4. Natural Gas Market Analysis--Use as a Chemical Feedstock

This section discusses the use of the methane component of natural gas as a chemical feedstock. In Section 2.2 of this report, it was stated that about 92% of the gas used in the industrial sector is for fuel and power and the remaining 8% of the gas consumption is used for process feedstocks. Since 42% of natural gas is consumed in the industrial sector, then natural gas consumption for chemical feedstocks would represent 3.5% of total natural gas consumption. Natural gas is used as a feedstock to produce ammonia, methanol, and hydrogen and other. The percent of total natural gas consumed as process feedstock for these materials is 60, 22, and 18, respectively. [23]

The market for ammonia, methanol and hydrogen is discussed. Additionally, the ethylene and light olefin market is described as a market where methane could be consumed depending on the success of technologies described in Section 9.5.

4.1. Ammonia

Ammonia is the basic intermediate for all nitrogen fertilizers. Ammonia is produced by the reaction of hydrogen with nitrogen. The hydrogen for the process is produced by reforming natural gas. The uses of ammonia are shown in Exhibit 4-1. As shown, 80% of the ammonia goes to the production of nitrogen fertilizers.

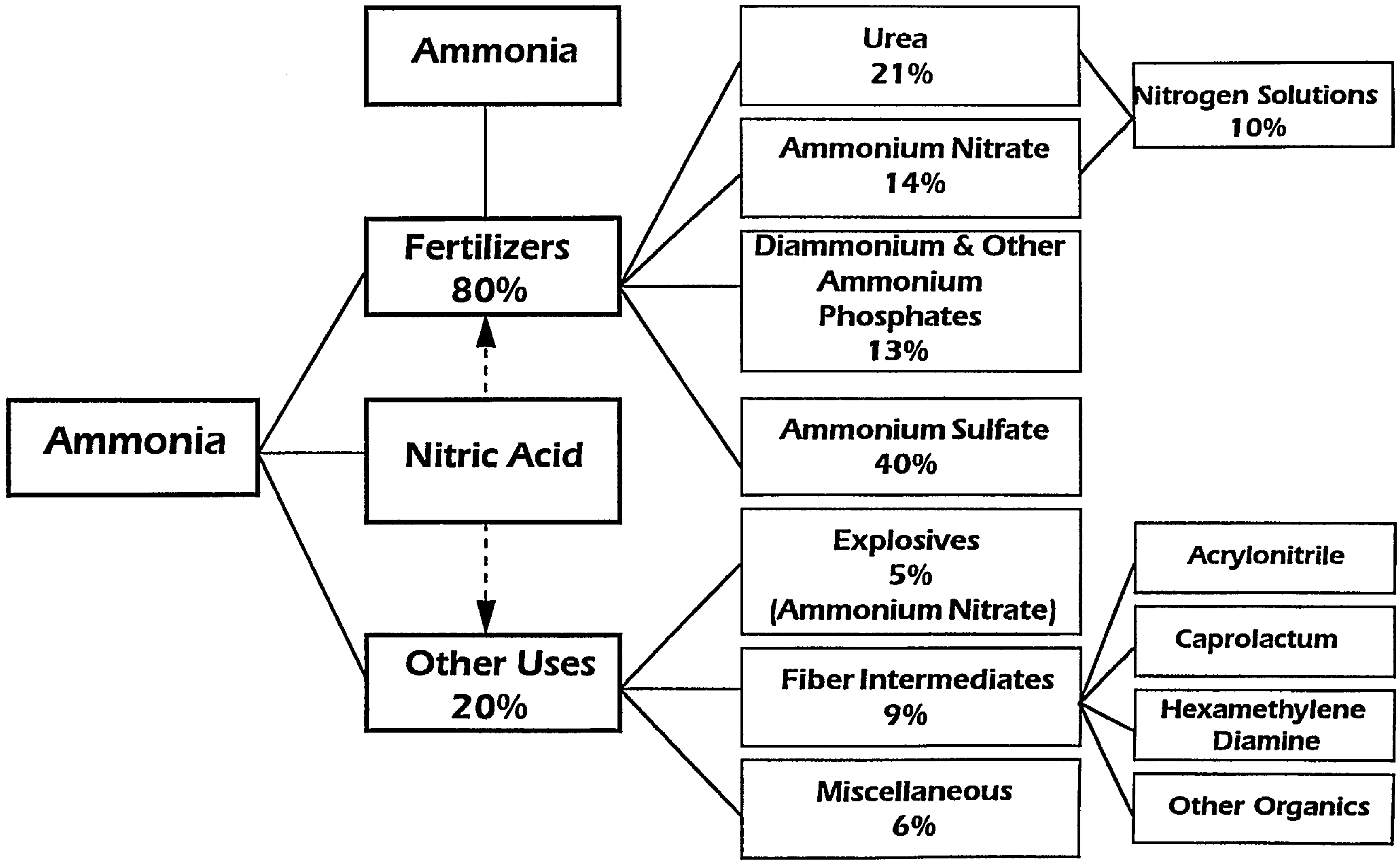
In the U.S., ammonia consumption has been stagnant and production capacity has been in decline; some older facilities have been shut down and a recent report [24] indicated that "In the last five years alone, an estimated 2 million to 3 million tons of capacity have been taken out of service, and the scaled-down ammonia facilities left in the U.S. are running at 3.5 percent over capacity".

Recently, ammonia prices have been very strong but there is little expectation that high prices will be sustained or lead to capacity and production expansion in the U.S. Ammonia is viewed as a very mature business with imports posing a strong competitor threat to domestic producers. An ADL Report [25] stated that:

> "The United States is one of the few major countries in the world with no import duties or other import restrictions on fertilizers and fertilizer raw materials. It has therefore, been a prime target market for nitrogen exporters, including Trinidad, Venezuela, the Soviet Union and Eastern Europe."

