CHAPTER 6

ECONOMICS OF GTL TRANSPORTATION THROUGH TAPS

6.1 INTRODUCTION

One of the greatest potential options for using the Gas-To-Liquid (GTL) technology is the possibility of harnessing and utilizing the abundant natural gas resources on the Alaskan North Slope (ANS). The advantage of using ANS gas is that it is possible to transport liquids converted from gas by the GTL process along with the crude oil produced from the North Slope through the existing Trans Alaska Pipeline System (TAPS). Many operational challenges are expected in order to implement the project since the GTL products will be transported through the arctic environment from the North Slope to Valdez on Alaska south coast. A very high quality, contaminant free, product is produced by the GTL synthesis process. At the same time, the product can contain long chain paraffin, which are desirable for a diesel fuel but can pose potential flow problems in a cold environment.

The real challenges are: i) choose the GTL processing option to produce a transportable product, ii) get these products down through TAPS with minimal contamination from the crude oil, iii) simply blend the product with crude oil and transport through the TAPS. Each transportation option available has different economic impacts on the overall economics of the project depending on how much investment is made to keep the fuel as clean as possible at the terminal.

The two transportation options considered in this study are either to batch alternate slugs of the products or to transport the crude oil and the GTL as commingled fluids through the TAPS. The main focus of this section of the study is the impact of the transportation method chosen on the overall project economics.

6.2 GTL TRANSPORTATION MODES

In transporting GTL products through the Trans Alaska Pipeline System (TAPS), two modes of transportation are evaluated in this study. The choice of the mode of transportation to adopt depends on the expected purity of the shipped product and a trade-off between loss in product value due to contamination and cost of keeping the product pure at the terminal.

The first method considered involves blending the ANS crude oil and the GTL products. This method is termed the commingled mode of transportation. The Second method is to pump alternate slugs of the GTL products and crude oil through the TAPS, a batch mode. Batching of the product could be achieved in three different ways namely; the traditional batching technique called the batch mode A in this study, batching with physical barriers such as pigs and some other spacers called batch mode B, and a third technique which uses modern batching technology called batch mode C.

6.2.1 Commingled Mode

To discuss this mode of transportation, it is necessary to take a close look at the physical properties of each of the products to be blended. Generally, the crude oil blend from the North Slope of Alaska is a dark brown medium crude with an API gravity of about 32°, viscosity of about 17 cp at standard conditions with wax deposition tendencies at standard condition of temperature and pressure. Samples of GTL products from pilot plants show that they lie in the boiling range of middle distillates found in a typical crude oil. The GTL product has a viscosity of about 1.5 cp at standard conditions, typically diesel and naphtha based product with API ranging from about 62° for 354°C distillate to 66° for the 254°C distillate. The blending proportion of crude oil and GTL product on the North Slope is assumed to be a matter of availability of each of the product at any particular time rather than an intended ratio. However, with the commencement of the GTL project, the ratio is expected to continue changing depending on the amount of crude throughput available for blending assuming the GTL production remains constant. From the operational perspective, blends such as 3:1 crude oil to GTL with a resultant API of about 39.9°, 1:1 of crude oil and GTL with a resultant API of about 47° have been studied.

The flexibility of using existing infrastructure to the fullest advantage with minimal addition to capital cost for transportation is the most attractive aspect of this mode of transportation. This includes the use of the present holding tanks at the North Slope and storage tanks at the Valdez Marine Terminal, elimination of extra piping to the respective tanks at the Valdez Marine Terminal and minimal logistic concerns. At first glance therefore, it would be intuitive to tag this method as the most cost-effective. In the pump stations, pressure relief tanks are required for emergency operations. They are expected to come in as temporary storage in case of any unforeseen valve or process malfunction to cushion any pressure build up in the pipeline. The commingled transportation does not require this additional facility because the present relief tanks system is capable of handling the crude – GTL blend together.

The GTL economic model analyzes the effect of these initial savings on the entire project economics.

6.2.2 Batch Mode of Transportation

In the batch mode of transportation, the GTL products could be batched in three different ways:

Uncontrolled batching of Products termed batch mode 'A'
Controlled batching using pigs and spacers termed as batch mode 'B'.
Controlled batching using modern batching techniques termed batch mode 'C'.

6.2.2.1 Batch Mode 'A'

The batch mode A or the as-is batching is considered the easiest of the batch modes of transportation. This mode of transportation requires minimal additions to capital and labor costs. Typically, any batch operation requires that there is segregated tankage for the GTL at NS and Valdez and clean tankers. Basically, the physics of the flowing liquid products (Crude

Oil and GTL) controls the behavior of the products while in the pipeline. This uncontrolled batching technique results in the creation of an interface zone in between the two phases (Crude Oil and GTL mixture). The length of this interface is a function of the viscosity, velocity and density difference between the two products, pipeline diameter and distance. Loss of product value due to contamination of the GTL products is at it's maximum in this mode when compared to other batching techniques. However, this is the common practice for refined products batching in the US. The interface generally gets downgraded to crude oil.

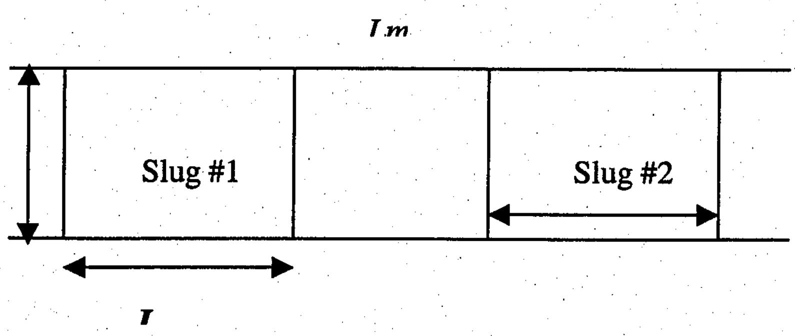

Figure 6.1: Typical Batch in TAPS

Equations have been derived for calculating the minimum slug length (please refer to Chapter 4), which can be translated to volumes for effective batching and minimal contamination for large diameter pipes. However, from the economic view point, it is pointed out that as slug length increases, segregated tankage requirements also increase. Further discussion on these is in the hydraulics section of this study (Chapter 4). In the case of Batch Mode "A" operations or any other batching technique, it is assumed that a special berth will be dedicated to GTL products at the Valdez Marine Terminal and special tankers will be used to carry only GTL products. This ensures that further secondary contamination does not take place beyond the Trans Alaska Pipeline System. This method of transportation is very similar to mode 'C' with the major difference coming from the employment of available technologies in the later to enhance purity of the transported products before, during and after transportation. The economics of this mode therefore forms a base case for the modern batching technique.

6.2.2.2 Batch Mode B

In this method, pipeline pigs are used to achieve the objective of phase or slug separation. It is expected that these pigs will effectively prevent mixing of the alternate slugs of GTL products and crude oil. This method requires the entire basic infrastructure that is used in the base case batch mode plus some additional capital. The GTL products will be stored in separate tanks both at the North Slope and in Valdez Marine Terminal. Transporting the products through the Trans Alaska Pipeline System would not be left to fluid dynamics to govern their movement in the pipeline since the pigs would keep the oil and GTL separate. The number of slugs expected to be in the pipeline at any time would determine the number of pigs required. Intelligent pigs with sensors attached to them are commonly available with capabilities of detecting product movement. Detecting product movement can minimize the time needed to divert flow from crude oil tank to GTL storage tanks.

A major operational challenge arises here. The pigs need to be diverted at every pump station along the TAPS where flow is diverted accordingly for the fluid to pass through the pumps. Additional labor is required at each pump station to carry out this task on a continuous basis.

Most operators are of the view that the use of pigs to batch these products would reduce or completely prevent the mixing of the products. Some other operators believe that batching with pigs would not reduce the mixing but rather increase the mixing due to increased turbulence. This task is currently under study. In this analysis, the assumption is that the pigs would help maintain product purity. Possibilities exist for improvement in pigging technology as deemed necessary. For instance, it is possible to attach sensors to the pigs that would enable automatic diversion of flow at the pump stations. The opening and closing of valves can fully be automated at the pump stations with good instrumentation and controls. Pigs are also available that are specifically designed for batching of petroleum products.

6.2.2.3 Batch Mode C

The modern batching technique, identified here as batch mode 'C' entails pumping alternate slugs of GTL and Crude oil while having fluid movement monitored by interface detection devices to minimize loss of product value. Available interface detection technologies include densitometers, sound-velocity interface detectors, colorimeters, pipeline interface detectors and photo detectors (Baum et al., 1998).

