

12235

HOUSE RES

3/2/07

PRESENTA

-TION:

GAS TO

LIQUIDS

Gas to Liquids Meeting

March 2<sup>nd</sup> 2007 House Resources

Confirmed:

Dr. Godwin Chukwu, Ph.D., P.E.  
Petroleum Development Laboratory  
Institute of Northern Engineering  
University of Alaska Fairbanks  
(his presentation will probably take one hour)

Cathy Foerster, Commissioner  
Alaska Oil and Gas Conservation Commission  
(via teleconference for questions)

Kevin Banks, Acting Director, Division of Oil and Gas  
Alaska Department of Natural Resources  
(via teleconference for questions)

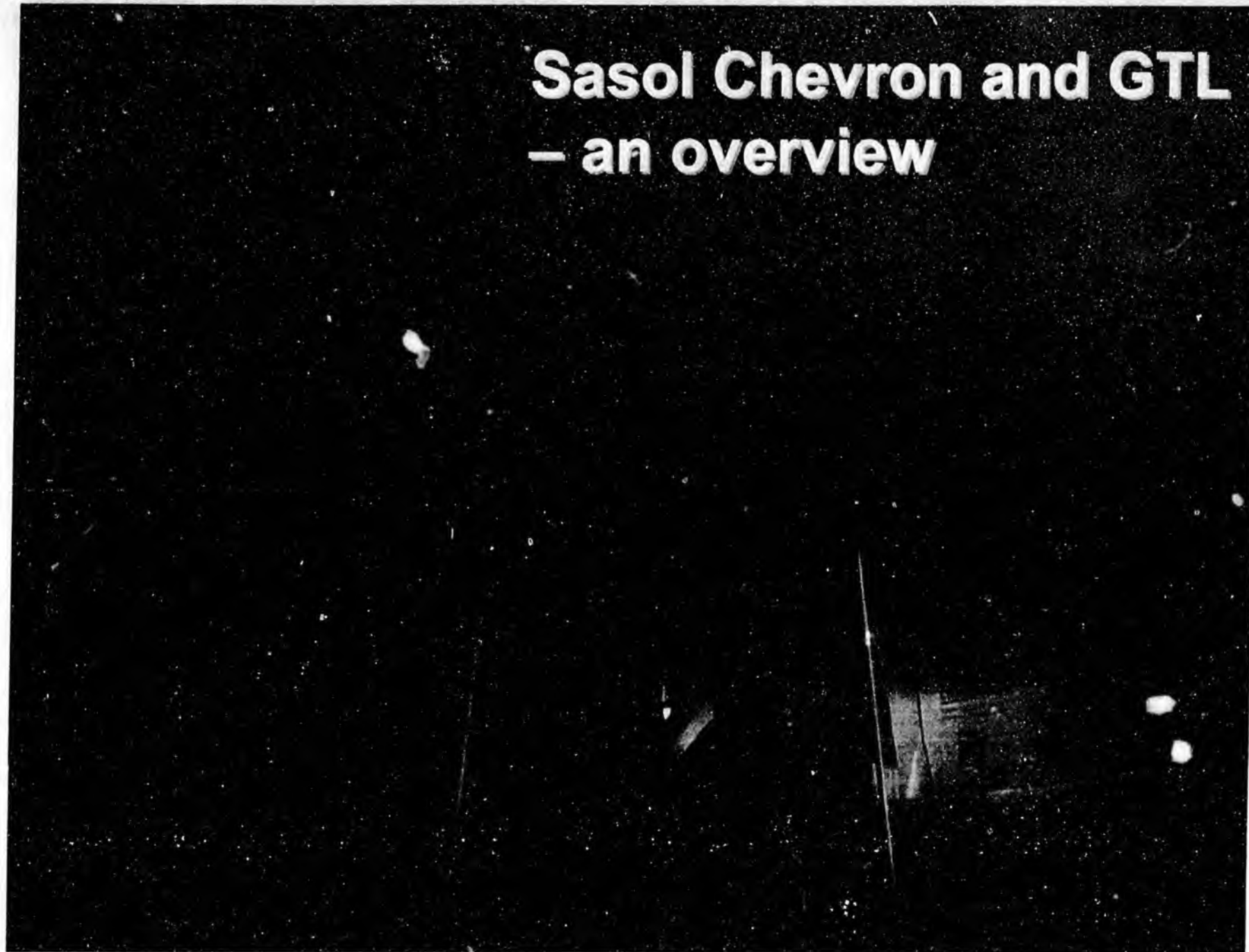
BP - Mike Gradassi, Project Development Manager for BP's Conversion Technology  
Centre  
(brief presentation, probably ten minutes)

SasolChevron - Peter Cook (Sasol London)  
(presentation for about half an hour)

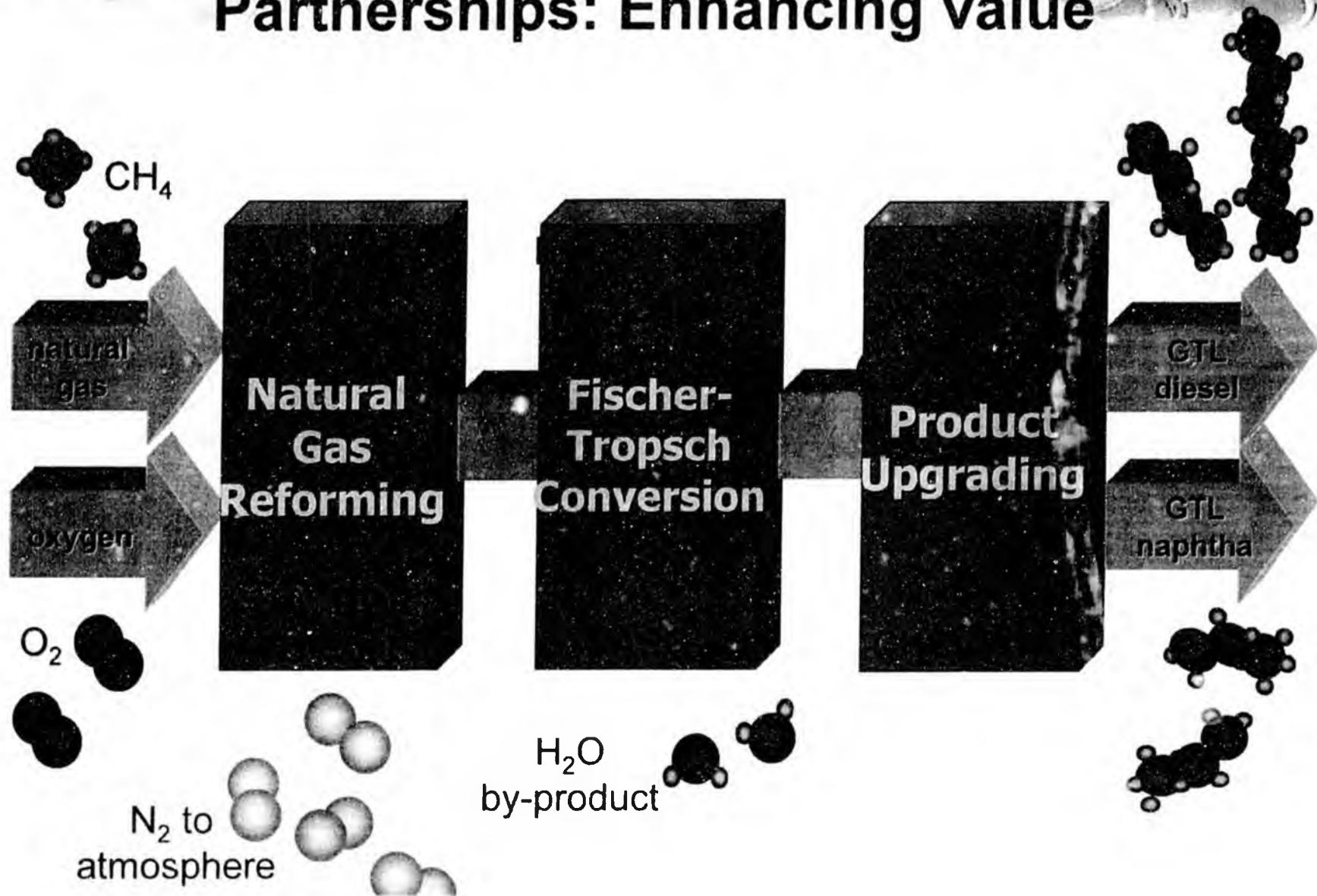
Invited:

Shell - Cam Toohey  
Exxon - Kevin Jardell  
Conoco Phillips - Michael Hurley, Gerry Gallagher  
Flint Hills - Bob Evans, Jeff Cook  
PetroStar - Royce Weller, Jerry Mackey, Doug Chapados  
Alyeska - Mike Heatwole  
AOGA - Kara Moriarty, Judy Brady  
American Petroleum Institute - Peter Lidiak (pipeline specialist)  
(probably most will be in the audience)