While ammonia plants are not being built, there may be some limited opportunities for LQNG use. Ammonia plants are a little less concentrated on the Gulf Coast than much of the petrochemical industry. Still the needed coincidence of LQNG production and ammonia production facilities will be quite limiting.

EXHIBIT 4-1
Use of Ammonia



Source: "The Role of Natural Gas in the Chemical Process Industry: Implications for the Future V.2", Mark L. Kesler and Barbara Ex, ADL for GRI, Dec. 1990 GRI - 90/0261.1

4.2. Methanol

Methanol is used in the production of a number of chemicals and is also used both directly and indirectly as a transportation fuel. The consumption is broken down by use in Exhibit 4-2. As is shown, the largest use of methanol is in the production of the fuel oxygenate MTBE. Use of methanol in fuel oxygenate production is also the area of major growth for methanol. As shown in Exhibit 4-2, the forecast is for U.S. methanol consumption in the year 2000 to be almost double the 1990 volume. Much of this growth is attributable to growth in MTBE production in the U.S.

The largest chemical use of methanol is in the production of formaldehyde which is primarily used in producing construction material such as foam insulation and as a resin binder for plywood and composition board. Use would normally be expected to increase with growth of the construction segment of the economy but concerns about reputed carcinogenicity has cast a shadow over growth in the use of formaldehydes. Acetic acid is the second largest chemical use. It is used in the making of paints, adhesives, coatings and other products. Demand is expected to increase at about 1.5% per year.

As shown below PACE [23] reports that the use of methanol to produce MTBE in 1991 was 489 million gallons. For the year 1994, the estimate is 857 million gallons. This represents a healthy growth rate of over 20% per year. But with the increased use of MTBE required to produce the reformulated gasoline which must be provided to about one third of the U.S. gasoline market, methanol consumption is estimated to jump to 1513 million gallons in 1995. U.S. methanol demand for MTBE production is expected to level off and future growth in the U.S. will depend on possible expansion of the reformulated gasoline program.

U.S. METHANOL CONSUMPTION FOR MTBE PRODUCTION						
YEAR	1991	1992	1993	1994	1995	1996
VOLUME	489	560	772	857	1513	1650

The U.S. is now experiencing an unusual growth period for methanol. This year will have seen the conversion of two ammonia plants into methanol plants. Terra Industries converted a 400 ton/day ammonia plant at Woodward, OK to a 130,000 Mt/year methanol plant and Cytec Industries converted an ammonia plant at Fortier, LA to a 570,000 Mt/year methanol plant [26]. But most dramatic has been the increase in methanol prices. In March, methanol was selling for about 55 cents per gallon, then the price began to increase at about 10 cpg each month and was about 1.30 $/gallon at the end of September.

Current methanol prices demonstrate that prices can represent an incentive for capacity growth. There is little doubt that methanol price will fall back as the tight supply situation eases. The compelling question relevant to this analysis is future methanol demand growth and domestic production that will utilize greater quantities of U.S. gas production. The growth propelled by the rapid increase in MTBE use will not continue. Methanol used directly as a transportation fuel could bring significant growth in the future but that is both starting from a very low base volume and has all the uncertainties associated

Exhibit 4-2. U.S. Methanol Supply/Demand (million gallons)

YEAR	CONSUMPTION	NET IMPORTS	PRODUCTION	CAPACITY	PRICE cpg
1981	1168	-100	1268	1522	65.4
1982	982	-115	1097	1872	52.3
1983	1146	5	1005	1870	45.1
1984	1386	151	1235	1235	40.2
1985	1377	347	1030	1185	41
1986	1428	341	1087	1140	31.4
1987	1512	375	1137	1040	32.5
1988	1765	657	1108	1255	56.6
1989	1637	397	1240	1460	43.7
1990	1586	328	1258	1480	40.6
1991	1675	362	1313	1492	51.9
1992	1721	437	1323	1570	37.6
1993	1766	398	1670	1689	40.8
1994	2050	465	1941	1954	
1995	2747	769	1978	2197	
1996	2906	591	2315	2572	
1997	2929	614	2315	2572	
1998	2952	637	2315	2572	
1999	2977	662	2315	2572	
2000	3006	691	2315	2572	

Source: Pace Petrochemical Service

Exhibit 4-2. Continued.

METHANOL USE FOR FUEL AND CHEMICAL FEEDSTOCK				
FUELS/CHEMICALS	**1991**		**1995**	
	MM Gals	**Vol %**	**MM Gals**	**Vol %**
FUELS				
MTBE/TAME	489	29.2	1513	55.1
DIRECT FUEL	56	3.3	60	2.2
SUBTOTAL FUELS	545	32.5	1573	57.3
CHEMICALS				
FORMALDEHYDE	430	25.7	493	17.9
ACETIC ACID	213	12.7	222	8.1
OTHER CHEMICALS				
DIMETHYL TEREPHTHALATE	34	2.0	38	1.4
METHYL AMINES	37	2.2	38	1.4
METHYL CHLORIDE	59	3.5	57	2.1
METHYLENE CHLORIDE & CHLOROFORM	36	2.1	37	1.3
METHYL METHACRYLATE	63	3.8	68	2.5
MISC	259	15.5	221	8.0
SUBTOTAL OTHER CHEMICALS	488	29.1	459	16.7
TOTAL CHEMICALS	1131	67.5	1174	42.7
TOTAL CONSUMPTION	1676		2747	

Source: *Pace Petrochemical Service*

with a new product gaining a successful position in an established market. A 3% U.S. methanol growth rate is estimated between 1995 and 2005 assuming expansion of RFG usage and favorable growth in direct fuel use.