A densitometer measures online the specific gravity of the product in the pipeline, and can detect even small changes in product density. In terms of accuracy, they can distinguish between premium and regular gasoline.

The sound velocity interface detector employs changes in the sound velocity rather than changes in density to detect different liquids.

A colorimeter detects color changes in the contents of the pipeline. It measures color quality with a dual wavelength, dual detector optical system. At the receiving terminal, which could be at a refinery or tank farm, a dynamic hydraulic model for optimizing control of product movement and a Distributed Control System (DCS) can optimize control of product movement. A DCS allocates the crude oil and GTL to their respective tanks at the optimal time reducing error in valve opening and closing and this is synchronized with the pumping at the plant end, employing already calculated optimum slug length from batch mode 'A', length of interface, the interface and slug velocities. This method would require additional storage tanks and shipping facility to ensure that purity of the products is maintained.

6.3 ECONOMIC PARAMETERS

In order to conduct the economic analysis of GTL transportation through TAPS, the following economic parameters are considered in this study:

- A large-scale GTL project consisting of three trains each capable of producing about 100,000 barrels of GTL products per day.
- Pipeline Tariffs obtained from available forecasts and charged based on throughput and is expected to pay for the pipeline, pipeline maintenance and storage cost at the terminal and some return on investment.
- A salvage value of zero.
- Each mode of GTL transportation has an associated capital cost which varies from minimal capital investments for the commingled mode to huge capital costs for the modern batching approach.
- Construction starts in 3 years by 2005, lasts 4 years through 2009 and production begins same year.
- Train 2 construction commences after train one has started production and train 3 commenced two years after train 2 is started to spread out the investment.
- All transportation costs rely on the existing infrastructure of the oil pipeline operation and maintenance, therefore; only additional capital costs specific to GTL will increase the cost.
- Discount rate of 10% is used for the capital costs
- Depreciation of property is by Modified Accelerated Capital Recovery System (MACRS).

6.3.1 Rate Of Return Analysis

Rate of return analysis was used in evaluating the various transportation modes. To conduct rate of return analysis, an accurate estimate of the capital and operational costs involved in the project was necessary as well as an estimate of expected product price and revenue. The project life was estimated to be twenty years. Based on construction costs, the construction schedule, the timing of product sales, and the expected revenue a rate of return was estimated. It is assumed that 100% equity financing is used which is typical for oil and gas firms when comparing different projects.

6.4 IDENTIFYING CAPITAL AND OPERATING COSTS

The capital costs include all costs from the GTL plant to the delivery of product onto the GTL tankers in Valdez.

The first common cost to all modes of transportation is the contingency plan capital. No production of GTL can begin until this capital is in place. Contingency plan capital refers to the capital that must be set aside to help handle emergency situations that might lead to shutting down the pipeline and ensure quick restart of operations. Laboratory measurements show that in the arctic environment a window of about thirty (30) days is allowed to restore operation in case of any shutdown during the winter season or risk shutting down operation once the crude oil in the pipeline gels due to very cold temperatures. The window for cold restarts in the winter for the pipeline when GTL is in the pipeline for either the commingled mode or the batch mode is estimated to be smaller compared to when only crude oil flows through the pipeline. This is given adequate treatment in the gel strength prediction section of this report for both a fast and slow ramp cooling process.

Another common cost to all modes of transportation is the cost of building a pipeline from the GTL plant to Pump Station 1. It is assumed that the GTL plant would be situated not more than one mile for pump station one.

The piping cost required to transporting the gas from the production wells and stations are not included in the GTL project cost. The drilling and completion cost of the gas wells are also not part of the GTL cost here but are assumed to be a part of the gas purchase cost. The GTL plant is assumed to come with a conditioning unit for removal of acid gases such as CO_2 and H_2S and are therefore not considered separately.

On the distinctive capital costs, batch mode 'A' does not incur any extra costs apart from that outlined above. Batch mode B incurs additional capital costs in purchasing pigs and labor to handle the pigs on a continuous basis at different pump stations.

Batch Mode 'C' requires additional investment costs from those outlined above including interface detection devices for minimizing impurities associated with mixing, product movement control devices that use the Distributed Control System (DCS), densitometers, colorimeters, and other complex instrumentation. This technology has been proven effective and has been used extensively by the petroleum products transportation industry in pipelines. Product movement control has two main components. The first is the dynamic hydraulic model and the second is a Distributed Control System (DCS). This system is complex and expensive.

6.4.1 Plant Cost

The capital cost of a GTL plant is estimated at between $25,000 per daily barrel (DBL) capacity and $35,000/DBL (Thomas et al., 1996). Current industry average for a US gulf coast plant puts the capital cost at about $24,000 / DBL. Most of the plants from which these cost estimates were derived are small-scale GTL plants with design capacity of between 30,000 to 50,000 barrels per day (bpd). As technology advances, these costs are expected to come down significantly. One such significant leap is the reduction in the size of the steam-reforming unit to about forty times less than the conventional size of the steam reformer. This is projected to result in a significant change in the capital cost for GTL plants. This is estimated to put the capital cost at about $20,000/ DBL for a commercial scale plant in the Gulf Coast. This compact reformer technology is currently being tested with a pilot plant in Nikiski, AK by BP Exploration (Alaska) Inc. The reformers come in compact units built to commercial scale. To increase output, additional whole compact reformer units are added to operate in parallel with existing ones and minor modifications made to other units in the plant to increase plant output capacity.

The Alaskan North slope is assumed to have a cost scaling up factor of about 1.3-1.5 times the cost of building the same plant in the Gulf of Mexico. If the compact reformer technology passes the test to commercial status, then the capital cost of the plant on the North Slope is anticipated to be at about \$28,000 /DBL capacity assuming the same plant is built at a cost of about \$20,000 /DBL in the Gulf Coast. However, this study evaluated a wide range of capital costs of GTL plants from \$35,000 /DBL down to \$20,000 /DBL.

Application of the learning curve as presented by Robertson et al (1999) was not employed in this study. Cost improvement based on a learning curve or progress curve plays a crucial role in the competitiveness of the chemical and petrochemical industry. It has been observed that more rapid cost improvement for a product results in expanding market share and profits. Though initial or pilot projects may be economically marginal, expectations of rapid cost improvement based on a learning curve is often the motivator to invest in such projects. As GTL technology unfolds and operators gain experience from building and operating earlier trains, a rapid cost improvement is expected. This is usually represented by a common rule of thumb based on observations from petrochemical plants as;

$$C_n = C_1 n^b$$

Where,

C_n = Cost of the nth unit,
C_1 = Cost of the first unit,

n = number of unit being estimated and
b = exponent equal to the improvement – curve rate divided by the log of 2

Cost improvement rate for organic chemical production was found to be 73.8 percent on the average. GTL plant falling under the same industry, would have the 'b' exponent given by:

$$b = \frac{\ln 0.738}{\ln 2.0} = -0.4383$$

In the learning curve advantage as presented, one or combinations of factors presented below are expected to play important roles in driving down cost of subsequent trains:

Learning by plant operators and designers
Technical improvement
Economies of scale
Probable decrease in cost of raw (feedstock) material

The scenarios presented assume that the capital cost remains the same in all the trains and this is the worst case possible since capital cost improvement would be significant in the second and third trains. As noted above, the Prudhoe Bay gas has a high carbon dioxide content and needs to be conditioned before it is fed to the GTL plant. The above cost is expected to cover the gas conditioning.

6.4.2 Storage, Product Separation and Other Costs

For the batch mode of transportation, it is assumed that three new holding tanks (APSC 2002) would be built on the North Slope. To arrive at this, the present tanks have a holding capacity per foot of 4,400 barrels. For an estimated 300,000 barrels per day of Gas-To-Liquid product conversion plant, the footage of temporary storage required would be given by:

$$\frac{300{,}000}{4{,}400} = 68.18\mathit{ft}$$

Maximum allowable height by OCC (Operational Command Center) is approximately 32 ft and an 8ft minimum level maintained, leaving out only 24 ft (APSC April 2002).

$$\frac{68.18\mathit{ft}}{24\mathit{ft}} = 3\mathit{StorageTanks}$$

Each of the tanks is estimated to cost about $50 million. This estimate includes fittings, accessories, piping and refrigerated foundation.