**Sasol Chevron and GTL**  
**– an overview**



# Partnerships: Enhancing value

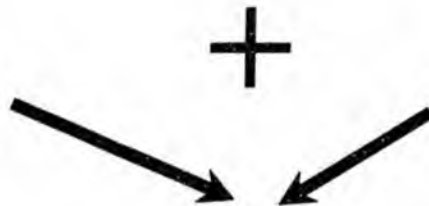




# Matching the GTL challenge

Global Drive For  
Cleaner Fuels

Monetise Abundant  
Global Gas Reserves



Proven GTL Technology  
Operating Experience  
GTL Marketing Experience

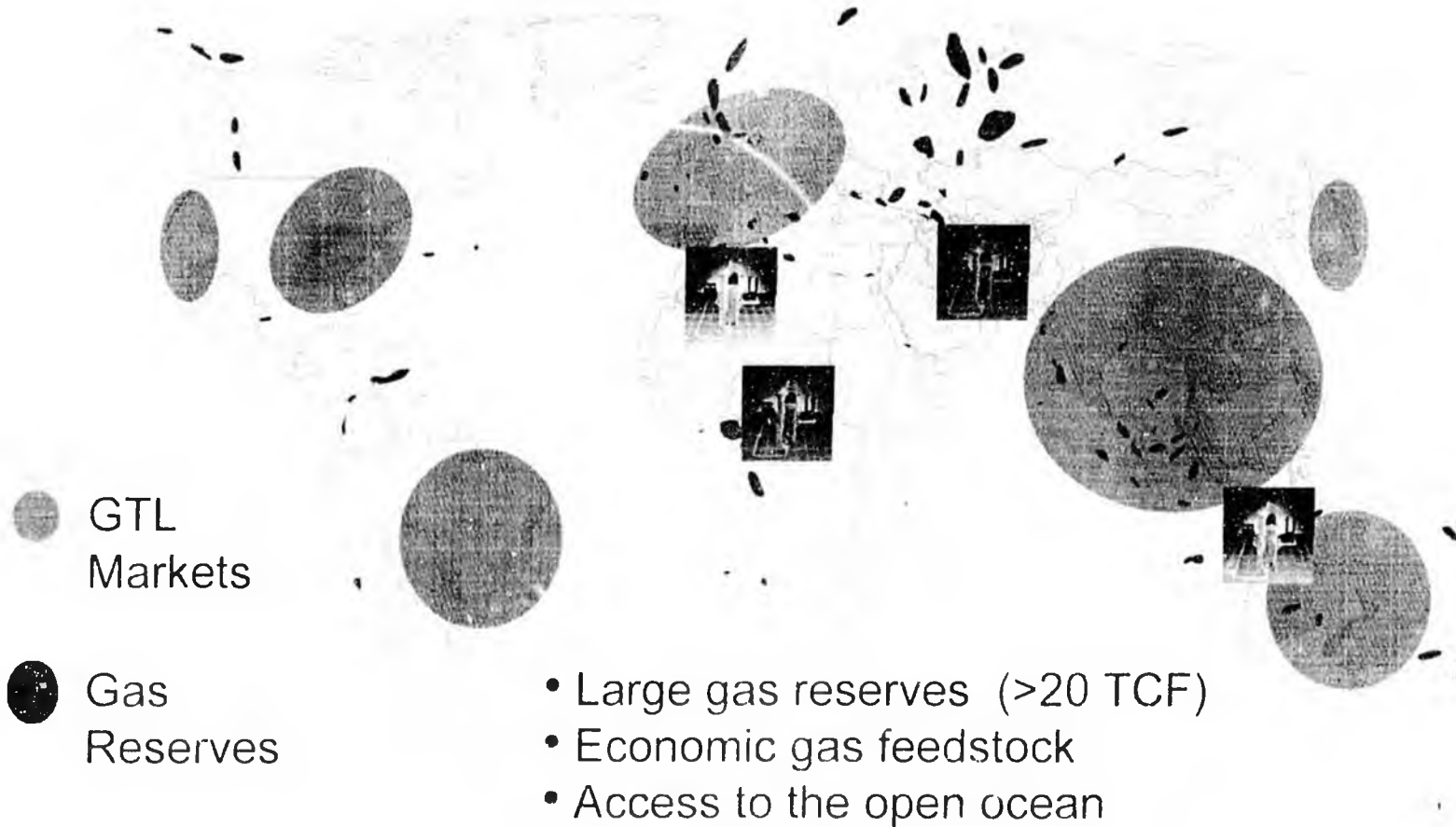


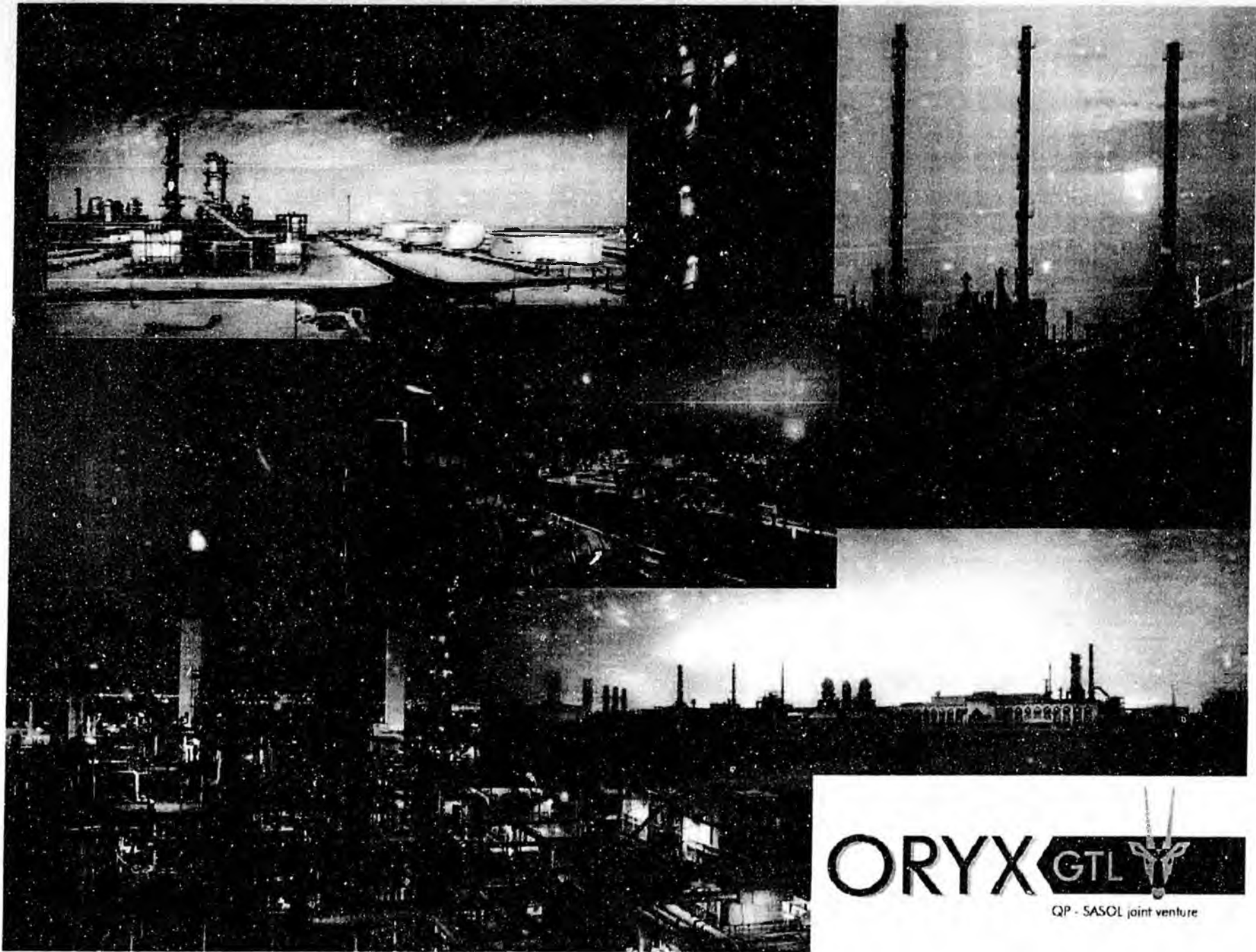
International Presence  
Marketing Expertise  
E&P Experience  
International Deal Making