Future gas use for methanol production in the U.S. also depends on whether U.S. methanol demand is satisfied by increasing domestic production or by increasing imports. Those considering new domestic production facilities are concerned about the threat of foreign competition from potential new methanol production in remote areas with little local gas demand and hence low market value gas as a feedstock. During the past decade in which natural gas prices have stagnated, expansion of methanol capacity in the U.S. has occurred. In the next decade, methanol capacity expansion will be based on assessments of demand growth, gas price growth rates, and the impact of foreign competition -- all of which have considerable uncertainties.

4.3. Ethylene

Ethylene is the largest-volume chemical of the entire petrochemical industry. In 1993, U.S. ethylene consumption was about 42 billion pounds compared to 12 billion pounds of methanol. Ethylene is the most basic building block of the chemical industry and is used in the production of a vast array of chemical products. The production of plastics represents the largest use of ethylene accounting for about 70% of ethylene consumption.

Historic and forecast ethylene consumption estimates are shown in Exhibit 4-3. During the 1980's decade, ethylene consumption grew at over 3% per year. From 1993 to 2003, consumption growth is forecast to be 2.2% per year.

Natural gas liquids, which are part of natural gas production are the largest components of ethylene feedstock. Currently, there is no use of methane in ethylene production; however, several gas conversion technologies now in R&D stage are exploring way of using methane as a feedstock for ethylene production (See Section 9.5).

Currently, about 50% of the ethylene is produced using ethane as a feedstock, about 20% is produced from propane and 7% from butane. The other 23% is produced using naphtha and gas oil fractions derived from the refining of crude oil. Virtually all of the ethane produced in natural gas processing goes to the production of ethylene and about one third of the propane is used in ethylene production.

Converting ethane and propane to ethylene is a less difficult conversion than conversion of methane to ethylene. But since propane is more expensive than methane on a per BTU basis, it is possible for methane to be cost competitive at a lower conversion level. The economics in Section 9.5 indicates that methane-to-ethylene conversion economics show some promise.

Exhibit 4-3. U.S. Ethylene Supply/Demand (million pounds)

YEAR	CONSUMPTION*	PRODUCTION	CAPACITY
1981	28,378	29,418	41,115
1982	27,473	24,501	39,140
1983	29,151	28,677	37,355
1984	30,809	31,383	35,280
1985	30,862	29,847	33,150
1986	31,897	32,859	35,055
1987	33,907	34,951	35,655
1988	36,516	37,204	37,255
1989	35,104	34,947	39,485
1990	38,337	37,474	41,585
1991	40,328	38,938	44,565
1992	41,221	41,254	46,215
1993	41,819	41,907	47,890
FORECAST			
1994	43,004	43,004	50,190
1995	43,791	43,791	50,690
1996	44,675	44,675	50,690
1997	45,780	45,780	50,690
1998	46,800	46,800	50,690
1999	48,021	48,021	50,690
2000	49,243	49,243	50,690
2001	50,300	50,300	50,690
2002	51,063	51,063	51,690
2003	52,164	52,164	53,690

Source: *Pace Petrochemical Service - 1993 Annual Issue*

5. Natural Gas Market Analysis--Use in Power Generation

Based on surveys by DOE and Power Engineering [27], about half of the planned new electric generating facilities are expected to be gas fired, primarily combined-cycle plants. These units are more efficient, less capital intensive, available in a range of capacities, and can be constructed more quickly than coal or oil fired units. Approximately 60% of the planned capacity additions from 1995 to 2000 are expected to be gas fired, and gas share of generation fuel will increase from 10 to 13% from 1993 to 2000 [28].

DOE's forecast of fuel use by utilities is shown below.

Fuel Use for Electric Generation (QBTU/yr)

Electric Utilities*	1990	1992	2000	2005	2010	Annual Growth 1990-2010 (%)	Annual Growth 1992-2010 (%)
Distillate Fuel	0.02	0.03	0.08	0.13	0.11	7.7	8.4
Residual Fuel	1.23	0.90	0.93	0.97	0.81	-2.1	-0.6
Natural Gas	2.88	2.86	4.36	5.24	5.10	2.9	3.3
Steam Coal	16.10	16.30	17.49	18.05	19.93	1.1	1.1
Nuclear Power	6.20	6.40	7.21	7.30	6.57	0.3	0.1
Renewable Energy/Other	3.64	3.20	4.23	4.55	5.21	1.8	2.7
Total	**30.07**	**29.69**	**34.30**	**36.24**	**37.74**	**1.1**	**1.3**

Source: *Energy Information Administration/Annual Energy Outlook 1994*

As shown, electricity generation represents an area for increased gas usage. In the economic analysis of Section 9.3, the economics of using both high and low quality natural gas are analyzed. There will be many more opportunities for high quality gas than for LQNG. The new planned gas generating facilities are located at diverse locations around the United States. High quality gas is available at many of these locations because of the gas pipeline distribution system. LQNG is only available in areas close to the LQNG production locations.

6. Process Routes from Natural Gas to Transportation Fuels, Chemical Feedstocks, and Utility Fuel

The U.S. makes good use of its abundant natural gas resources for residential heating, commercial and industrial energy requirements and power generation. However, there is a substantial untapped role for natural gas in the form of conversion to transportation fuels. This is particularly important in overcoming our increasing dependency on foreign energy supplies for transportation fuels.