At the Marine Terminal in Valdez, a first case where new tanks are built for storage of GTL is considered first. This represents the worst-case scenario. For a one-week storage capacity, four new tanks are required at the Valdez Marine Terminal where the tanks are 500,000 barrels capacity each. The cost of these four tanks is estimated at approximately $270 million or $65 million each. This cost is expected to cover some fittings and appurtenances such as; pressure relief valves, emergency relief vents, tank piping, mixers, internal heaters, water draw-off valves, tank instrumentation, tank insulation, thief hatch, corrosion control. Another option is to recondition and reconfigure four of the 18 existing tanks for GTL storage. This is an optimistic assumption. The cost of reconditioning and reconfiguring each of the tanks is put at approximately $5 million dollars so about 20 million dollars is estimated to recondition the four tanks.

Emergency relief tanks for GTL at pump stations 3, 4, 5, 7, 9, and 12 are required. Building these tanks is another major cost in the transportation model. These emergency relief tanks are 55,000-barrel capacity tanks. To maintain GTL product purity, each of the pump stations may require a separate emergency relief tank for GTL products. Each of these tanks is estimated to cost about $16 million bringing the cost for all the pump stations mentioned above to $96 million. In the second and optimistic scenario, it is assumed that the emergency relief tanks will not be required since such emergency operations are only very occasional. The present emergency tanks are therefore assumed sufficient to handle the situations as long as they are kept clean and ready to receive any products in case of emergency.

For batching of products with pigs, by applying the optimum length of slug for batching of product, the number of pigs required is obtained and the cost added to the cost of batching with pigs. Labor is required to handle these pigs at the pump stations. This is also accounted for in the economic analysis of this mode of transportation.

Vapor pressure estimates from the laboratory show that the vapor pressure of GTL products is within the acceptable limits and can be handled by the existing vapor pressure recovery system. Further study of the vapor pressure of GTL products are also in progress. The vapor pressures are required for live GTL products from the plants under pipeline conditions of pressure and temperature to obtain the true behavior of the GTL products in pipeline conditions. However, some piping modification will need to be done and together with all other piping jobs to the tanks, an estimate of $10 million dollars might be required.

Table 6.1
Capital Cost Schedule For the Various Modes of Transportation

SUMMARY OF CAPITAL COST ESTIMATES FOR DIFFERENT MODES OF TRANSPORTATION						
No	**Item**	**Estimated Cost each ($mm)**	**Batch Mode A**	**Batch Mode B**	**Batch Mode C**	**Commingled**
4	**Tanks @ Valdez**	65	260	260	260	0
3	**Tanks @ Slope**	65	195	195	195	0
6	**Pressure Relief Tanks**	16	96	96	96	0
1	**Contingency Plan Capital**	20	20	20	20	0
1	**Additional Piping**	10	10	10	10	10
	Labor Cost/ yr	2.72	0	2.72	0	0
	Cost Of Pigs	5	0	5	0	0
	Cost of DCS and Accessories	20	0	0	20	0
	Total ($mm)		**581**	**589**	**601**	**10**

6.4.3 Energy Cost

The Products from the North Slope to Valdez pass through several pump stations at the moment. These stations are booster stations and consume fuel for running the pumps and power generators. The first four pump stations are run on gas fuel. Currently the gas is supplied to the pump stations at no extra cost from the North Slope. The other stations are run on diesel fuel. The fuel cost is a function of throughput of the TAPS. A plot of throughput versus energy cost at various oil prices is presented in Figure 6.2. The gas is assumed to sell at the same price as the gas supplied to the GTL plant and half (for simplicity sake) of the calculated cost for running these stations tied to the GTL process. Equations were fitted through the gas consumption curve to determine what the gas consumption would be at rates that have not been transported through the TAPS and which are anticipated in the future as throughput continues to decline.

6.4.4 Cost of Upstream Natural Gas

Typically natural gas supplied to the GTL plant will be sold by gas producers. The gas producers will price the feed gas high enough to pay for their costs of extraction however they could also add a premium to account for other opportunities to sell the gas. In this analysis, we only consider the minimum cost of feed gas to pay for extraction costs and a profit margin.

To determine the amount of gas needed as feedstock to produce a barrel of GTL, it is necessary to relate the energy content of the produced liquid fuel to the gas used in a common energy unit usually in BTU.

The energy content of a typical barrel of oil is estimated to be 5.8 MMBTU. The energy content of GTL is assumed to be the same with that of a typical barrel of oil. For natural gas, the energy content is about 1 MMBTU per MCF. Solving for the gas energy required per barrel as below:

$$\text{Gas energy per barrel of GTL} = \frac{5.8\dfrac{MMBTU}{BBL}}{1.00\dfrac{MMBTU}{MCF}} = 5.8\frac{MCF}{BBL}$$

At 60% conversion efficiency, the feedstock needed to produce a barrel of GTL is:

$$\text{Gas to GTL conversion} = \frac{5.8}{0.6} = 8.33\frac{MCF}{BBL}$$

$$\text{North Slope gas price} = \frac{\text{(North Slope GTL Price) X (gas Product net back)}}{\text{Gas to GTL Conversion}}$$

Where the North Slope GTL price is also known as the wellhead price.

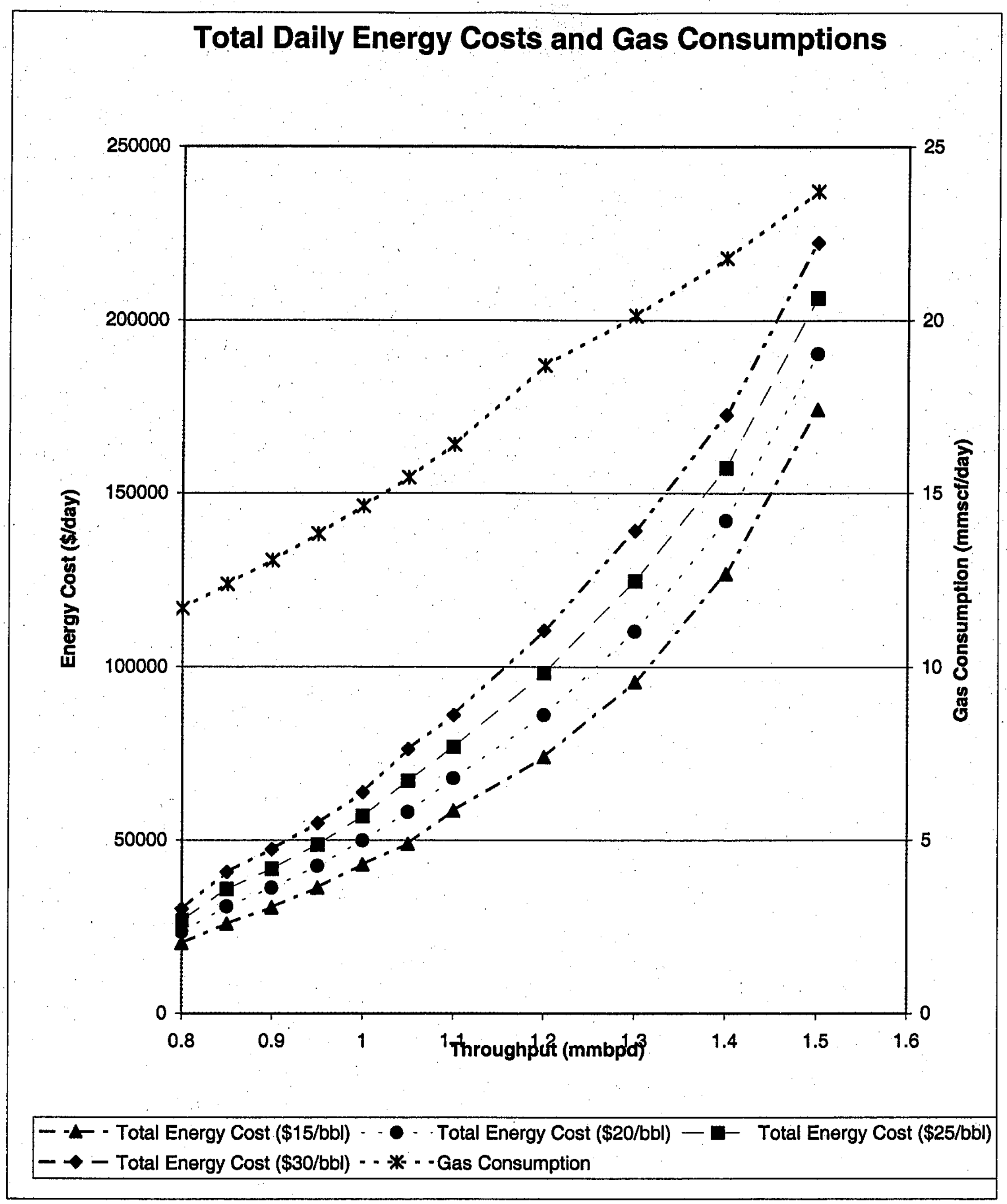

Figure 6.2 Energy cost as a function of throughput. (APSC 2001)

The North Slope gas price is often known also as the gas transfer price and is the cost of the gas feed stock to the buyers which in this case is the GTL operator. The term gas product 'net back' refers to the net fraction of the gas sales as GTL that goes to the owner of the gas. It is usually determined based on agreement on a return on investment expected by the gas owners. As an example, if the price of GTL is $28 and a net back of 10% is used, then the gas transfer price would be approximately $0.34 per MCF. The daily cost of natural gas is estimated at over $1 million. This number is arrived at as follows.