**Build, Own & Operate Plants - Market GTL Products**

**GTL PRODUCTS – COMBINING HIGH PERFORMANCE WITH  
LOWER ENVIRONMENTAL IMPACTS**

## Locations for GTL

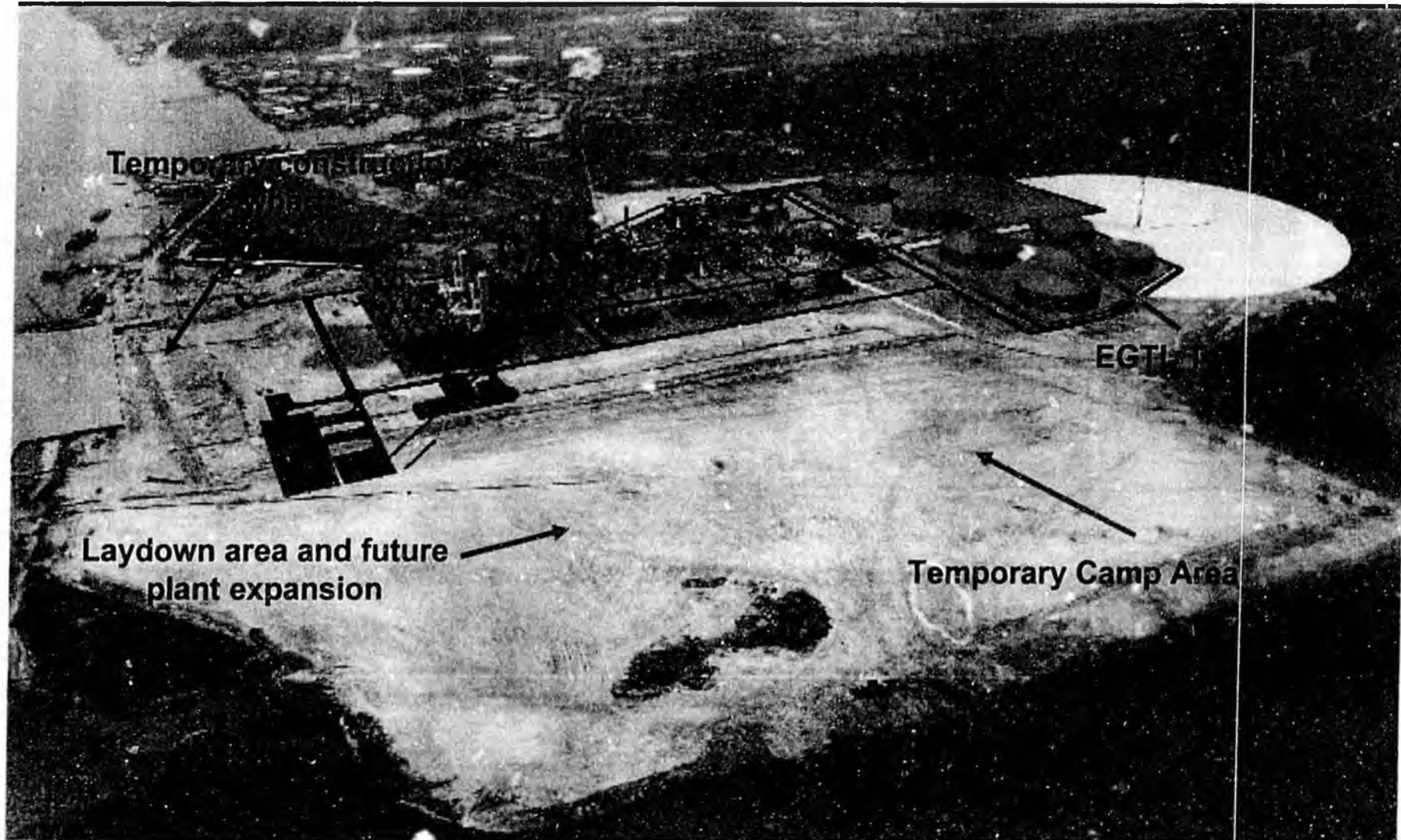




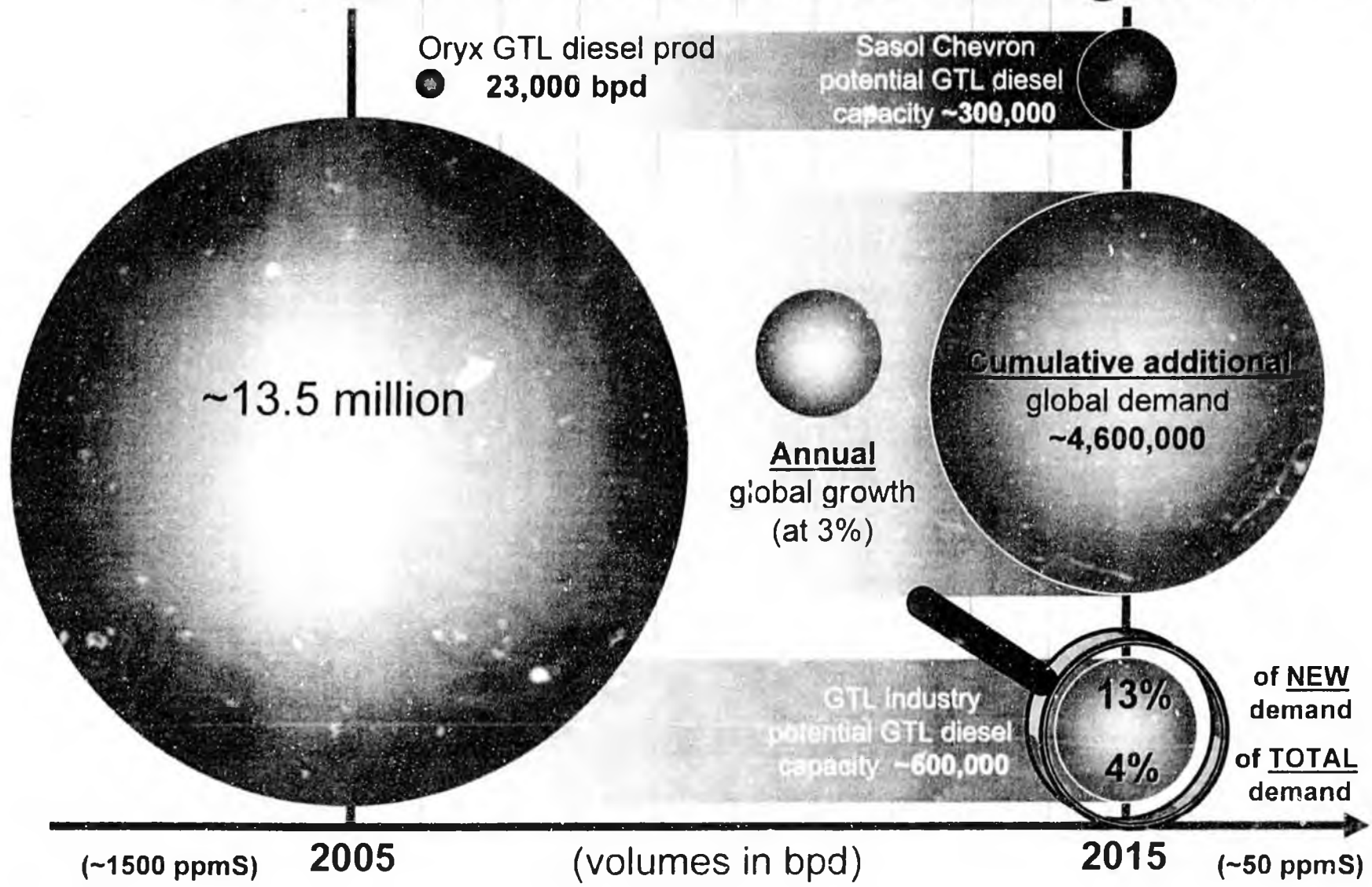
**ORYX** **GTL** 

QP - SASOL joint venture

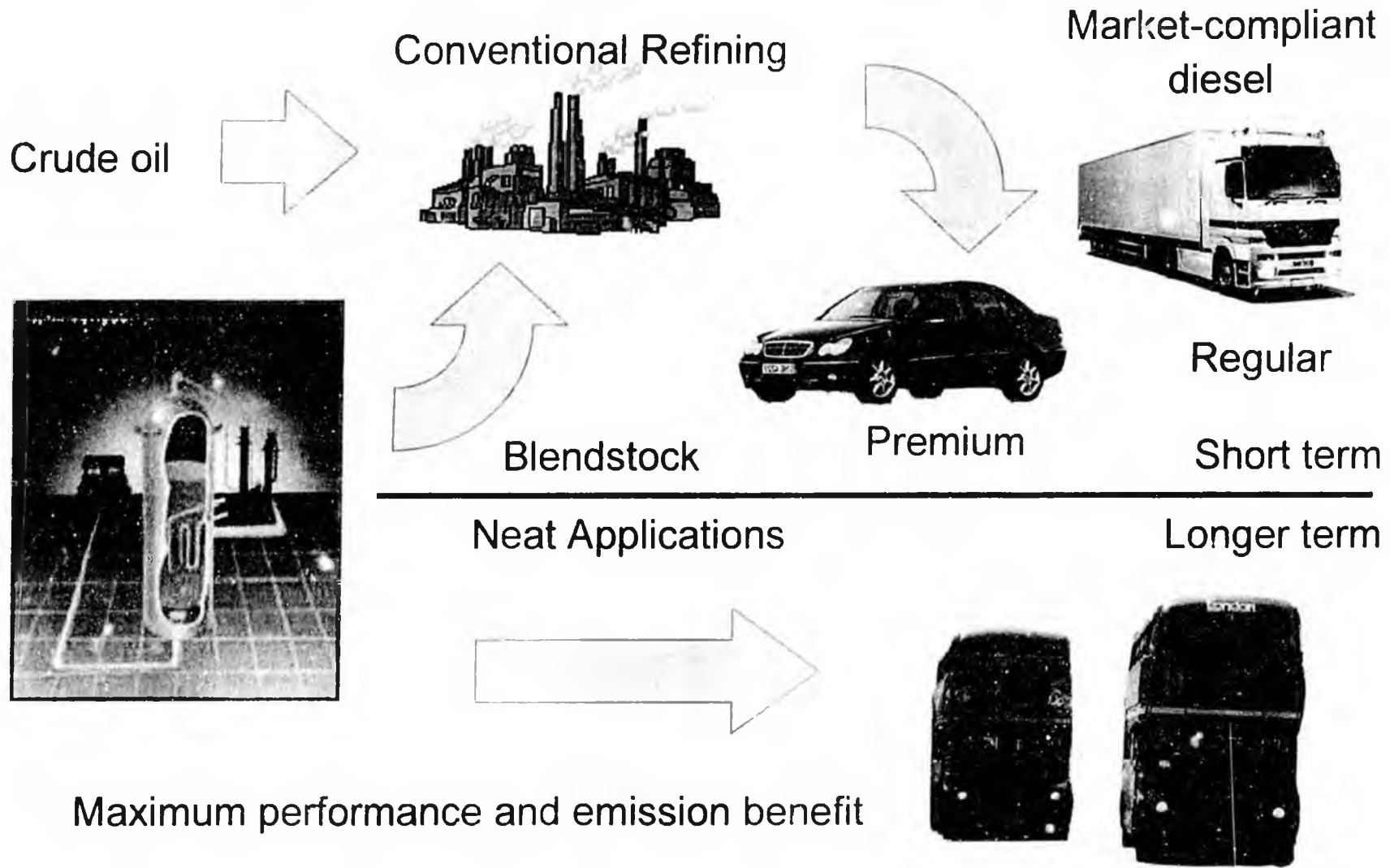
# EGTL – Escravos, Nigeria



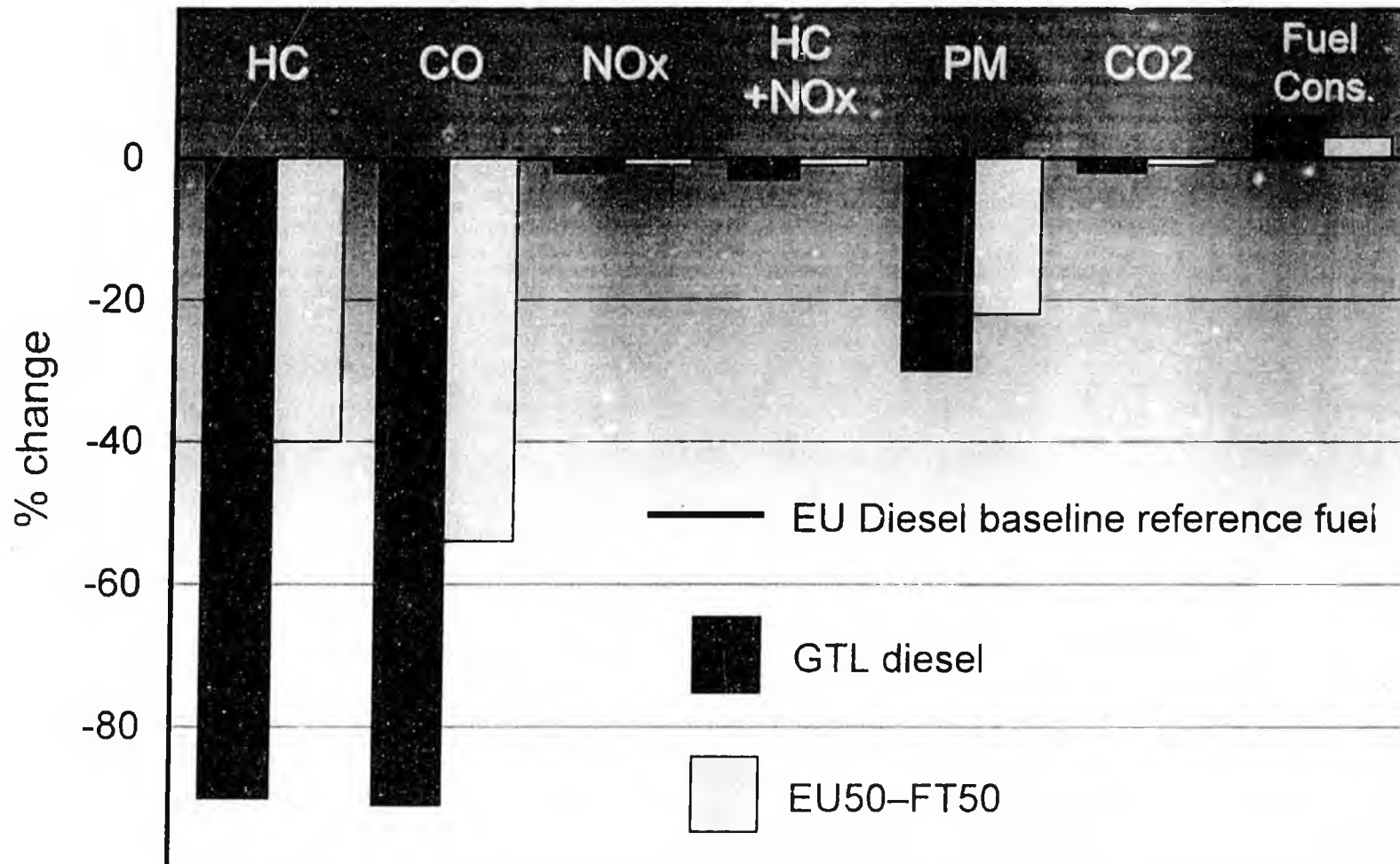
# Market scale: diesel demand growth



# GTL diesel market channels



# Meeting new air quality demands



Results from passenger engine trials with Daimler Chrysler



asfe

alliance for synthetic fuels in europe

Co-operation with OEM's

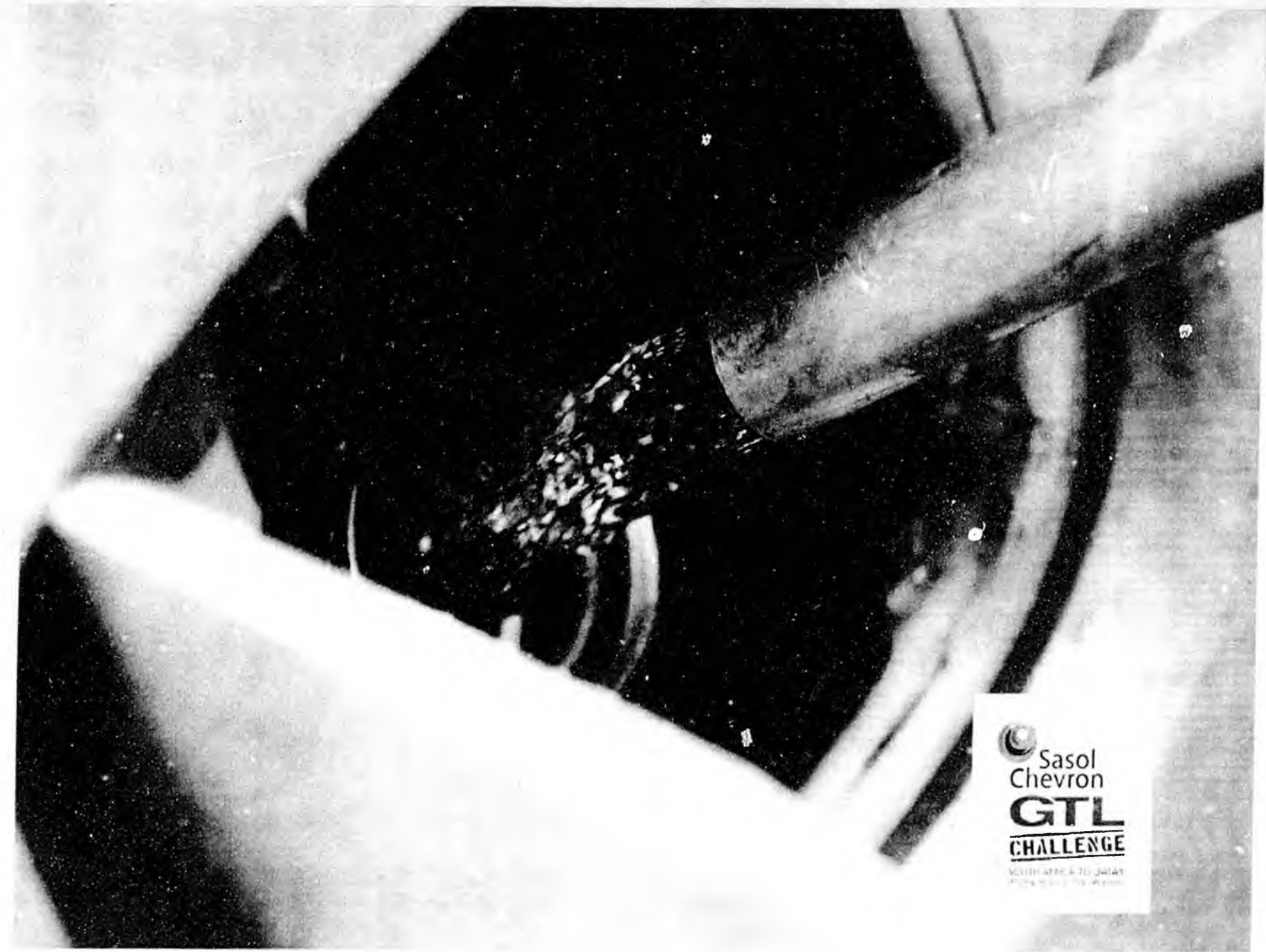


Saudi  
Chevron

# The Sasol Chevron GTL Challenge

- A standard diesel vehicle (Toyota Raider)
- 11,000 kilometres
- 46 days
- No problems (with the car and the fuel at least)

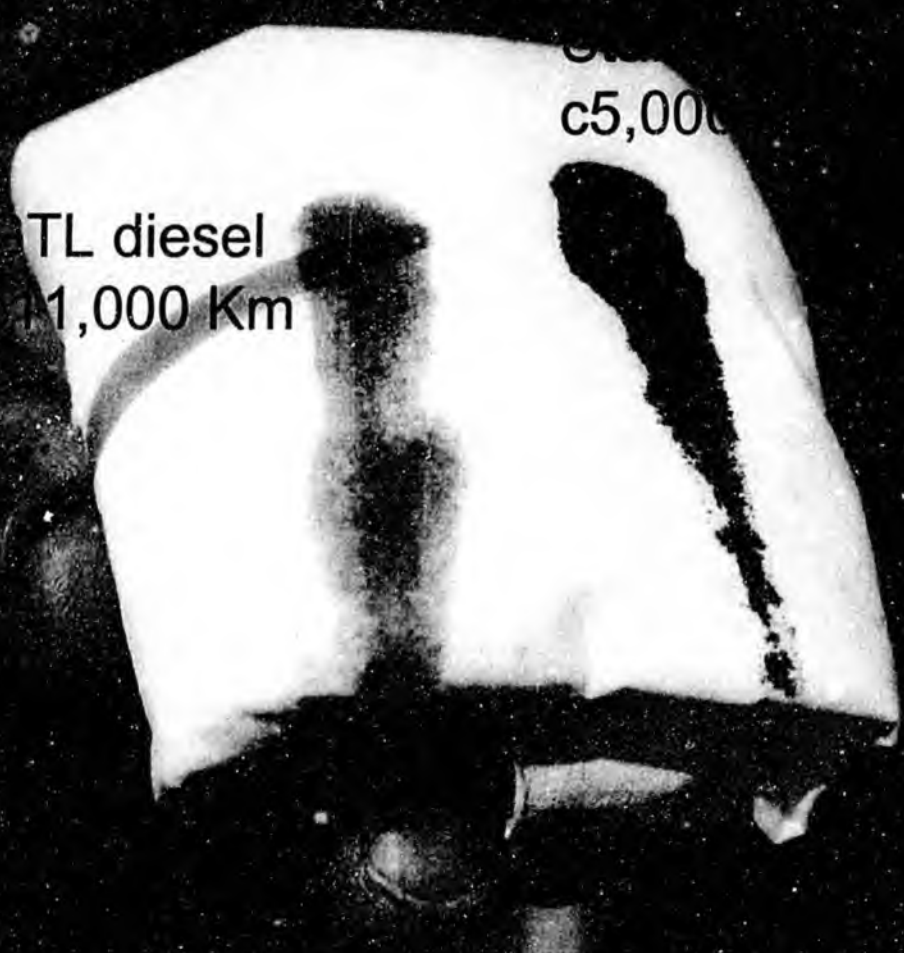




Sasol  
Chevron  
**GTL**  
**CHALLENGE**

MOUJIBABE & TIL QATAY  
MOTOR OILS & LUBRICANTS

# Journey's End



c5,000

TL diesel  
11,000 Km

Sasol  
Chevron  
**GTL**  
**CHALLENGE**  
SOUTH AFRICA TO QATAR  
Rally of the 21st Century



**A GREAT  
CHALLENGE  
NEEDS A  
GREAT DIESEL.**

**The GTI. Challenge convoy**  
in Matewi during its epic 11,000 kilometre  
journey from South Africa to Qatar.

**DRIVING ON GTL**

[www.sasolchevron.com](http://www.sasolchevron.com)

Sasol  
Chevron  
**GTL**  
**CHALLENGE**  
- FATHAMEN 99 9416

**OPERATIONAL ISSUES IN GAS-TO-LIQUID (GTL)  
TRANSPORTATION THROUGH  
THE TRANS ALASKA PIPELINE SYSTEM (TAPS)**



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**Presented to the Alaska State Legislature  
(House Resources Committee)**

**March 2, 2007**

**Godwin A. Chukwu (PhD, PE)  
Professor of Petroleum Engineering  
Department of Petroleum Engineering  
University of Alaska Fairbanks**

# **OUTLINE**

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- **ANS Gas Resources**
- **ANS Gas Utilization Options**
- **Problem Statement**
- **Possible Solution**
- **Gas to Liquid Technology**
- **Features of TAPS**