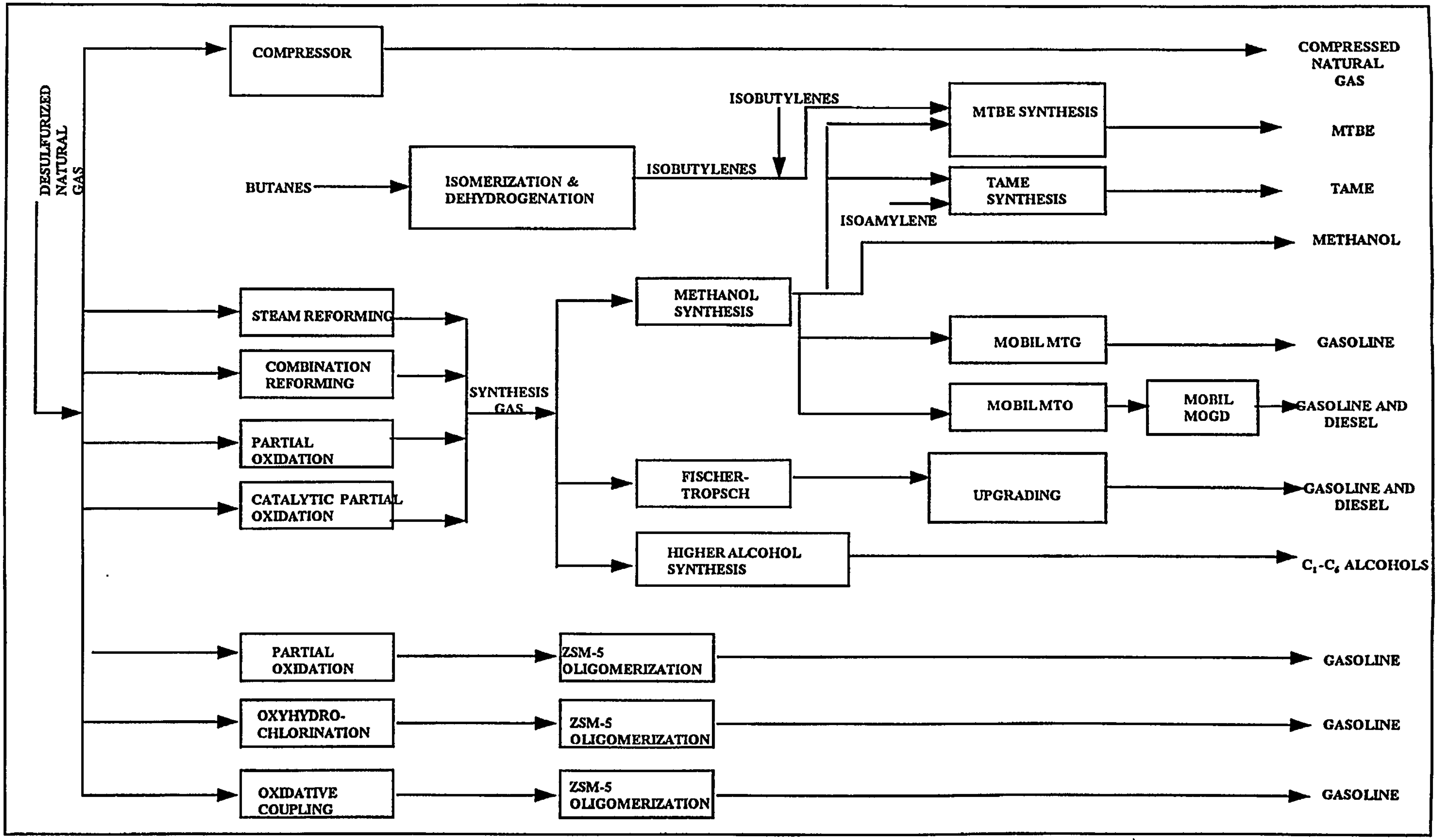
Exhibit 6-1 gives an overview of the major routes for converting natural gas to transportation fuels. Natural gas can either be: a) converted to synthesis gas (a mixture of CO and H_2), which is then converted to a variety of liquid fuels, or b) reacted directly to produce other intermediates which in turn are converted to liquid fuels or c) used directly in a vehicle as compressed natural gas or liquified natural gas.

A fundamental problem in converting natural gas to other commercial products is the chemical stability of the methane molecule. The bonds in methane are among the most unreactive of any of the hydrocarbons. Reactions that convert methane to other chemical forms are usually irreversible and difficult to control. For example, combustion or complete oxidation gives CO_2 and H_2O, neither of which can be used as a fuel. Therefore, a widely practiced means of utilizing natural gas has been to convert it to synthesis gas by steam reforming. The intermediate CO + H_2 syngas mixture in turn is used to synthesize liquid fuel products.

The fuels which can be made from natural gas include gasoline, diesel oil, oxygenates, methanol, LNG and CNG. The most prominent examples of oxygenates are methyl tertiary butyl ether (MTBE), tertiary amyl methyl ether (TAME) and C_1-C_6 alcohols. Recent work has also shown that dimethyl ether can be used as a diesel fuel.

Some of the routes to transportation fuels have been commercialized. Methanol is being made from synthesis gas commercially by methods such as the ICI and Lurgi processes. Gasoline has been produced commercially from synthesis gas by the Fischer-Tropsch process. A newer scheme, also operated commercially, is the conversion of methanol to gasoline (MTG). A similar process converts methanol to olefin (MTO) and then to gasoline and diesel oil (MOGD). Both MTG and MTO/MOGD processes have been developed by Mobil using a unique ZSM-5 zeolitic catalyst.

EXHIBIT 6-1
CONVERSION OF NATURAL GAS TO TRANSPORTATION FUELS



The development and commercialization of the MTG and Fischer-Tropsch processes represent major breakthroughs in synthetic fuels technology. However, both of these routes depend on manufacture of synthesis gas, which is inherently the most costly step in these processes from the standpoint of both capital and fuel requirements.

Other commercial processes have been developed to manufacture MTBE and TAME from methanol and C_4 or C_5 hydrocarbons. Natural gas is also used commercially in buses or trucks in the form of compressed gas (CNG) or liquified natural gas (LNG).