6.4.5 The TAPS Tariff

The TAPS tariff is the most significant cost item in the economics of the transportation of the GTL products through the pipeline. Six independent companies own the Trans Alaska Pipeline System (TAPS). Each of the owners charges their own tariff per barrel of product transported through the pipeline. The tariff is expected to cover the cost of operation and maintenance of the pipeline, the cost of storage, cost of dismantling and demobilizing the TAPS at the end of its operations and in addition to the above yield some return on investment for the owner companies. Operating the pump stations with GTL and Crude oil passing through the TAPS would require an increase in the cost of diesel fuel to run the pump stations. This energy cost is a function of both the throughput and the world spot oil price (Figure 6.2). Presently, pump stations one to four have gas turbines and the gas is supplied at no cost to the pipeline company. When the GTL project commences, the gas is expected to attract extra cost. This is because the gas for the pump stations operations will be an added cost, purchased at the going price of natural gas on the North Slope. The amount of gas required to run the pump stations is also a function of the TAPS throughput. A plot of the amount of gas required to run stations versus throughput is also presented in Figure 6.2.

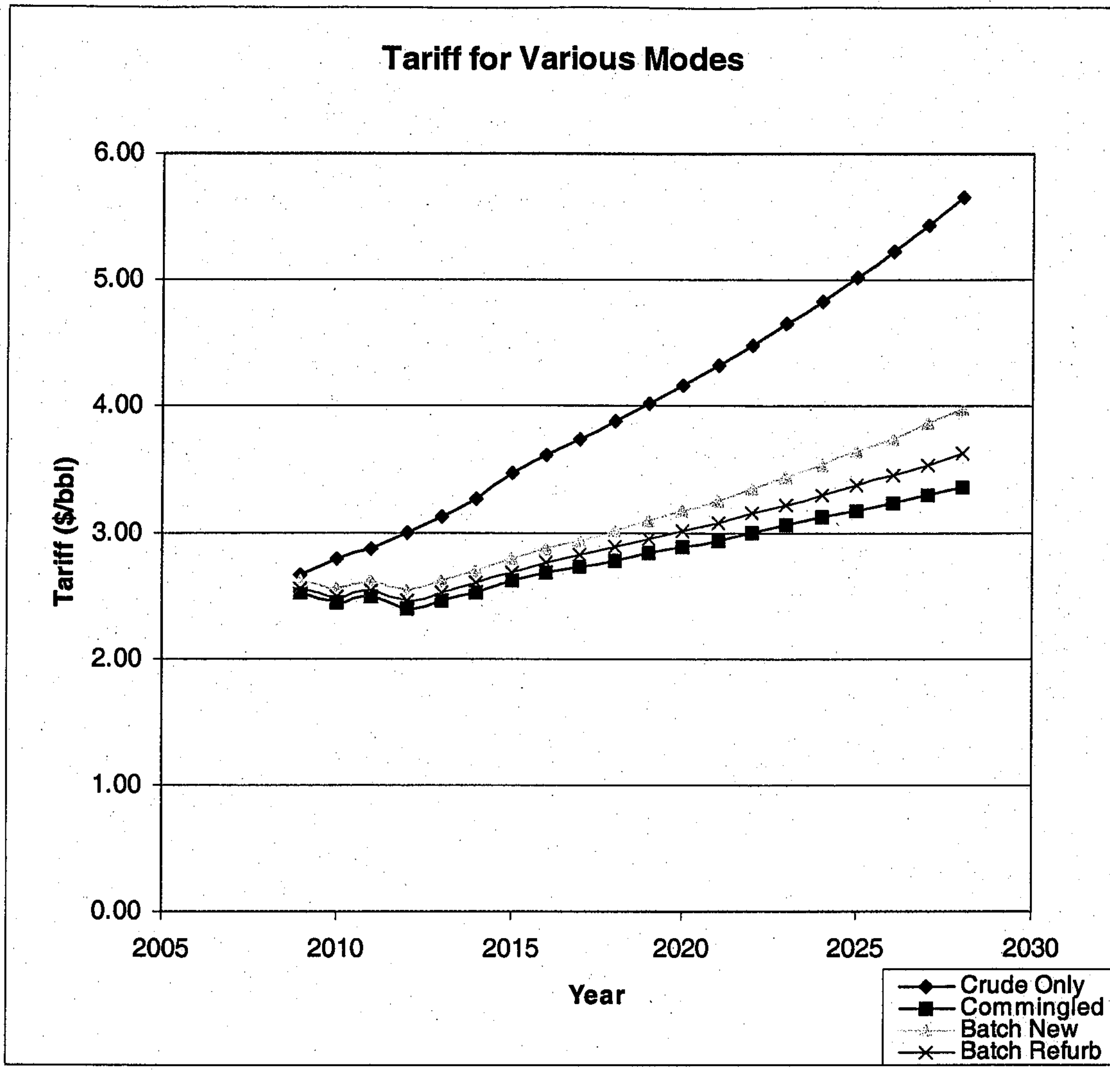

Figure 6.3 Tariff estimate for different scenarios of fluid through pipeline

Table 6.2 TAPS Tariff Estimate for Various Modes

TAPS TARIFF ESTIMATE FOR DIFFERENT MODES							
No of Periods				20			
Discount Rate				15%			
Capital Inv				601000000		260000000	
Period	Year	Crude Only	Commingled	Batch New ($/bbl)		Batch Refurb ($/bbl)	
1	2009	2.66	2.51	$0.06	$2.57	$0.02	$2.54
2	2010	2.78	2.43	$0.06	$2.50	$0.03	$2.46
3	2011	2.86	2.48	$0.07	$2.56	$0.03	$2.52
4	2012	2.99	2.40	$0.09	$2.48	$0.04	$2.43
5	2013	3.12	2.46	$0.10	$2.56	$0.04	$2.50
6	2014	3.26	2.52	$0.11	$2.63	$0.05	$2.57
7	2015	3.46	2.61	$0.13	$2.74	$0.06	$2.66
8	2016	3.62	2.67	$0.15	$2.82	$0.06	$2.73
9	2017	3.74	2.72	$0.17	$2.89	$0.07	$2.79
10	2018	3.88	2.77	$0.20	$2.97	$0.09	$2.86
11	2019	4.02	2.83	$0.23	$3.05	$0.10	$2.92
12	2020	4.16	2.88	$0.26	$3.14	$0.11	$2.99
13	2021	4.32	2.94	$0.30	$3.24	$0.13	$3.07
14	2022	4.48	2.99	$0.35	$3.34	$0.15	$3.14
15	2023	4.65	3.05	$0.40	$3.45	$0.17	$3.22
16	2024	4.83	3.11	$0.46	$3.57	$0.20	$3.31
17	2025	5.02	3.17	$0.53	$3.70	$0.23	$3.40
18	2026	5.22	3.23	$0.61	$3.84	$0.26	$3.50
19	2027	5.43	3.30	$0.70	$3.99	$0.30	$3.60
20	2028	5.65	3.36	$0.80	$4.16	$0.35	$3.71

The TAPS tariff as noted above incorporates some return on investments for the owners of the pipeline after the operation and maintenance cost. The six owners of the pipeline charge different rates for their 'space' in the pipeline. Therefore, it is not very correct to generalize and assume one particular discount rate for all the companies though they all fall within a range. The discount rate charged by each company depends on the company's view of rate of return and their perception of 'risk'.