# **OUTLINE (Cont'd)**



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- **Project Focus**
- **Proposed Modes of GTL Transportation through TAPS**
- **GTL Transportation Issues**
- **Operational Challenges**
- **Conclusions**



# **ANS GAS RESOURCES**

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- **Proven and Recoverable Conventional Natural Gas Reserves: 38+ TCF**
  - Prudhoe Bay (29+ TCF)
  - Point Thompson (9+ TCF)
  
- **Other Potential Resources:**
  - Conventional Gas in ANWR (31 TCF)
  - ANS Gas Hydrates (590 TCF)
  - Coal – Bed Methane (1000+ TCF)

# **ANS GAS UTILIZATION OPTIONS**

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- **Transportation through a Newly Constructed Trans-Alaska Gas pipeline**
- **Conversion to miscible injectant (MI) for Enhanced Oil Recovery (EOR) operations on the north slope**
- **Build Natural Gas based petrochemical complex**
- **For Electrical Power generation**
- **Burning Natural Gas to Generate Steam for potential Thermal Recovery Options**
- **Chemical Conversion to GTL products and transport through TAPS**

# **PROBLEM STATEMENT**

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- **Dwindling oil production on Alaska North Slope (ANS) is exerting increased burden on economic operation of the TAPS**
- **How do we continue to operate the TAPS economically in the future**
- **What do we do with such vast gas resources?**
- **Domestic gas market far away from ANS**
- **Very small local demand**
- **Limited natural gas use in EOR and other operations**

# **POSSIBLE SOLUTION**

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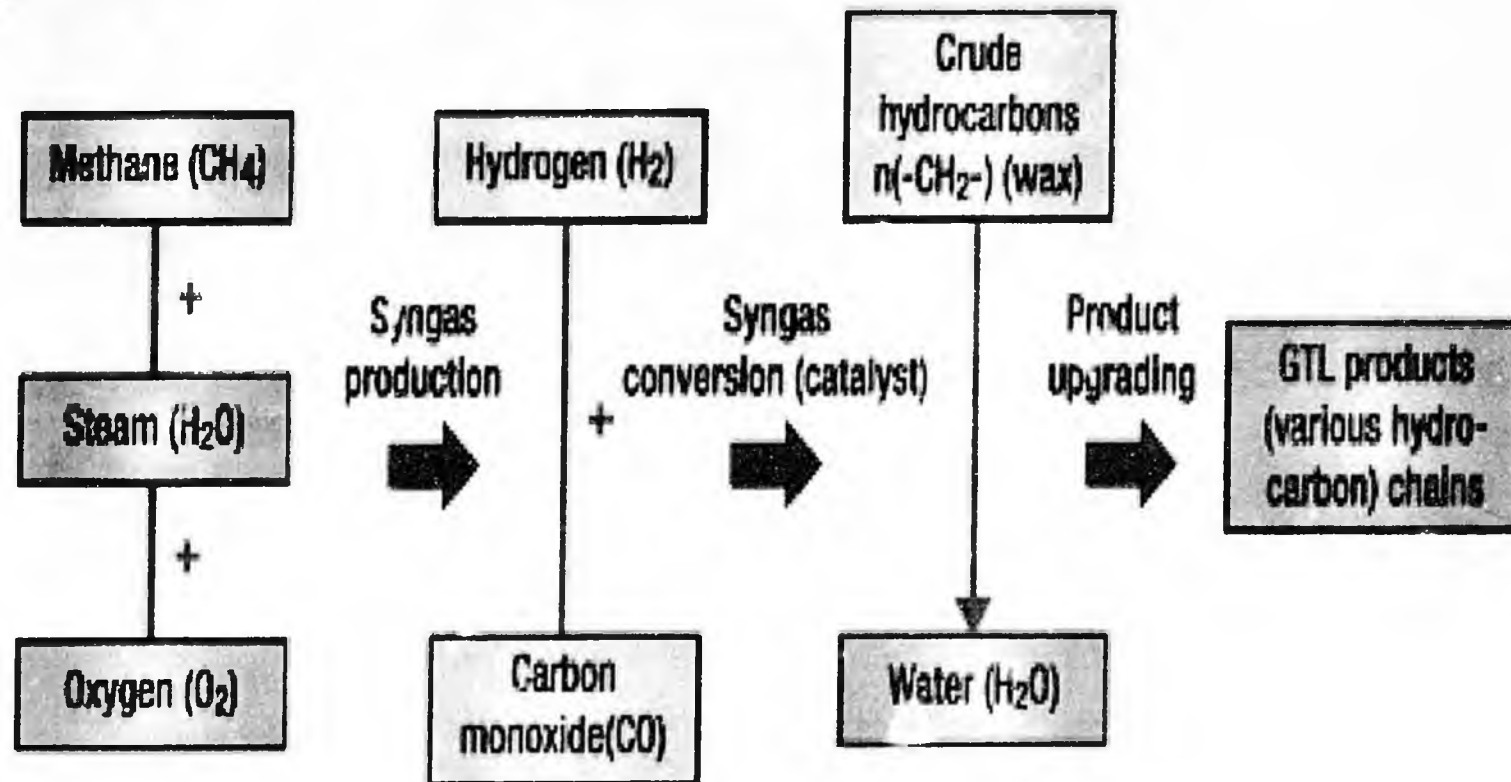
- **A combination of the two part problem statement can lead to a feasible solution**
- **The vast natural gas resources on the ANS can be converted to Gas-to-Liquids (GTL) products using the Fischer-Tropsch (FT) process that dates back to WW II period**
- **These so called GTL products can be utilized to fill up the Trans Alaska Pipeline System (TAP) with crude oil**
- **In this manner we can address both the issues, i.e., increase the economic life of TAPS and monetize the huge gas resources on the ANS**