A significant portion of the current gas-to-liquids research program emphasizes direct conversion of methane to intermediates which in turn can be converted to liquid fuels, thus bypassing the conventional synthesis gas step. Processes concerned with the newer approach use partial oxidation, oxyhydrochlorination, or oxidative coupling to break the carbon/hydrogen bonds in methane and produce reactive intermediates. These processes are in various stages of research and development.

Although steam reforming is commonly used for making synthesis gas, other methods, such as partial oxidation and combination reforming are being explored. Likewise, other methods of making methanol such as the liquid-phase methanol process (LPMEOH) have been given serious consideration. In the Fischer-Tropsch area the use of the slurry reactor has been the subject of research as an alternative to the commercial methods used in South Africa. The processes developed by various companies for producing C_1-C_6 alcohols are still in the developmental stage and have not reached full commercial status.

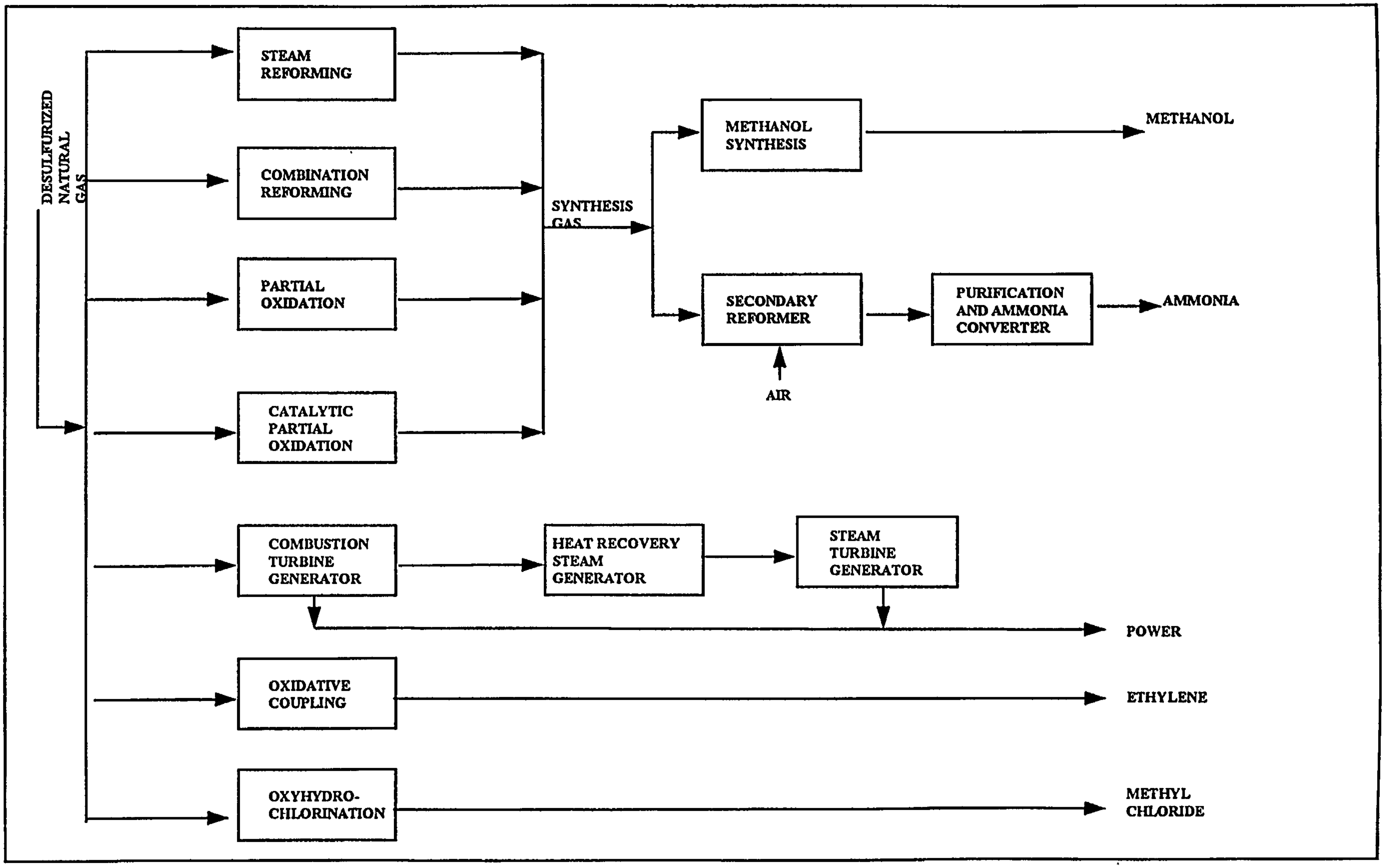
In the following sections, process descriptions, flow diagrams, major reactions, material balances and economics will be given for:

- The liquid-phase methanol process (LPMEOH)
- Fischer-Tropsch process
- Gasoline by oxidative coupling or oxyhydrochlorination of methane and oligomerization
- Higher alcohols by the IFP process
- UOP method of producing MTBE

These processes are chosen for the presentation of process descriptions and economic analysis because (1) their technology was either on the leading edge of process development or are typical of processes for their general category of process, (2) sufficient process descriptions and economic data were available to obtain fairly reliable economics and (3) they permitted good cost comparisons with other process costs and market values.

In addition to using natural gas for making transportation fuels, natural gas may also be used to produce chemical feedstocks and power. Exhibit 6-2 gives an overview of the major routes for converting natural gas to chemical feedstocks and power. The exhibit shows three types of routes: (a) conversion to synthesis gas followed by production of chemical feedstocks; (b) combustion for power production; and (c) reacted directly to produce chemical feedstocks.

