of capital cost**
- **Significant cost reduction unlikely**
- **Production cost tied to gas prices**