# **GAS-TO-LIQUID (GTL) TECHNOLOGY**

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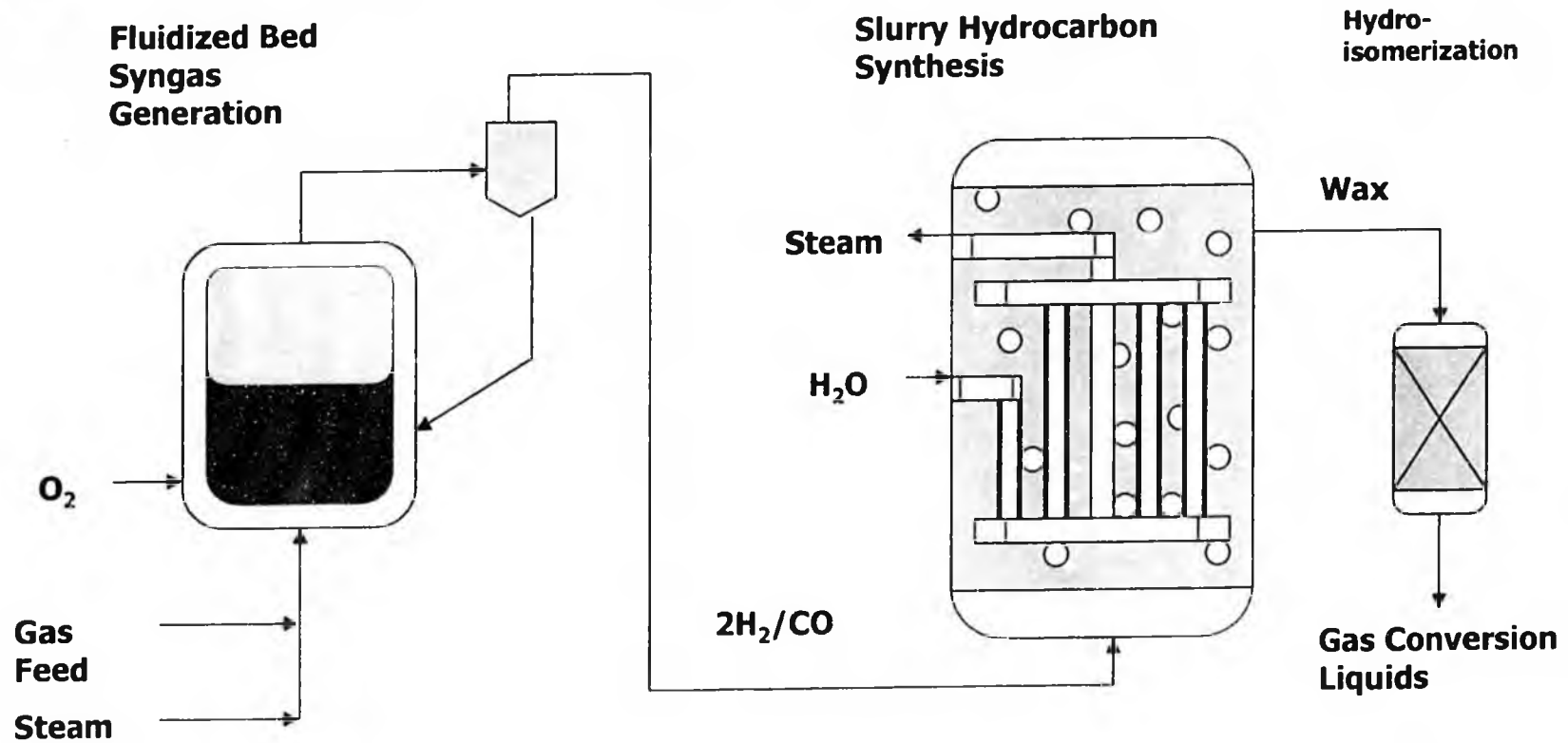
- **3-step Fisher-Tropsch chemical process for converting natural gas ( $\text{CH}_4$ ) to synthetic crude**
- **Direct production of Diesel, Naphtha, Kerosene**

# GAS-TO-LIQUID (GTL) TECHNOLOGY (cont'd)



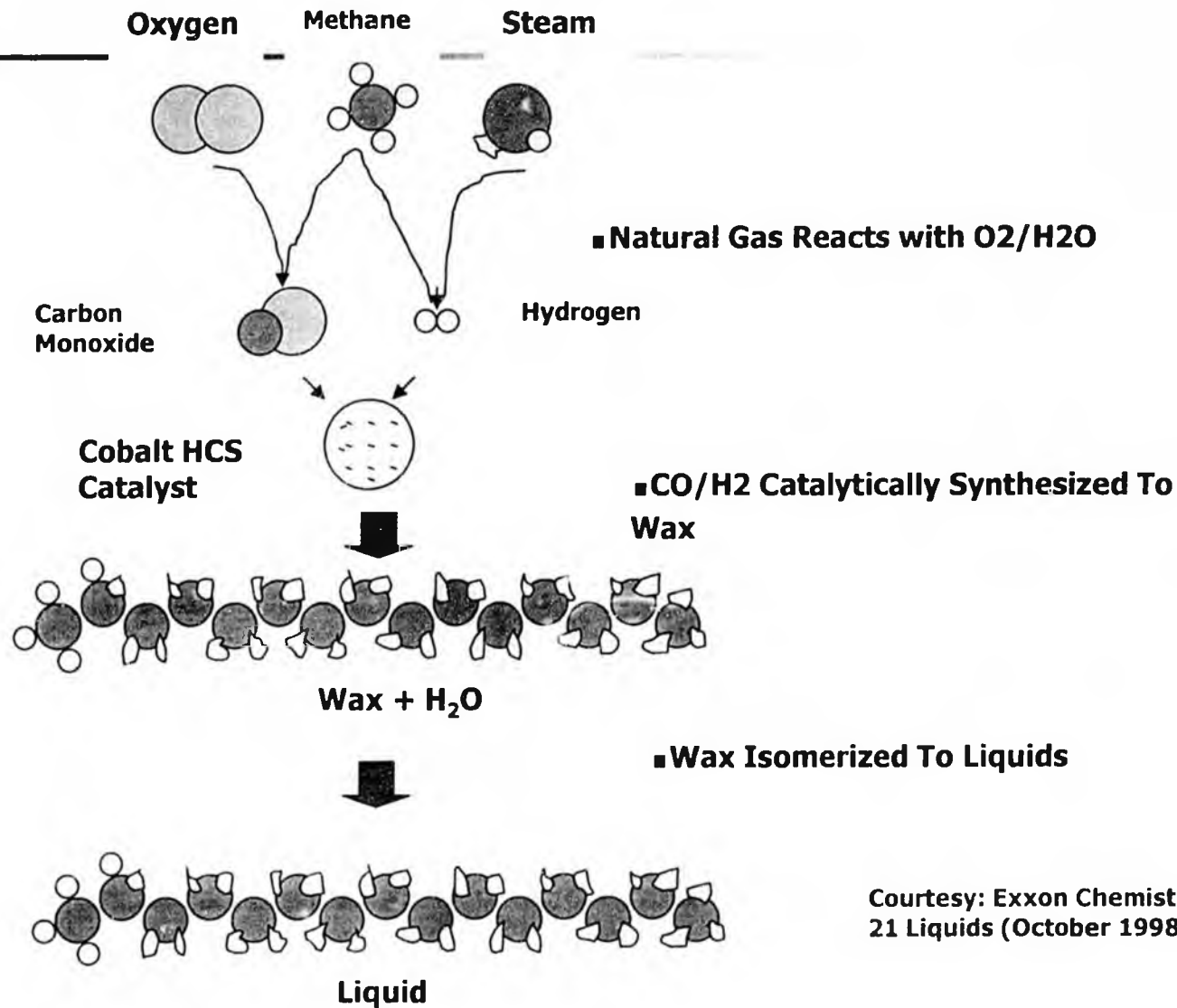
Courtesy: Fischer-Tropsch process for obtaining GTL products (Fischer, 2001)

# GAS-TO-LIQUID (GTL) TECHNOLOGY (cont'd)



Courtesy: Exxon AGC-21 (Advanced Gas Conversion for the 21<sup>st</sup> Century), October, 1998

# GAS-TO-LIQUID (GTL) TECHNOLOGY (cont'd)



Courtesy: Exxon Chemistry for producing AGC-21 Liquids (October 1998)

# **GTL TECHNOLOGY (cont'd)**

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## **Why?**

- **Significant worldwide volumes of stranded gas reserves**
- **Diversify marketing options**
- **Production of Environmentally Friendly Fuels**

## **Why now?**

- **Technology advances have significant reduced capital costs**

## **Why Alaska?**

- **No economic gas utilization option now**
- **Investigate all potential options**
- **Continued operation of TAPS will require significant increase in throughput**

# **BENEFITS OF GAS-TO-LIQUID (GTL) PRODUCTS**

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- **GTL is an attractive way to utilize ANS gas resources**
- **A "clean" source of energy**
  - **environmentally friendly**
- **Make use of existing TAPS infrastructure**
- **Work as diluent in future diverse throughput of ANS heavy oils**
- **GTL transport will increase TAPS throughput and economic operational life**



## **FEATURES OF TAPS**

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- **Existing infrastructure for transporting crude oil**
- **800 miles, 48 inch diameter, Prudhoe Bay to Valdez**
- **Underground and above ground sections**
- **Crosses three mountain ranges**
- **Ambient air temperature as low as  $-80^{\circ}\text{F}$**
- **Designed for 2.2 Million BPD throughput. Currently at less than 800,000 BPD and declining**
- **Continued operation of TAPS will require significant increase in throughput**

# PROJECT FOCUS

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- **TAPS was originally designed for transporting ANS crude oil**
  
- **(A)**
  - **Introduction of GTL products will unavoidably pose some challenges to the operation of the pipeline**
  
- **(B)**
  - **Anticipated problems include**
    - **Gel formation during cold weather shutdown**
    - **Possibility of vapor formation**
    - **Altered pumping pressure requirements**
    - **Solids precipitation and deposition**

# **PROPOSED MODE OF GTL TRANSPORTATION THROUGH TAPS**

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## **■ Batch Flow**

- Otherwise known as "slugging": alternate batches or slugs of Crude Oil and GTL are transported through TAPS**