EXHIBIT 6-2
CONVERSION OF NATURAL GAS TO CHEMICALS AND POWER



The most prominent chemicals which can be made from natural gas are methanol and ammonia. These have been commercialized using a variety of processes. Both of these processes depend on the production of synthesis gas. The synthesis gas step is the most costly step in the processes. The production of power from natural gas by combusting the gas and using the gas to generate power is widely used commercially.

Research work has been done on the direct conversion of methane to produce chemicals such as ethylene and methyl chloride. Ethylene is made commercially available by the steam cracking of ethane, propane and other hydrocarbons. Direct conversion of methane to ethylene can not compete commercially at this point. Methyl chloride is not useful commercially but could be converted to liquid transportation fuels.

Economics were obtained for a variety of processes using natural gas. Methods of producing chemicals, power and transportation were analyzed. Processes which represented either high volume or potentially high-value uses of natural gas were emphasized. In some of the cases, economics for both high and low quality natural gas (LQNG) feedstocks were included in order to determine the value of the LQNG by calculating the differences in feedstock costs needed to obtain comparable product costs. The cost of upgrading a high nitrogen content, LQNG was determined using a nitrogen rejection process to compare upgrading LQNG to high quality gas with use of LQNG in conversion processes.

Sections describing the economics of producing ethylene and methyl chloride from natural gas were also included. Conversion of natural gas to ethylene is discussed but no economic case analysis is provided.

In the following sections, process descriptions, flow diagrams, major reactions, material balances and economics are provided. The processes included are:

- Production of methanol by the Liquid Phase method using both high-quality and low-quality natural gas as feedstocks

- Production of ammonia using both high-quality and low-quality natural gas as feedstocks

- Production of power with combined cycle technology using both high-quality and low-quality natural gas as feedstocks

- Upgrading of high nitrogen-content natural gas by cryogenic nitrogen rejection

- Literature review on the production of ethylene from natural gas with emphasis on direct conversion processes

- Production of methyl chloride

7. Gas Use in Transportation Fuels--Economic Analysis

7.1. Price Forecast--Transportation Fuels and Components

The economic competitiveness of producing the various transportation fuels in future years will depend on the prices of their feedstocks and the relative price of their products. A price forecast has been developed for feedstocks and transportation fuel products. The forecast has been developed using the crude oil and natural gas price forecast developed by DOE/EIA and published in the "Annual Energy Outlook 1994" [7]. Price forecasts for other individual feedstocks and products were developed by K&M based on the EIA crude and natural gas price paths.

The transportation fuels price forecast is presented in Exhibit 7-1 and is based on the DOE/EIA Reference Case forecast. In the reference case, the price of natural gas is forecast to grow at an annual constant dollar growth rate of 3.9%, while crude oil is forecast to grow at 2.5% annually. In the forecast, the prices of gasoline and diesel are primarily dependent on the price of crude oil but will grow at a slightly higher rate to reflect the added cost of gasoline reformulation required by the CAAA. Natural gas prices are forecast for the Gulf Coast states of Texas and Louisiana, both at the wellhead and for the industrial delivered prices, which the process industries would be expected to pay.

The prices for the gas liquids, propane, and normal butane, are somewhat dependent on natural gas prices but are more dependent on the prices of distillate heating oil, diesel fuel and gasoline. The methanol price forecast is a function of the natural gas prices, while the MTBE price forecast is a function of the prices of methanol and butane (the feedstocks) and gasoline (the product into which it is blended).

The forecast of Exhibit 7-1 which is stated in 1992 constant dollars has been restated in current dollars in Exhibit 7-2 along with historical data for the various fuels.

Exhibit 7-1. Transportation Fuels Price Forecast (Prices in 1992 $)

	Refiner Acquisition Cost Crude Foreign $/BBL	Refiner Acquisition Cost Crude Composite $/BBL	Unleaded Regular Wholesale Gasoline Avg. US cpg	Wholesale Diesel Avg. US cpg	Well-head Natural Gas Louisiana $/MCF	Well-head Natural Gas Texas $/MCF	Well-head Natural Gas Total US $/MCF	Industrial Customers Natural Gas Louisiana $/MCF	Industrial Customers Natural Gas Texas $/MCF	Avg. Spot Propane Mt. Belvieu cpg	Avg. Spot Butane Mt. Belvieu cpg	Avg. Spot i-Butane Mt. Belvieu cpg	Contract MTBE cpg	Metuol USilf c
1992	18.20	18.43	64.4	59.0	1.73	1.76	1.74	1.93	2.12	32.1	38.5	46.3	108.5	3
1993	15.75	16.41	59.3	57.1	1.94	1.94	1.94	2.14	2.44	2.81	36.8	42.5	106.7	4
1994	16.20	16.50	58.3	53.0	1.95	1.95	1.95	2.15	2.45	25.9	34.1	39.9	102.9	4
1995	16.89	17.19	63.7	54.8	2.00	2.00	2.00	2.20	2.50	26.8	35.3	41.0	104.9	4
1996	17.60	17.90	65.6	56.6	2.08	2.08	2.08	2.28	2.58	27.7	36.4	42.1	106.8	4
1997	18.35	18.65	67.6	58.5	2.15	2.15	2.15	2.35	2.65	28.7	37.6	43.3	108.8	4
1998	19.13	19.43	74.4	60.5	2.23	2.23	2.23	2.43	2.73	29.7	38.9	44.6	111.8	4
1999	19.94	20.24	76.5	62.5	2.32	2.32	2.32	2.52	2.82	30.8	40.2	45.9	113.9	4
2000	20.79	21.09	78.8	64.7	2.40	2.40	2.40	2.60	2.90	31.9	41.6	47.2	116.1	4
2001	21.56	21.86	80.8	66.7	2.49	2.49	2.49	2.69	2.99	32.9	42.9	48.4	118.2	4
2002	22.35	22.65	82.9	68.7	2.59	2.59	2.59	2.79	3.09	33.9	44.1	49.7	120.3	4
2003	23.17	23.47	85.1	70.8	2.68	2.68	2.68	2.88	3.18	35.0	45.5	51.0	122.5	5
2004	24.02	24.32	87.3	72.9	2.79	2.79	2.79	2.99	3.29	36.1	46.9	52.4	124.8	5
2005	24.91	25.21	89.7	75.2	2.89	2.89	2.89	3.09	3.39	37.2	48.3	53.8	127.2	5
2006	25.53	25.83	91.3	76.8	3.00	3.00	3.00	3.20	3.50	38.0	49.3	54.7	129	5
2007	26.17	26.47	93.0	78.4	3.11	3.11	3.11	3.31	3.61	38.8	50.3	55.7	130.9	5
2008	26.82	27.12	94.7	80.1	3.23	3.23	3.23	3.43	3.73	39.7	51.3	56.7	132.8	5
2009	27.49	27.79	96.5	81.8	3.35	3.35	3.35	3.55	3.85	40.5	52.4	57.8	134.7	5
2010	28.18	28.48	98.3	83.5	3.47	3.47	3.47	3.67	3.97	41.4	53.5	58.8	136.8	6