The tariff estimates for the next two decades are obtained from the Alaska Department of Revenue (Table 6.2). The estimates give separate numbers for a case where GTL is transported through the TAPS with the crude oil and the tariff if crude oil alone continues to be transported through the pipeline. The tariff for the crude oil and GTL represents the commingled mode, which does not account for the extra capital investment required for batching of the products. For the batch modes, the huge capital costs required to keep the products as clean as possible is factored into the tariff. The tariff for the batch modes is therefore different for the various modes of transportation (Figure 6.3). This illustrates one of the arguments for GTL, that it provides added liquid fill for the pipeline as crude oil production decreases. That is, it gives a longer life and makes it economic to transport the lower volume of crude oil. This is because it will get so expensive on a per barrel basis that crude oil transportation would have to be shut down were it not for GTL.

For the batch modes, the additional capital investment is allocated on a per barrel basis and a 10% discount rate.

6.4.6 Taxes

6.4.6.1 Property Tax (Ad Valorem)

Each of the three trains is depreciated depending on the number years it is expected to operate within in the 20-year period. Train one, is depreciated over twenty years, train two is depreciated over a 15-year period and train three is depreciated over a 13-year period. The tax base is computed and the property tax derived. The property tax rate is 2%.

6.4.6.2. State Corporate Income Tax

The state corporate income is given by; (income before State and Federal taxes – State Income Tax depreciation) X State Income Tax Rate.

The income tax depreciation is calculated using the MACRS depreciation method. The State Income tax rate used is 9.40 % based on recent values of this rate from the State Department of Revenue (DOR).

6.4.6.3 Severance Tax

The State gas severance tax is assumed to be zero for the GTL project. This assumption is based on the DOR's tax model for the gas projects and would serve as some tax relief to encourage the take off of the gas utilization project.

6.4.6.4 Federal Corporate Income Tax

This is calculated using the income before state and federal income taxes, less the depreciation and multiplied by the Federal Income Tax rate. The Federal Income Tax rate used here is 35% based on current values of this tax.

6.5 GTL PRODUCT PREMIUM

GTL products are expected to receive some price premium compared to conventional crude oil products to reflect their high quality and environmental attractiveness as a fossil fuel. This premium is dependent on the marketing strategies of the GTL. It is expected to follow the world crude oil and oil product pricing system closely. An important crude oil marker grade is the Brent crude oil produced in the North Sea. It is traded internationally on the Internal

Petroleum Exchange (IPE) and the futures market, a rapidly growing trend in world crude oil marketing. The price of crude oils have continued to fluctuate over the past decade and future trends difficult to predict. For example, at low point, Brent sold for $10 per barrel in 1998, but rose to about $33 per barrel in September 2000. In the last decade, the average Brent price was about $19 per barrel and projections put the average at over $22 per barrel in the next five years. Typical GTL yield assessment like 20% naphtha and 80% diesel is assumed reasonable. The GTL diesel is superior to the conventional crude oil refined diesel with regards to sulfur, cetane number, aromatic content and density. However it has relatively poor cold flow properties. Typical GTL diesel has a cetane number greater than 70, compared to a usual diesel product end specification of 50 (Duckler and Hubbard, 1975). This means that opportunities exist for utilizing GTL diesel as a blend stock to upgrade refinery middle distillates products. The zero aromatics content of GTL diesel gives it another advantage for blending with conventional distillates where aromatic content specification becomes a limiting factor. Various numbers have been advanced for GTL product premium. Generally, the GTL diesel product is predicted to have between $2 and $2.5 per barrel premium over conventional diesel. In the model used, a premium of 1.3 times the world crude oil spot price is used. The choice of relating the product premium and price, as a function of the world crude oil price is an obvious one taking into account that price refined products follow the trend of crude oil prices.

Table 6.3
Economic Assumptions

ECONOMIC ASSUMPTIONS	
Conversion @ 60% efficiency	8.33 MScf / Bbl
Plant Uptime Efficiency	95%
Project Life	20 years
Plant Capacity	100 MBPD
Taxes	
State Income Tax	9.4%
Federal CIT	35.0%
Property Tax	2%
Depreciation	Modified Accelerated Capital Recovery Scheme

The assumptions made in Tables 6.3 and 6.4 are part of the major input parameters in the economic model and are used to show the effect of each mode of transportation on the entire project economics.

Table 6.4
Model Parameters

MODEL PARAMETERS FOR ROR
Cost Estimates
Plant Cost ranging from $20,000/BPD to $35,000
Gas Cost based on net back of 10%
Annual Operating and Maintenance cost of 5.6% of Plant Cost
Transportation and storage estimated with Tariff estimates.
Capital investment are amortized over the project life and worked out per barrel of product.
Revenue Estimates
ROR calculation based on $21.00 per barrel crude price.
GTL products given a premium of 1.3 times Spot Oil price
Batch Transportation efficiency of 95%

6.6 SENSITIVITY ANALYSIS

Key parameters in the rate of return analysis were modified to identify those with the greatest influence on the results. The parameters include:

Capital Expenditure was varied between $20,000 per daily barrel and $35,000 per daily barrel to accommodate speculated range of plant costs and possible North Slope scale up factor.
The crude oil price was varied between $21.00 per barrel and $35.00 per barrel
For the batching operation, installing new storage and relief tanks at the terminal and pump stations respectively versus refurbishing some old tanks to accommodate GTL production and storage.

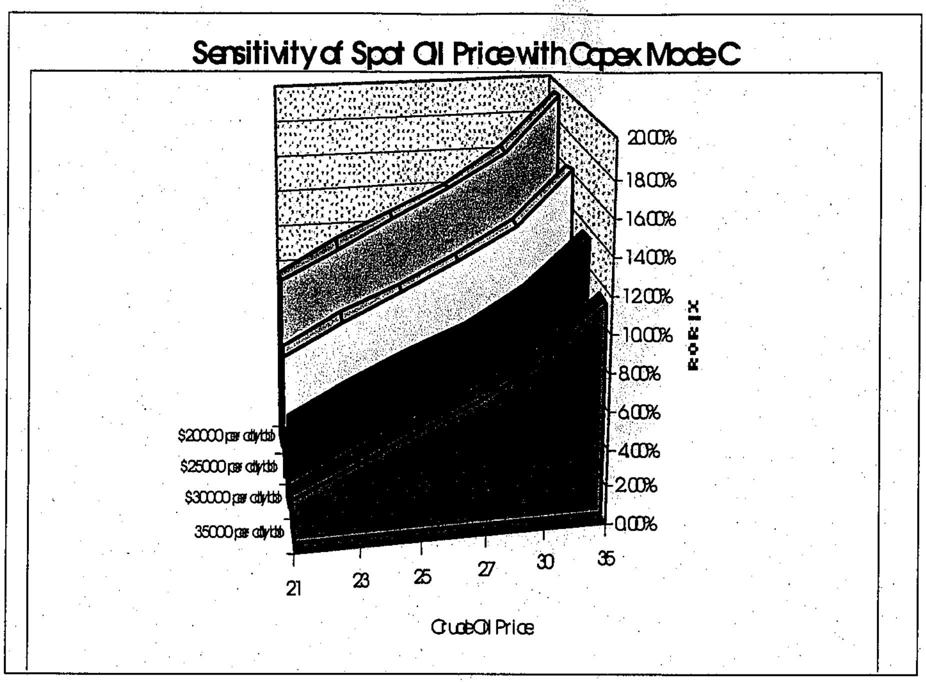

Figure 6.4 Sensitivity Analysis with Various World Oil Prices and Various Capex

Table 6.5
Summary of Results

Summary of Sensitivity Using Batch Mode C				
Crude Price/ Capex $/DBL	35000	30000	25000	20000
21	1.03%	3.30%	5.91%	9.05%
23	2.68%	4.93%	7.54%	10.70%
25	4.16%	6.40%	9.02%	12.22%
27	5.50%	7.75%	10.40%	13.64%
30	7.34%	9.60%	12.29%	15.61%
35	10.02%	12.34%	15.12%	18.57%

6.7 METHOD OF EVALUATION

The capital investment required for transportation of GTL products was amortized and will be paid back through the twenty years of the project life at a discount rate of 15%. The yearly amortization was divided by the throughput to arrive at the extra cost in $/bbl of batching GTL product either by purchase of new infrastructure or refurbishing of existing infrastructure.

6.7.1 Investment Pattern

Construction is assumed to start in year 2005 and last till 2008 for the first train. The capital cost is varied between $20,000 /DBL and $35,000 / DBL invested equally between the four years. The second train is assumed to commence immediately the first is completed and put on production and the third after two years of commencing of the construction train 2. Operating and maintenance cost for each of the trains commenced comes in the same year with production for each of the three trains.