## **■ Commingled Flow**

- GTL and Crude Oil are premixed and transported through the pipeline as a single phase fluid**

## **PROPOSED MODE OF GTL TRANSPORTATION (CONT'D)**

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### **Transportation Modes:**

- **Batch Mode A: As – is Batching**
- **Batch Mode B: Batching with pigs**
- **Batch Mode C: Modern Batching**
- **Commingled Mode**



## **BATCH MODE A: AS-IS**

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- **Batch slugs of GTL and crude oil letting physics control slug movement in TAPS**
- **Minimal additions to capital and labor**
- **Increased levels of mixing between slugs**



## **BATCH MODE B: WITH PIGS**

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- **Traditional batching with pigs physically separating oil and GTL**
- **Pig sensors can detect product movement**
- **Pigs must be transitioned between pump stations**
- **Transitioning pigs requires additional labor**
- **Pigs may cause increased turbulence between slugs**



## **BATCH MODE C: MODERN**

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- **Uses new technology for interface detection and tracking product movement**
- **Successful use in other pipelines have been reported (proven technology)**
- **Helps maintain GTL purity better than other modes**
- **Complex technology, hence expensive to install and maintain, but effective**



# **CAPITAL INVESTMENTS**

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- **New Holding Tanks on Slope**
- **New Storage Tanks at Terminal**
- **DCS and Accessories (at inlet and outlet points)**
- **Relief Tanks at Pump Stations**
- **Additional Piping**
- **Pigs (if needed)**
- **Contingency Plan Capital**

## **COMMINGLED MODE**

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- **Requires minimal capital and labor**
- **Low grade GTL can be produced at North Slope**
- **GTL purity is fully lost, but higher output of diesel and gasoline at downstream end**



## **WHY COMMINGLED MODE**

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- **The expected loss of purity of the product mixture and a trade-off between loss in product value due to contamination and cost of keeping the product pure at the terminal**
- **Flexibility of using existing infrastructure with minimal addition to capital cost for transportation**
- **The commingled mode of transportation does not require additional facility because the present relief tanks system is capable of handling the crude oil-GTL blend product**

# **GTL TRANSPORTATION ISSUES**

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- **TAPS designed for specific type of crude oil**
- **GTL flow behavior through TAPS**
- **Cold temperature effects on the gel strength of the crude oil-GTL blends with respect to cold restart of the pipeline during prolonged shut downs**
- **The phase behavior of the GTL products and any vapor pressure concerns**
- **Effects of solids precipitation and deposition of the blends (wax and/or asphaltenes) within the pipe**

# OPERATIONAL CHALLENGES

TASK	PURPOSE
Gel strength Measurement	Deals with cold restart issues
Density and viscosity Measurement and Modeling	Required to characterize flow conditions In the pipeline for a given fluid blend
Flow Rheology	For pumping horsepower requirement
Solid deposition Study	Evaluate the tendency for asphaltene and wax deposition, crude oil stability, WAT measurements

# **EFFECT OF GEL STRENGTH**

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- **Fluid gel strengths generally do not pose a problem during normal pipeline operations at high ambient temperatures, but could pose a problem at sub-zero temperatures.**
- **Gel strengths are reduced as the percentage of GTL in the crude oil-GTL mixture increases even at low temperature of -20°F. This therefore is favorable to pipeline re-start condition after an extended shut down at temperatures down to -20°F (cold re-start condition).**
- **The potential for cold restart problems after a prolonged winter shutdown of the pipeline increases as fluid gel strengths increase.**

# DENSITY EFFECTS

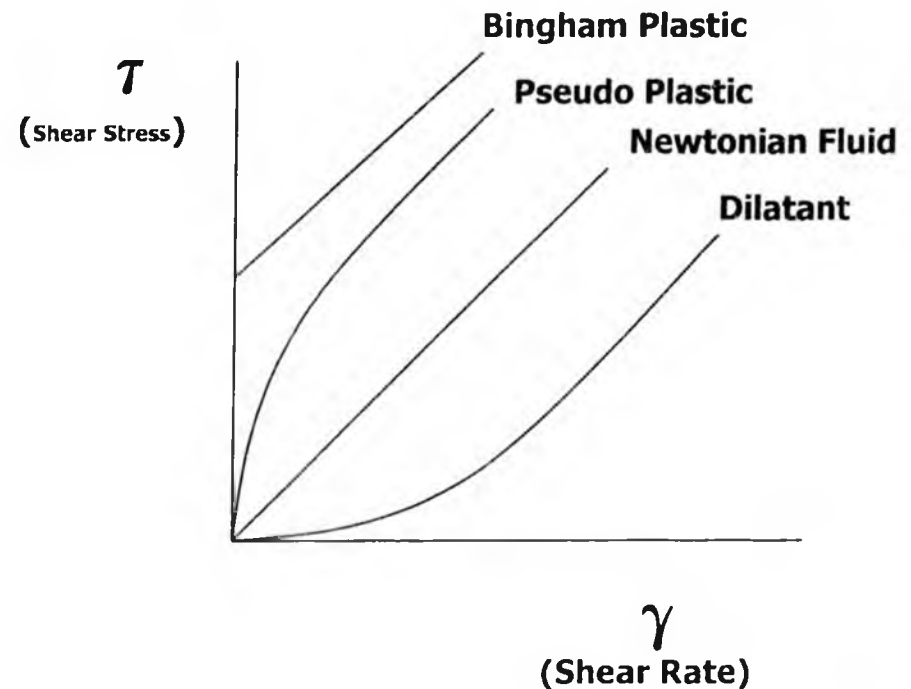
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- The density of each of the samples was measured at different temperatures from 0°C to 50°C (32°F to 122°F), inclusive.
- As expected, the density values decreased with increasing temperature.
- Addition of AKGTL to the samples caused a reduction in density, because the blends contain more light ends than the pure crude oil.

# EFFECTS OF RHEOLOGY (SHEAR STRESS VS SHEAR RATE RELATIONSHIP)

## Viscous fluid classification for pumping requirements

- **Newtonian**
- **Non-Newtonian**
  - Bingham Plastic
  - Power-law fluids



# **EFFECTS OF RHEOLOGY (SHEAR STRESS VS SHEAR RATE RELATIONSHIP) (cont'd)**

- **AKGTL shows pseudoplastic behavior at all temperatures in the given temperature range (50°C to -20°C).**
- **Crude Oil shows Newtonian behavior at temperatures 20°C and above and shows Bingham plastic behavior below 20°C.**
- **Blends of AKGTL and Crude Oil shows Pseudoplastic behavior at higher temperatures (above room temperature), Newtonian at intermediate temperatures (around room temperature) and Bingham plastic behavior at lower temperatures (near zero degree Celsius and below) in the given temperature range.**
- **This Bingham Plastic flow characteristic indicates that high pumping power requirements are necessary to re-start the pipeline after extended shut down at low temperatures.**

# EFFECTS OF VAPOR PRESSURE

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- **The vapor pressure increased with the addition of AKGTL but the values are below the minimum TAPS operating pressure, ensuring a single phase only-liquid flow of the blends.**
- **The bubble point pressure results showed that the blends would flow through the TAPS as compressed liquids from inception to discharge.**
- **Therefore, Vapor formation in the pipeline as the blends are transported is not possible.**
- **It is determined that under current TAPS operating conditions and for all blend ratios considered in the study, the fluid will always exist as a single phase liquid through out the pipeline conditions**

# EFFECTS OF SOLIDS DEPOSIT

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- **Asphaltene flocculation and deposition is a potential major problem in the transportation of the blends through the TAPS.**
- **Asphaltenes are stable in pure TAPS crude oil. This means that ANS crude has the ability to retain Asphaltene in solution in TAPS.**
- **Addition of AKGTL caused a disruption of this stability and precipitation of significant amount of the asphaltenes from the crude oil as a result of its light ends.**
- **Asphaltene flocculation occurred in a blend containing as little as 5.7% by volume of AKGTL.**

# CONCLUSIONS

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- **The results of the study show that gel strength is not a significant factor of concern at all the four tested ratios of GTL-Crude oil blend mixtures for the TAPS cold re-start after a prolonged shut down at temperatures above -20°F.**
- **The Bingham fluid flow characteristics exhibited by the blends at low temperatures indicate high pumping power requirement during prolonged shut down of the pipeline.**

## **CONCLUSIONS (cont'd)**

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- **Based on the phase behavior studies, the GTL-Crude oil mixture will flow as a single fluid system at all the four (1:1; 1:2; 1:3; 1:4) blend ratios.**
- **The mitigation of solids deposition remains the primary challenge of transportation of GTL –Crude oil products through the TAPS.**
- **Under commingled flow profile, decrease in throughput in the TAPS can result to faster and more deposition of these solids along the pipe wall. This will result to frequent pigging of the pipeline or, if left unchecked, can result to pipeline corrosion.**



**THANK YOU**

**QUESTIONS**



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## SHORT BIO- FOR: GODWIN A. CHUKWU

Dr. Godwin A. Chukwu is a professor in the department of petroleum engineering at the University of Alaska Fairbanks. He received his Ph. D in petroleum engineering from the University of Oklahoma Norman, M.S and B.S degrees in petroleum engineering from the University of South Western Louisiana Lafayette.

Dr. Chukwu has worked for the firms of elf petroleum, Petroleum Associates of Lafayette, Agip Energy and Natural Resources, in different engineering and professional capacities. He has taught both undergraduate and graduate engineering and related economics courses at the University of Port-Harcourt Nigeria, the University of Oklahoma Norman, and currently the University of Alaska Fairbanks. In addition, he has taught several short courses in fluid hydraulics and hydrodynamics, and drilling optimization, as a consultant. He served as the chair of the petroleum engineering department at UAF from 1992-1995 and 1996-2002.

Dr. Chukwu has authored and co-authored over 70 research publications in the areas of drilling, hydraulics, gas-to-liquids transportation, petroleum geology and natural resource utilization. He is internationally known for his work in the area of non-Newtonian fluid hydraulics applied to oil well drilling/production technology, and hydrodynamics of GTL transportation in pipes. His notable research work in gas-to-liquid transportation and operational challenges through the Trans-Alaska Pipeline System was sponsored by the US Department of Energy, and supported by Alyeska Pipeline Service Company.

Dr. Chukwu is a registered professional engineer in the state of Alaska. He has served in several professional bodies and organizations which include the Society of Petroleum Engineers (SPE) and the Accreditation Board for Engineering and Technology (ABET).

**Chairman's Opening Remarks:**

Ladies and Gentlemen: I will like to welcome every one of you to this 8<sup>th</sup> Annual Conference on GTL. To some of us, this has become a resourceful and professional event that everyone who has attended once should look forward to. The benefits derived from interactive discussions and deliberations have proved successful from prior years participants' comments.

I will like to make some few comments on the conference focus subject area.: The two most viable options for the utilization of natural gas are the LNG and GTL. These two options are widely pursued world wide, and will be the main focus of this conference with more emphasis on the future of GTL in world energy market.

Declining GTL production costs (due to positive learning curve), growing world- wide diesel demand, projected high crude oil prices, stringent diesel exhaust emission standards, and fuel specifications are driving the petroleum industry to revisit the GTL process for producing higher quality diesel fuels. As of today, Qatar stands out as one of the most active countries that remain committed to achieving dependence on GTL as an alternative fuel source. Companies like Sasol Chevron, Shell, ExxonMobil, BP, Rentech, to mention some, are committed to the development of this resource. I am happy that we have representatives from these companies to share their experiences with us and to update us on their companies' GTL project status.