Exhibit 7-2. Transportation Fuels Price Forecast (Prices in Current $)

	Refiner Acquisition Cost Crude Foreign $/BBL	Refiner Acquisition Cost Crude Composite $/BBL	Unleaded Regular Wholesale Gasoline Avg. US cpg	Wholesale Diesel Avg. US cpg	Well-head Natural Gas Louisiana $/MCF	Well-head Natural Gas Texas $/MCF	Well-head Natural Gas Total US $/MCF	Industrial Customers Natural Gas Lousiana $/MCF	Industrial Customers Natural Gas Texas $/MCF	Avg. Spot Propane Mt. Belvieu cpg	Avg. Spot Butane Mt. Belvieu cpg	Avg. Spot i-Butane Mt. Belvieu cpg	Contract MTBE cpg	Metiol US If c
1985	26.99	26.75	84.3	77.2	2.66	2.33	2.51	3.03	3.19	37.7	54.8	58.9		
1986	14.00	15.55	52.2	45.2	2.21	1.65	1.94	1.91	2.46	24.2	30.8	35.2		
1987	18.13	17.90	56.9	53.4	1.78	1.47	1.67	1.80	2.06	24.3	36.8	42.6		
1988	14.56	14.67	54.8	47.3	1.81	1.51	1.69	1.99	2.19	22.1	29.6	33.3		
1989	18.08	17.97	61.8	56.7	1.82	1.53	1.69	1.97	2.24	22.5	28.9	36.3		
1990	21.76	22.22	75.8	69.4	1.83	1.57	1.71	2.00	2.18	35.1	42.5	49.8	100.5	3
1991	18.70	19.06	67.2	61.5	1.73	1.59	1.64	1.74	1.93	33.9	42.2	47.1	98.2	5
1992	18.20	18.43	64.4	59.0	1.73	1.76	1.74	1.93	2.12	32.1	38.5	46.3	108.5	3
1993	16.14	16.41	59.3	57.1	1.99	1.99	1.99	2.51	2.51	28.0	36.8	42.5	106.7	4
1994	17.00	17.30	60.4	55.1	2.05	2.05	2.05	2.58	2.58	26.9	35.4	41.2	106.2	4
1995	18.50	18.80	68.0	58.9	2.19	2.19	2.19	2.74	2.74	28.9	37.9	43.6	110.8	4
1996	19.89	20.19	71.6	62.4	2.34	2.34	2.34	2.91	2.91	30.7	40.1	45.8	114.6	5
1997	21.38	21.68	75.6	66.2	2.51	2.51	2.51	3.09	3.09	32.6	42.5	48.1	118.6	5
1998	22.98	23.28	84.6	70.3	2.68	2.68	2.68	3.28	3.28	34.7	45.2	50.7	123.9	5
1999	24.70	25.00	89.1	74.7	2.87	2.87	2.87	3.49	3.49	37.0	47.9	53.4	128.5	5
2000	26.54	26.84	94.0	79.4	3.07	3.07	3.07	3.71	3.71	39.4	51.0	56.4	133.5	6
2001	28.37	28.67	98.8	84.0	3.28	3.28	3.28	3.94	3.94	41.7	53.9	59.3	138.5	6
2002	30.33	30.63	104.0	89.0	3.51	3.51	3.51	4.19	4.19	44.3	57.1	62.4	143.8	6
2003	32.42	32.72	109.5	94.3	3.76	3.76	3.76	4.46	4.46	47.0	60.5	65.7	149.5	7
2004	34.65	34.95	115.4	100.0	4.02	4.02	4.02	4.74	4.74	49.9	64.1	69.2	155.6	7
2005	37.04	37.34	121.7	106.1	4.3	4.3	4.3	5.04	5.04	53.0	68.0	73.0	162.1	7
2006	39.15	39.45	127.3	111.5	4.6	4.6	4.6	5.36	5.36	55.7	71.4	76.3	168.1	8
2007	41.37	41.67	133.2	117.1	4.92	4.92	4.92	5.71	5.71	58.6	74.9	79.8	174.4	8
2008	43.72	44.02	139.4	123.1	5.26	5.26	5.26	6.08	6.08	61.6	78.7	83.5	181.1	9
2009	46.20	46.50	145.9	129.4	5.63	5.63	5.63	6.47	6.47	64.8	82.7	87.4	188.1	9
2010	48.82	49.12	152.9	136.1	6.02	6.02	6.02	6.88	6.88	68.1	86.9	91.5	195.6	10

There is much uncertainty in forecasting energy prices and, in addition to the Reference Case, the DOE/EIA produces several other energy price scenarios. Shown in Exhibit 7-3 are the 1992 and 2010 prices for crude oil and natural gas along with the average annual growth rate between 1992 and 2010 for the Reference Case and the High and Low Oil Price Cases.