The property tax is calculated from a tax base obtained after depreciating the capital cost using the MACRS and using the taxation formula obtained from the state's department of revenue to calculate property tax base and finally obtain the tax, which is 2% of the tax base. A cash flow model was set up to analyze the same. For the different modes of transportation, the associated capital cost was included under the tariff and comes as cost per year. The cost of gas both as raw material for the GTL plant and the cost of gas for running the first four pump stations are all included in the cost section. The revenue was obtained as a product of the expected product sale price and the total product transported. The taxation was then applied appropriately to calculate net revenue and profit.

6.8 RESULTS AND DISCUSSION

The rate of return analysis result for the various transportation modes are presented below (Figures 6.5-6.7).

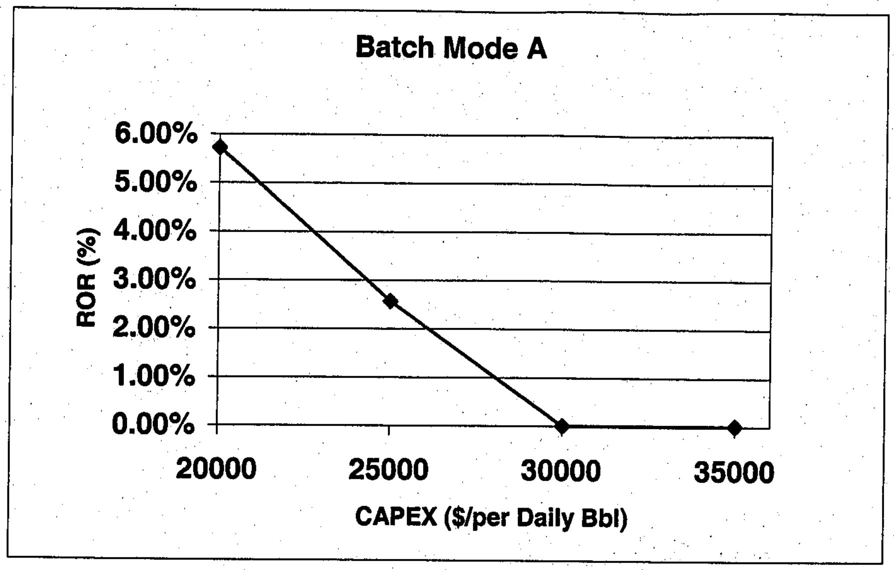

Figure 6.5 ROR analysis for Batch Mode A

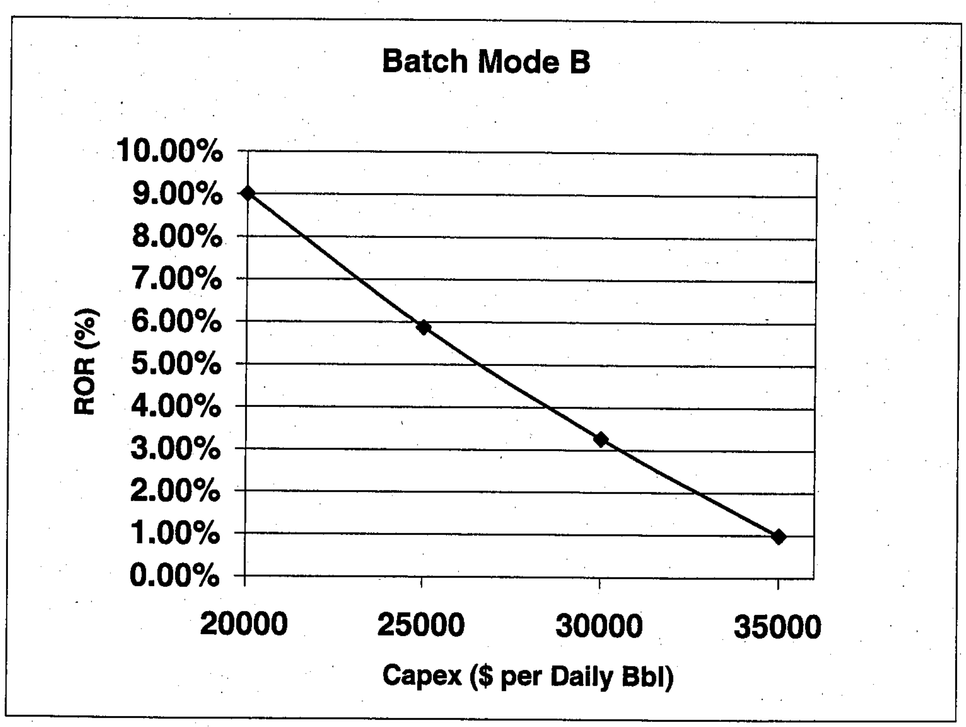

Figure 6.6: ROR analysis for Batch Mode B

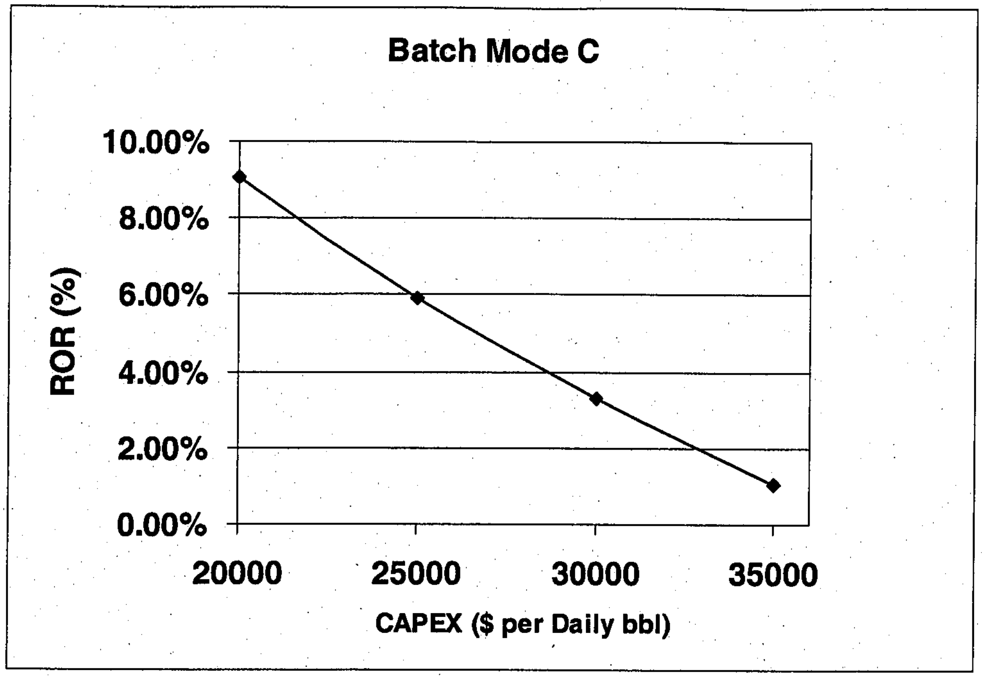

Figure 6.7 ROR analysis for Batch Mode C

Batch mode C had the highest return on investment among all the transportation modes and for all plant capital investments scenarios studied. The recovery efficiency of pure GTL product here was put at 95%. This assumes that 5% of the GTL mixes with the lead crude to form an interface and is expected to clean the pipeline for the pure GTL product as the middle fluid followed by another interface of GTL crude oil mixture. Experience of operators that carry out similar operations show that typically, the length of the interface does not depend on the volume pumped but rather on the difference in the physical properties such as density and viscosity of the leading and tailing product as well as the velocity of the fluids in the pipeline. This implies that holding capacity at the North Slope may play a significant role in the optimization process to help minimize the number of slugs to be pumped through in a day.

The GTL premium used in this calculation is 1.3 times the world spot oil price. To arrive at this number, a survey carried out showed that conventional diesel products over the years sold for about 1.42 times the price of crude on the average. A typical GTL plant in this study assumed a product with an 80% yield of Fischer Tropsch (FT) diesel and 20% yield of Naphtha products. Naphtha was given a number of about 1.19 times the price of oil from the historical survey. Combining these two in their ratio of yield and price will give the combined GTL product a value of about 1.37 times the price of crude oil. However, to adopt a conservative approach, 1.3 times the world spot oil price was taken to perform the evaluation. Many authors in the subject are also of the opinion that the GTL diesel should sell at a higher price than the conventional diesel product from typical crude oil distillation process considering its environmental superiority as discussed above. This edge for the GTL diesel was not taken into account in the study. Figure 6.8 shows various rates of return for different GTL product premium prices.