With world- wide interest in GTL technology on the increase, I find the following GTL industry common denominations (presented by Beatrice Fisher of IFP & Axens, France at the 5<sup>th</sup> Doha Conference on Natural Gas at Doha, Qatar on February 28, 2005) interesting:

- Educating stakeholders about the impact of GTL projects and the benefits of the GTL industry.
- Helping gas rich countries (other than Qatar) to develop the right policies and practices to develop GTL projects.
- Encouraging policy makers and regulators to consider policies or programs that support GTL products.
- Lowering costs, increasing efficiencies, identifying synergies, reducing emissions and improving project products.
- Developing high value markets for GTL products.

In summary, and borrowing the remarks of Qatar Second Deputy Premier and Minister of Energy & Industry, H.E. Abdulla Bin Hamad Al-Attiyah, at the 5<sup>th</sup> Doha Conference on Natural Gas, Doha, Qatar (Feb. 28, 2005), "---developing this industry involves greater cooperation and consultation between consumers and producers for market stability", --- "and the potential of consumers to contribute to production projects, and provide

*Smi 8<sup>th</sup> Annual Conference on Gas-to-Liquid, October 24 & 25, 2005, Central London*

*(Chairman's Opening Remarks continues)*

satisfactory funding conditions from financial institutions, thus increasing gas production projects which will lead to further industry and consumption growth”.

Again, I welcome all of you to this conference and I hope that you will enjoy the presentations and discussions as we progress in the day. Thank you.

*Dr. Godwin A. Chukwu, Professor  
University of Alaska Fairbanks, USA  
October 24 Conference Chairman*

**OPERATIONAL CHALLENGES IN GAS-TO-LIQUID (GTL)  
TRANSPORTATION THROUGH TRANS ALASKA PIPELINE  
SYSTEM (TAPS)**

**FINAL REPORT  
(Reporting period: 10/1/2001 to 6/30/2006)**

**Principal Author: Godwin A. Chukwu, Ph.D., P.E.**

**August, 2006**

**Work Performed under Cooperative Agreement No. DE-FC26-01NT41228**

**Submitted by:**

**Petroleum Development Laboratory  
Institute of Northern Engineering  
University of Alaska Fairbanks  
P.O. Box 755880  
Fairbanks, AK 99775-5880**

**Prepared for:**

**The US Department of Energy  
National Energy Technology Laboratory  
P.O. Box 880  
Morgantown, WV 26507-0880**

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## **OPERATIONAL CHALLENGES IN GAS-TO-LIQUID (GTL) TRANSPORTATION THROUGH TRANS ALASKA PIPELINE SYSTEMS (TAPS)**

### **EXECUTIVE SUMMARY**

The Alaskan North Slope (ANS) has a huge amount of natural gas reserves, which can be exploited in many different ways. It is seen as an excellent economic potential for the state of Alaska. The estimated ANS proven and recoverable reserves of natural gas in known oil and gas reservoirs is about 38 trillion standard cubic feet (TCF) [1]. Currently the Natural Gas in the Alaska North Slope is primarily used for pressure maintenance, miscible injection, running gas turbines in pump stations 1 to 4, power oil production facilities and for Enhanced Oil Recovery (EOR) projects. Most of the gas may remain unused upon depletion of North Slope recoverable oil and will thus be stranded unless a means of transportation is developed to make it marketable.

The various options being examined for operational and economic feasibility for the optimum use of ANS natural gas include: constructing a new Alaska Natural Gas Transportation System (ANGTS) to transport the gas to lower 48 states via Canada; constructing a shorter Liquefied Natural Gas (LNG) pipeline to Valdez from where the gas would be shipped to the markets; and converting the gas to gas-to-liquid products (GTL), blend it with the ANS crude oil and transport the resulting liquid through the existing Trans Alaska Pipeline System (TAPS). Previous studies [1] proved that the best of these three options is the third option (that is, the GTL option). The GTL technology might also prove the best method for monetizing other stranded natural gas reserves worldwide.

With the dwindling production of oil from the ANS fields, the throughput of oil into the Trans Alaska Pipeline System (TAPS) is declining steadily and is expected to continue to decline in future. It is projected that by the year 2015, ANS crude oil production will decline to such a level (200,000 to 400,000 bbl/day) that there will be a critical need for pumping additional liquid through the pipeline in order to maintain economic operation

of the TAPS [2]. Production of GTL from ANS natural gas and transporting it through TAPS will increase the pipeline throughput and its economic life.

The schematic commercialization of stranded natural gas resources using GTL technology has received much attention from both the government and private industry. As new GTL technologies have improved and matured, energy companies continue to invest significant money to move improved GTL technologies from small pilot facilities to commercial developments. British Petroleum Exploration Alaska (BPXA) has completed and tested a 300 bbl/day pilot GTL facility in Nikiski, Alaska. Production from this pilot facility was to demonstrate a new synthesis gas generation technology and to assess challenges of GTL production in a cold climate. Experiences from this facility may be applied to a possible commercial GTL facility on the ANS.

GTL products are less viscous than crude oil. The viscosity of North Slope oil has been increasing with the increase in production of oil. The TAPS was originally designed for less viscous fluids. Thus the increasing viscosity of the present crude oil might have adverse effects on the life of TAPS. The blending of the light GTL products with crude oil would help in retaining the API of the fluid that the TAPS was originally designed for. Also presently the daily transfer of fluid through TAPS is less than the capacity of TAPS. This increases the tariff on the pipeline. Transporting GTL through TAPS would meet the capacity of TAPS and would decrease the tariff.

The TAPS was specifically designed for transporting ANS crude oil. Introduction of GTL products into the pipeline might lead to some operational problems. Anticipated problems include altered pumping power requirements, possibility of vapor formation, solids precipitation and deposition and gel formation.

The primary goal of the proposed research will be to study the flow of GTL/ANS crude blend mixtures through TAPS in view of these operational challenges. The scope of this

work would include experimental and simulation study of the properties of GTL products and their blends at all possible TAPS operating conditions, including a cold weather shutdown.

### Conclusions

Based on the work presented in this report, the following main conclusions are drawn. It appears that fluid gel strengths generally do not pose a problem during normal pipeline operations at high ambient temperature, however TAPS operations are far from normal. The potential for a prolonged winter shutdown of the pipeline increases as fluid gel strengths increase. High gel strengths significantly reduce the amount of time available to make repairs and return the pipeline to a flowing condition before restart is possible.

The result of this study also indicates that by altering the final boiling point of the GTL introduced into the pipeline, the gel strength of the commingled GTL and crude oil may be controlled. Additionally, the resulting mixture has gel strength lower than that of crude oil with which the GTL is mixed.

Blends of AKGTL and Taps Crude Oil show Pseudo-plastic behavior at higher temperatures (above room temperature), Newtonian at intermediate temperatures (around room temperature) and Bingham plastic behavior at lower temperatures (near zero degree Celsius and below) in the given temperature range.

Blends of AKGTL and TAPS crude oil indicate that:

- GTL has the tendency to flocculate Asphaltenes, as a result of its light ends.

- GTL is not as strong a precipitant as n-pentane or n-heptane.

- TAPS crude oil is a stable crude in terms of Asphaltene deposition

Considering the low TAPS operating temperature and high flow pressure it is determined from this study that if GTL were to flow through TAPS in either the batch mode or as

commingled mixture, under current TAPS operating conditions, the fluid will always exist as a single phase liquid through out the pipeline conditions.

### **Recommendations**

GTL technology may be an available means of recovering and or transporting huge resource of Alaska heavy oils. Feasibility study and characterization of the flow of blends of AKGTL and ANS heavy oil through the TAPS is necessary. Such study if found feasible, will further be evaluated for economic viability compared to other technologies in place.

A study of solid deposition of GTL/ANS crude oil mixtures under dynamic conditions will be important to investigate. This will help to understand the true behavior of such mixtures for practical applications.

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## Rheology of Gas-to-Liquid Products, Alaska North Slope (ANS) Crude Oil and Its Blends for Transportation Through the Trans-Alaska Pipeline System (TAPS)

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### Abstract

It is projected that by the year 2015, Alaska North Slope (ANS) crude oil production will decline to such a level (200,000 to 400,000 bbl/day) that there will be a critical need for pumping additional liquids through the pipeline in order to maintain economic operation of the Trans Alaska Pipeline System (TAPS). The estimated proven and recoverable gas reserves of 38 trillion cubic feet (TCF) on the North Slope of Alaska can be converted to a high premium liquid product using the Gas-to-Liquids (GTL) technology. The GTL product can be transported from the ANS to the Southern port of Valdez, Alaska through the TAPS.

One of the proposed modes of transportation of the GTL products from ANS to market is by commingling it with crude oil as a single phase and pumping the mixture through the TAPS. This mode of transportation changes the properties of the GTL as well as the crude oil. The focus of this work therefore was to determine the physical and chemical properties of GTL and its blends with ANS crude oil, analyze the energy requirements for flowing the mixture through TAPS, and to determine the optimum blend ratio that would maximize the transportation economics. Four blends of GTL/crude oil mixture in the ratios of; 1:1; 1:2; 1:3; and 1:4; were prepared for their rheological evaluation and pressure drops at different temperature conditions.

The results of the analysis show that flow behavior of the GTL and GTL blends are temperature sensitive. Viscosity and density of the blends were found to decrease with increasing amount of GTL and increasing temperature. The optimum GTL/crude oil blend ratio of; 1:2.5 (28%: 72%) was determined to take full advantage of the economics of commingled flow of GTL/crude oil mixture through the TAPS.

### Introduction

The ANS has a huge amount of natural gas reserves, which can be exploited in many different ways. It is seen as an excellent economic potential for the state of Alaska. The estimated ANS proven and recoverable reserves of natural gas in known oil and gas reservoirs is about 38 TCF (Thomas, et al. 1996). Currently the Natural Gas in the ANS is primarily used for pressure maintenance, miscible injectant (MI), running gas turbines in pump stations 1 to 4, power oil production facilities. Most of the gas may remain unused upon depletion of ANS recoverable oil and will thus be stranded unless an option for transportation is developed to make it marketable. The various options being examined for operational and economic feasibility for the optimum use of ANS natural gas include: constructing a new Alaska Natural Gas Transportation System (ANGTS) to transport the gas to lower 48 states via Canada; constructing a shorter pipeline to Valdez from where the gas would be converted to Liquefied Natural Gas (LNG) and shipped to the markets; and converting the gas to gas-to-liquid products (GTL), blend it with the ANS crude oil and transport the resulting liquid through the existing TAPS. Previous studies (Thomas, et al. 1996) proved that the best of these three options is the third option (that is, the GTL option). The GTL technology might also prove the best method for monetizing other stranded natural gas reserves worldwide.

With the dwindling production of oil from the ANS fields, the throughput of oil into the TAPS is declining steadily and is expected to continue to decline in future. It is projected that by the year 2015, ANS crude oil production will decline to such a level (200,000 to 400,000 bbl/day) that there will be a critical need for pumping additional liquids through the pipeline in order to maintain economic operation of the TAPS (Khataniar et al, 2004). Production of GTL from ANS natural gas and transporting it through TAPS will increase the pipeline throughput and its economic life.

The TAPS was specifically designed for transporting ANS crude oil. Introduction of GTL products into the TAPS might lead to some operational problems. Anticipated problems include altered pumping power requirements, possibility of vapor formation, solids precipitation and deposition and gel formation.