Exhibit 7-3. Oil and Natural Gas Prices

Oil Prices ($/Bbl)	1992 Price (1992 $)	2010 Price (1992 $)	Growth Rate 1992-2010
Low Oil Price Case	18.20	20.15	0.6
Reference Case	18.20	28.16	2.5
High Oil Price Case	18.20	34.11	3.6
Natural Gas at Wellhead ($/MCF)			
Low Oil Price Case	1.75	3.25	3.5
Reference Case	1.75	3.47	3.9
High Oil Price Case	1.75	3.54	4.0

For the Reference Case a higher growth rate is projected for the wellhead price of natural gas than for world oil prices. Oil and gas price projections are based on different factors. U.S. gas price forecasts are based on the disappearance of the supply surplus which has existed for the past decade and price growth based on healthy demand and rising exploration cost for new gas. The key factor in oil prices is the worldwide supply/demand balance and the pressure the OPEC cartel can bring to bear on the market. The worldwide oil market is seen as having greater uncertainty than the U.S. gas market. In addition to the two scenarios shown, EIA also developed high and low economic growth cases. The growth price rate for the oil price cases and for the economic cases (not shown) ranges from 0.6% - 3.6% for oil prices compared to a more narrow range of 3.0% to 4.0% for natural gas. In all cases, a higher price growth rate is forecast for gas than for crude oil, which means that the forecast does not indicate an improving economic situation for gas and gas-derived products versus products from other energy resources.

7.2. Economic Evaluation–Analysis Methodology

Data was taken from a variety of previous economic studies to develop the evaluation of the natural gas to products economics presented later in this section. 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 costs were escalated to December 1993 using Nelson-Farrar Indexes in the "Oil and Gas Journal". No adjustment was made for differences in plant capacity from one set of economics to another. The basic data taken from the economic sources in the literature are as follows:

- Design Capacity of Product
- Service Factor
- Process Field Cost (PFC)
- Offsite/Utility Field Cost (UFC)
- Operators/Shift
- Catalyst and Chemicals Cost
- Utilities Cost or Rate
- Feed Gas Rate
- Total Maintenance Cost

After establishing these basic economic data, the other economic data were calculated from them using the following factors:

- Process Units Project Contingency (PC): 15% of PFC
- Process Units Home Office: 6% of (PFC + PC)
- Process Units Engineering: 6% of (PFC + PC)
- Offsite/Utilities Project Contingency (UPC): 15% of UFC
- Offsite/Utilities Home Office: 6% of (UFC +UPC)
- Offsite/Utilities Engineering: 6% of (UFC + UPC)
- Initial Fills: 0.8% of Total Facilities Construction Investment
- Start-up: 20% of Annual Operating Cost
- Prepaid Royalties: 0.5% of Total Facilities Construction Investment
- Maintenance Labor: 40% of Total Maintenance
- Maintenance Materials: 60% of Total Maintenance
- Direct Labor Cost: $18.08/hour
- Total Direct Labor (TDL): Direct Labor + Maintenance Labor
- Supervision: 25% of TDL
- Benefits: 25% of TDL
- General and Clerical: 45% of TDL
- Corporate Overhead: 30% of TDL

A discounted cash flow (DCF) rate of return calculation was done using the initial operating year economics as a basis (see detailed description in Appendix A). Some of the factors used in the calculation are as follows:

• Fraction Inflation	0.0301
• Fraction Capital from Equity	0.8
• Fraction Capital from Debt	0.2
• Fraction Return on Equity	0.142
• Fraction Return on Debt	0.09
• Book Life Years	20
• Tax Life Years	20
• Fraction Tax Rate	0.4
• Construction Period Years	3
• Fraction Escalation Rate during Construction	0.0301

Since the types of feeds and products were different, growth rates in feedstocks prices and product costs varied from one set of economics to another based on the price forecast of Section 7.1. Economics and process descriptions will be discussed for six processes for conversion of natural gas to transportation fuels, chemicals, electric power and for upgrading natural gas. Detailed economics for one of the processes are given in the Appendix A, Exhibit A-1 in the form of computer spreadsheets. On the first page of the economics analysis spreadsheet cost estimating inputs and process, offsite/utility and total plant investments are given. Costs for maintenance, labor and overheads, catalyst and chemicals, utilities, taxes and insurance and feedstocks, total operating and maintenance costs and working capital are on the second page. The third page contains input for a DCF calculation and a lists of intermediate results. The bottom line shows the price of the product in the initial year assuming a constant return on investment for all cases. Appendix A contains summary tables for the economic cases shown in the report. More detail is provided than is given in the economics in Sections 8.1 to 8.7 and 9.1 to 9.6. Exhibits A-3 and A-4 have summaries of economics for the conversion of natural gas to transportation fuels. Exhibit A-5 has a summary of economics for conversion of natural gas to chemicals. Exhibit A-6 has a summary of economics for conversion of natural gas to power and nitrogen rejection. Exhibits A-7 and A-8 have summaries of economics for the sensitivity analysis of converting natural gas to Fischer-Tropsch liquids.

In the economic summaries in the text and in Appendix A, the feed, operating, and capital costs are based on initial-year costs, and the product price is based on a DCF calculation and thus takes into account the cost growth during the period covered. Therefore, the cost components do not add up to the product price.