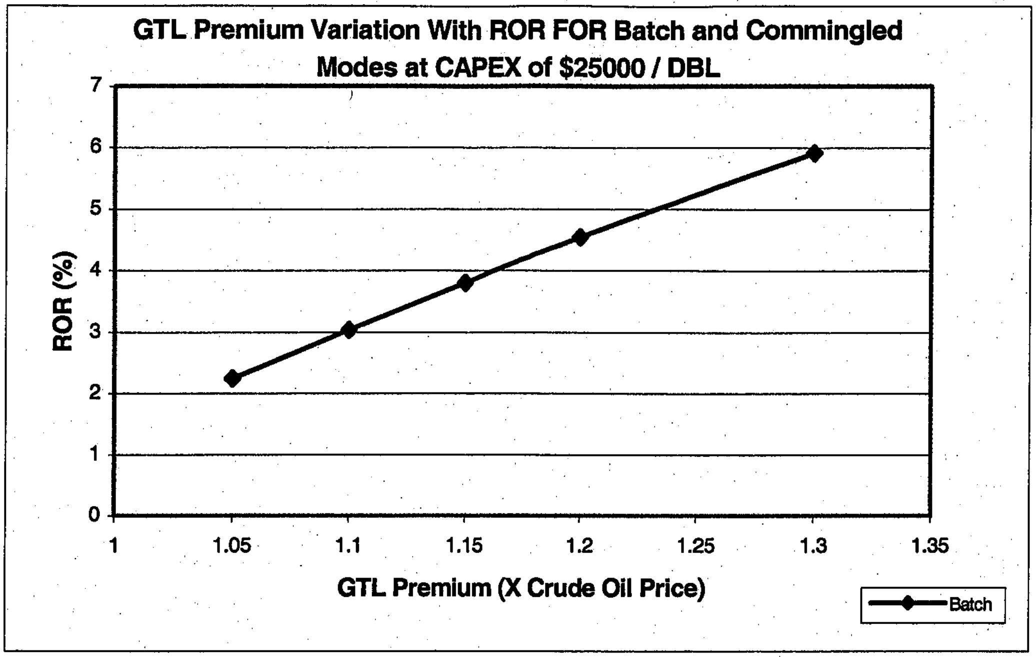

Figure 6.8 GTL Premium Variation with Rate of Return

Another interesting comparison that was conducted out for the adopted batch mode was to compare the difference in the rate of returns between building new tanks at the terminal and reconfiguring existing ones.

Table 6.1 and Figures 6.5-6.7 show the projected difference in capital cost and rate of return respectively.

Table 6.6
Effect of Reconfiguring versus Building New Tanks

CAPEX ($/DBL)	Reconfigure Old Tanks	Build New Tanks
20,000	9.16%	9.05%
25000	6.03%	5.91%
30000	3.43%	3.30%
35000	1.17%	1.03%

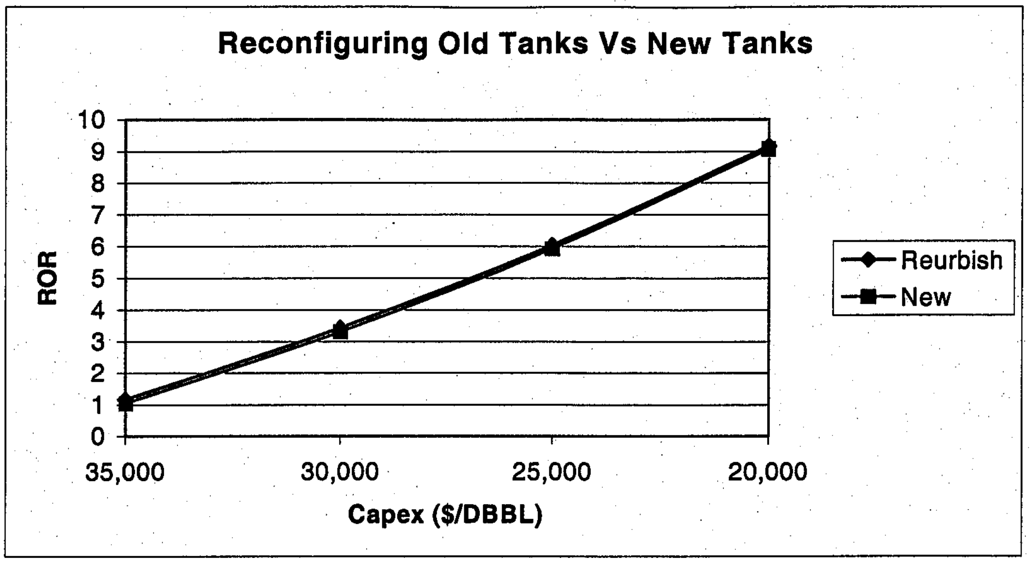

Figure 6.9 Effect of Building new Tanks versus Reconfiguring existing tanks at terminal.

Based on the above, it may appear that there is no major benefit of reconditioning and reconfiguring existing tanks at the terminal for batching operations. However, it is important to take into account the huge capital investment in this project, which means that a slight difference in the rate of returns represents a significant sum of money.

Next to batch mode C on the return on investment analysis is the batch mode B. Product purity is assumed maintained in this mode of transportation with the 95% pure GTL recovery. The labor cost for transitioning the pigs at the pump stations on a continuous basis is the major drawback of this method of batching. Another set back here is that the running such rigorous operation on a continuous basis may introduce a lot of human error factors. Pipeline Pig manufacturers believe the pigging technology can be adapted to suit the TAPS operation and reduce the labor required for this operation. However under the current assumptions, the return on investment for mode B is just slightly less than the batch mode C. The cost of obtaining the extra technology for batch mode C is offset by the high pure product recovery.

The batch mode A is just a base case which is similar to mode C except that no investment is made towards pure product recovery and therefore expected high mixing of the Gas-to-Liquids products and Crude oil is expected in this case.

The commingled mode shows the least returns on the investment. This mode assumes that minimal investment is made to the transportation of the products. The piping from the GTL plant to pump station one on the North Slope is the only major capital investment made on this mode of transportation. The commingled product was initially assumed to sell at same price as the spot crude oil price. When the improvement in the API gravity of the crude oil was put into consideration and assuming that the commingled product will have a higher yield of middle distillate when compared to the original crude oil, a one-dollar raise in product value was assigned and the model run again. The batch mode gave the higher return on investment. The difference in the return on investment between the batch and the commingled mode is very significant considering the fact that any minute difference in ROR figure of even less than 1% for such capital intensive project runs into hundreds of millions of dollars.

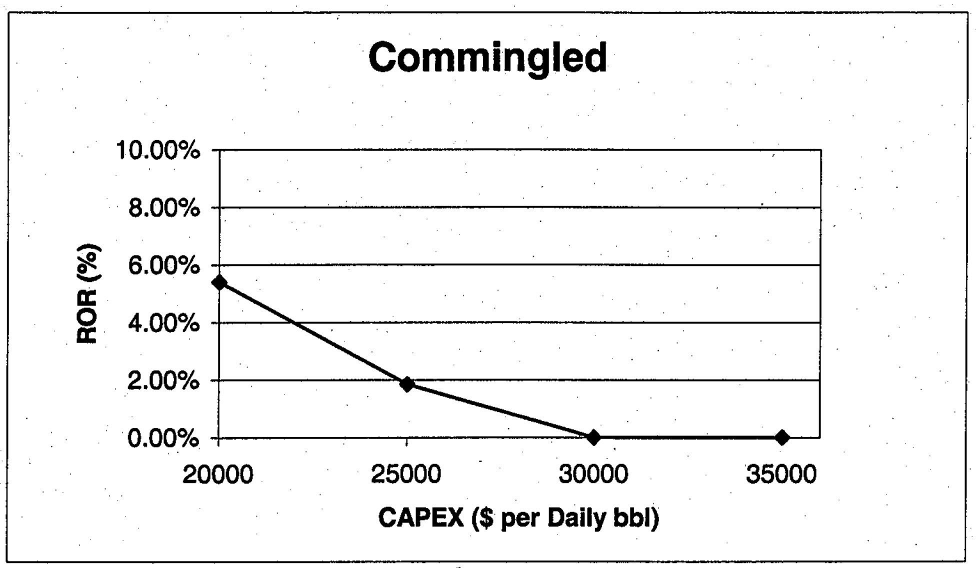

Figure 6.10 ROR analysis for Commingled Mode

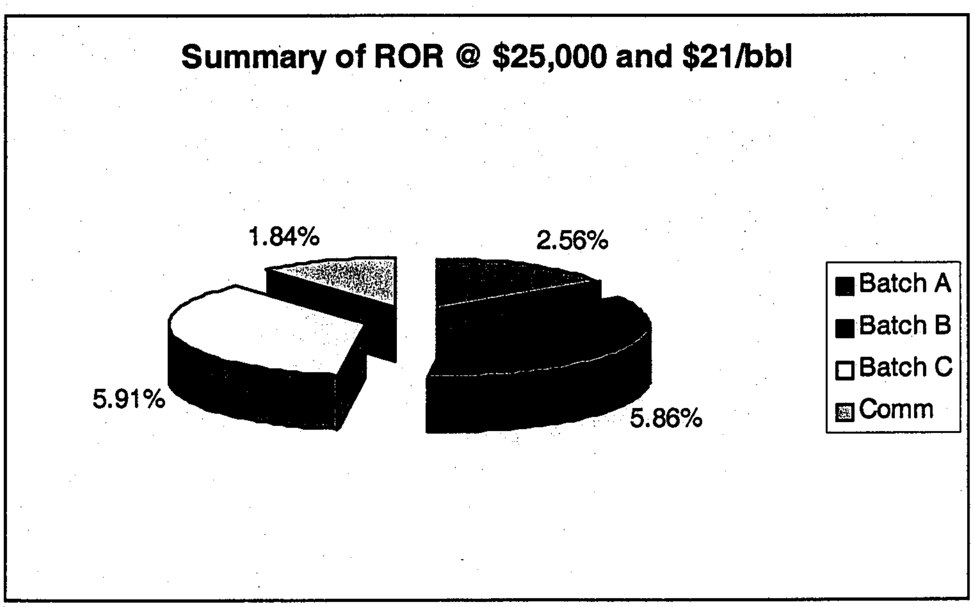

Figure 6.11 Summary of ROR Analysis For all Modes of Transportation

6.9 SUMMARY AND CONCLUSIONS

The modern batching approach consistently gave the highest return on investment and is recommended for transporting the Gas-To-Liquid products from the North Slope of Alaska to Valdez. The major concern with batching is the length of the mixing zone or interface and the purity of the GTL products as they arrive the Marine Terminal in Valdez. Since experience shows that the length of this interface is independent on volume pumped, it becomes an optimization issue to find the optimum holding capacity on the North Slope that can give the minimum number of batches at any given production period. The optimum fluid velocity in the pipeline should be determined with reasonable accuracy based on the density and viscosity difference of the two products to be transported to ensure minimum interface.

One reason for the low numbers in the rate of return analysis is that the project life assumed is not long enough to enable the project make adequate profits after pay out. Considering the investment pattern, train 2 and 3 for example barely had enough time to pay out and start making profit. Typical pay out times are shown in the figure 6.11 below:

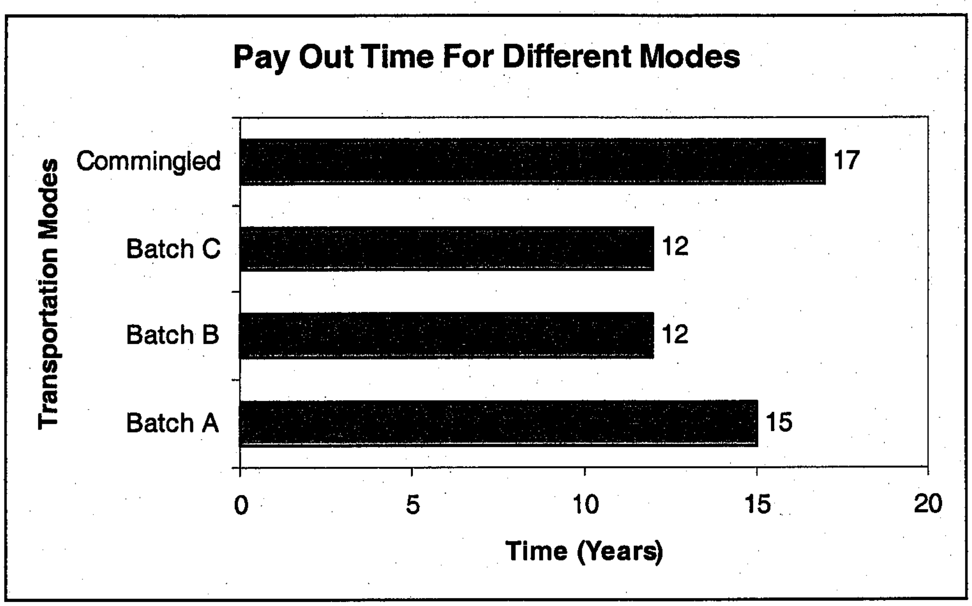

Figure 6.12 Summary of Payout time for Capex $25,000 / DBL and Crude price of $21/bbl

From Figure 6.11 above, it is evident that the project has not had enough time to make sufficient profit for the 20-year evaluation. One quick way to make projection after the twenty years period is to make a plot of the ROR progress over the observed years and make forecasts. Figure 6.12 shows these results.

From Figure 6.12, the projection on the ROR curve shows that the project still has about 8 years before the project life chosen would not matter anymore. Since this study is focused on a comparative analysis of the transportation modes, the magnitude of the rate of return is not the key concern.

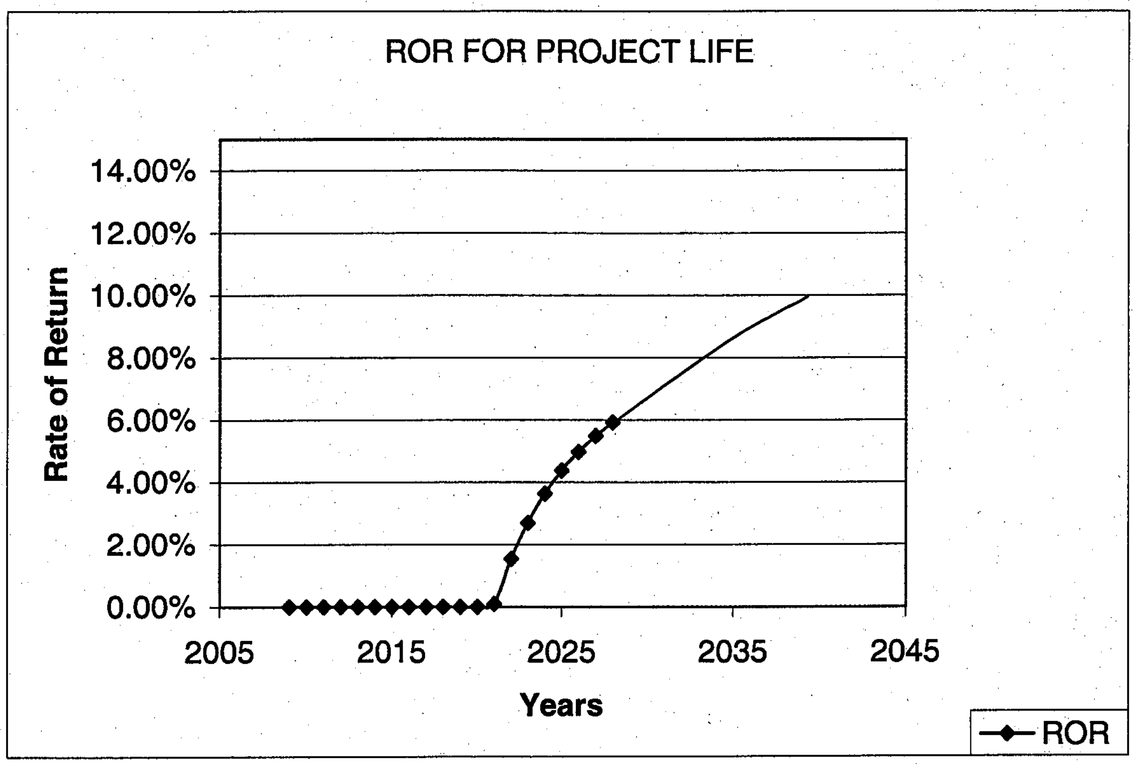

Figure 6.13 Project Life evaluation time.

NOMENCLATURE

ANS	Alaska North Slope
APSC	Alyeska Pipeline Service Company
DBL	Daily Barrel Liquid
DCS	Distributed Control System
DOE	Department of Energy
EIA	Energy Information Administration
GTL	Gas-to-Liquids
LNG	Liquefied Natural Gas
ROR	Rate of return
TAPS	Trans-Alaska Pipeline System
CAPEX	Capital Expenditure
L_m	Length of Mixing Zone, m [ft]
L_s	Slug Length, m [ft]

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