The objectives of this study are:

- 1) to evaluate rheology and density of GTL, ANS crude oil and their blends at different temperatures;
- 2) to determine and analyze the energy requirements for flowing the fluids through the TAPS;
- 3) and to determine the optimum GTL/Crude Oil blend ratio that can flow through the TAPS.

#### Study Background and previous work:

The schematic commercialization of stranded natural gas resources using GTL technology has received much attention from both the government and private industry. As new GTL technologies have improved and matured, energy companies continue to invest significant resources to move improved GTL technologies from small pilot facilities to commercial developments. BP Exploration (Alaska), Inc. (BPXA) has already started the production of GTL from pilot GTL facility in Nikiski, Alaska and also started the production to demonstrate a new synthesis gas generation technology and assess challenges of GTL production in a cold climate. Experiences from this facility may be applied to a possible commercial GTL facility on the ANS.

GTL products are less viscous than crude oil. The viscosity of North Slope oil has been increasing with the increase in more and more viscous oil production. The TAPS was originally designed for less viscous fluids. Thus the increasing viscosity of the present crude oil might have adverse effects on the life of TAPS. The blending of the light GTL products with crude oil would help in retaining the API of the fluid that the TAPS was originally designed for. Also presently the daily transfer of fluid through TAPS is less than the capacity of TAPS. This increases the tariff on the pipeline. Transporting GTL through TAPS would meet the capacity of TAPS and would decrease the tariff.

#### Modes of transportation:

The two modes of flow considered for GTL transportation through TAPS are:

- 1) *Batch mode*: - The transport of GTL and crude oil in slugs or batches results in creation of an interface zone between both fluids. This interface zone is made up of air pockets and a mixture of both fluids. The magnitude of the interface zone is a function of the fluid velocity, density differences, viscosity, pipe diameter, pipe length, time and composition (Baum et al, 1998). A complex two-phase flow is created by this mode.
- 2) *Commingled mode*: - In this mode of transportation, the crude oil and GTL are blended before being sent through the pipeline as a single liquid phase mixture.

The pressure drop and energy balance equations were determined for both batch and commingled flow modes of transporting GTL through the TAPS. The solutions to these equations were presented for determining pressure gradient and optimum slug length for batch operations. The Bernoulli equation of pressure for the flow of fluids in pipes was used to derive flow equations applicable to specified operating conditions or constraints of the TAPS, (Akwukwaegbu, 2001).

The results of the Akwukwaegbu study indicates that the pressure gradient obtained from the batch flow calculations are higher than those obtained from that of commingled flow. The reason is that for batch flow, the pressure gradient is the ratio of the total pressure drop across the slug to the length of the slug, whereas for commingled flow, it is the ratio of the total pressure drop to the length of the pipe segment. In pressure drop calculations different flow patterns that might occur in either batch or commingled flow should be taken into account.

In commingled mode of flow calculations, the GTL and crude oil samples were premixed to represent a single phase fluid system. Since both GTL and crude oil are hydrocarbons they should have a similar fluid properties and a homogenous mixture can be expected. This was supported by the results of the tests conducted by Ramakrishnan (2000). Phase behavior results by Sharma (2003) show that at TAPS temperature and pressure conditions the mixture of GTL and crude oil is single homogenous phase. Thus in this study, the GTL/crude oil blends will be treated as a single liquid phase.

#### Rheology:

When a fluid is flowing, a force exists in the fluid that opposes the flow. This force is known as shear stress, which can also be seen as the frictional force between the two adjacent layers of fluid. And the relative velocity with which an individual layer moves with the neighboring layers is shear rate. The shear stress is a function of pressure and the shear rate is a function of geometry and average velocity of the fluid. The relationship between shear stress and shear rate defines the flow behavior of the fluid.

The rheology of fluids is dependent on their shear stress-shear rate relationship. Linear relationship of shear stress and shear rate on a Cartesian plot, which passes through the origin, indicates that the fluid exhibits Newtonian characteristics. The non-Newtonian behavior of fluids can be characterized by either the Bingham Plastic or Power-Law fluid flow model (among others), depending on the fluid's shear stress-shear rate relationship. Figure 1 shows the rheogram of Newtonian, Bingham Plastic and Power-Law fluids.

The corresponding equations of these fluid models are given in equations 1, 2 and 3, respectively.

*For Newtonian fluids:*

$$\tau = \mu\gamma \quad (1)$$

The absolute or true viscosity ( $\mu$ ) is constant for Newtonian fluids.

*For Bingham Plastic Fluids:*

$$\tau = \mu\gamma + \tau_0 \quad (2)$$

The plastic viscosity ( $\mu_p$ ) of Bingham plastic fluids is described as that part of resistance to flow caused by mechanical friction. Primarily, it is affected by (a) solids concentration (b) size and shape of solids, and (c) viscosity of the fluid phase. An increase in plastic viscosity indicates an

increase in the percent by volume of solids, a reduction in size of the solid particles, a change in the shape of the particles, or a combination of all. Yield point is that part of the resistance to flow caused by the attractive forces between particles.

*For Power-Law fluids:*

$$\tau = k(\dot{\gamma})^n \quad (3)$$

$n$  and  $k$  are called the parameters of Power-Law model. The parameter  $n$  shows the degree of deviation of fluid from Newtonian fluid characteristics. Based on the value of  $n$ , fluids can be classified as follows:

$n = 1$  ---Newtonian *examples: air, water, high viscosity fuels*

$n < 1$  ---Pseudoplastic *examples: grease, printer's ink, soap*

$n > 1$  ---Dilatant *examples: clay, starch in water, peanut butter*

#### Experimental Methodology:

Laporte light GTL samples were used for the initial experimental investigation in this study. This GTL was distilled in three sample cuts as suggested by Timmecke (2002) at temperatures of 254, 302 and 344°C so that a wide range of GTL products that may be transported through TAPS is obtained for the study. GTL field samples were received from BPXA GTL pilot plant. The samples therefore are referred to as AKGTL or GTL and the sample cuts are denoted as GTL254, GTL302 and GTL344. Crude oil samples were taken from the TAPS at pipeline conditions and preserved in constant pressure Welker cylinders. GTL and crude oil sample blends were prepared gravimetrically in the ratios of 1:1, 1:2, 1:3 and 1:4 for density, rheology and viscosity measurements at different temperatures.

#### Density Measurements:

The density of the GTL cuts, AKGTL, TAPS crude oil and their blends were determined in the laboratory using the Anton-Paar digital densitometer at atmospheric pressure. Two different crude oil samples were used to blend with the GTL cuts and AKGTL. This work concentrates more on study of AKGTL compared to the GTL cuts because AKGTL might be the representative sample of the GTL that would be produced from the ANS natural gas. A wide experimental range of temperature (0°C to 50°C) was selected for AKGTL and its blends with crude oil. The results obtained from the density measurements are shown in tables 1 through 4.

It can be seen from the results of density measurements that AKGTL has higher densities at all temperatures than GTL344. Hence AKGTL is heavier than all the GTL cuts.

#### Rheology and viscosity measurements:

Brookfield's cone plate viscometer was used to measure the viscosity of the fluid samples. The readings within the 10% to 100% torque range were accepted for accuracy as mentioned in the manual. For viscous fluids and at lower temperatures the 100% torque is achieved at comparatively lower shear rates. Hence fewer data points are obtained at low temperatures as well as for viscous fluids. These shear stress values are plotted against shear rate values. Regression coefficient ( $R^2$ ) is used to

decide the best fit curve. Flow behavior parameters  $n$  &  $k$  and viscosities are determined with the help of these curves. GTL, crude oil and their blends are then classified as Newtonian or non-Newtonian fluids based on the best fits and values of  $n$  and  $k$ .

#### Crude oil

TAPS crude oil shows Newtonian behavior at higher temperatures (>20°C). At lower temperatures it shows Bingham Plastic behavior with some yield point. Viscosity of crude oil is determined by the slope of the shear stress vs. shear rate plot. The experimental results are plotted on the cartesian graph. The representative rheograms at temperatures 50 °C, 30 °C and 10 °C are shown in figures 2 through 4. The classification of crude oil behavior based on temperature is tabulated in table 5. The table also summarizes the absolute viscosities for Newtonian behavior and plastic viscosities (PV) and the yield values for Bingham Plastic behavior.

#### AKGTL

From the experimental results, the rheograms of AKGTL field sample were plotted on the cartesian graph. Log-log plots ( $\log \tau$  vs  $\log \dot{\gamma}$ ) were used to determine the  $n$  and  $k$  values. From the plots and values of  $n$  it was concluded that GTL shows pseudoplastic behavior at all the temperatures in consideration. The representative rheograms and the log-log plots at temperatures 50 °C, 30 °C, 10 °C and -10 °C are shown in figures 5 through 8. The  $n$  and  $k$  values are tabulated in table 6.

#### AKGTL/Crude Oil Blends

Blends of GTL and crude oil show Newtonian, pseudoplastic and Bingham Plastic behavior depending on the temperature. At higher temperatures (above room temperature) pseudoplastic behavior is observed, at intermediate temperatures (around room temperature) Newtonian behavior can be seen whereas at lower temperatures (around 0 °C and below) Bingham plastic behavior is noted. This is summarized in tables 7 through 10.

#### Application of Pressure Drop:

The total pressure drop in TAPS while transporting fluid from pump station one to the Valdez Marine terminal is due to friction, elevation change and some other minor losses like fittings losses. Pressure losses due to acceleration are neglected since it is assumed that the flow rate is constant. For calculation purpose, TAPS is divided into 5 segments between pump station one (PS-1) on the ANS and Valdez Marine terminal. Only the operating pump stations are considered here. The center line elevation of each pump from sea level, elevation change between two consecutive pump stations, distance of each pump station from PS1 is given in table 12. The table also shows the assumed values of minor losses, which were used for calculations. These minor losses are considered constant for all the fluids. The data in table 12 were calculated using appropriate model based on the rheological evaluation results (either Newtonian or Power Law). Pressure drop per mile is evaluated at various temperatures based on the daily throughput of 1.02 MMBPD. Total pressure drop along TAPS at various temperatures for

GTL samples, crude oil and their blends are shown in tables 13 through 15. From tables 13 through 15, pressure drop along TAPS can be found at various temperatures considering that particular temperature is constant throughout the TAPS length. In reality, temperatures along the TAPS varies, hence average pressure drop at current TAPS temperature conditions between pump stations are shown in table 16. These average temperatures are assumed to remain constant throughout the particular pipe segment in consideration.

#### Power required to transport fluids between Pump Stations:

The hydraulic horsepower required to flow liquid from one point to the other is a function of the pressure drop between the points, and the fluid flow rate. The hydraulic horsepower required to flow fluid between two consecutive pump stations was calculated. In this study, the flow rate is kept constant at 1.02 MMBPD. Pressure drop varies with temperature and fluid behavior. Details on pump specifications and efficiency are not considered in the present analysis. The results are tabulated in tables 17 through 19. Hydraulic horsepower required between pump stations at the present average temperature conditions for AKGTL, crude oil and their blends is shown in figure 9.

#### Optimum blend ratio for transportation through the TAPS:

In order to determine the optimum blend ratio or optimum amount of GTL in the blend, average pressure drop per mile due to respective fluid was calculated and plotted against percent amount of GTL in blend as shown in figure 10. The minimum of this curve gives the optimum amount of GTL in the GTL/crude oil blend. It should be noted that various factors such as flow behavior parameters of the fluid, pipeline characteristics, elevation changes, temperature conditions among others are responsible for this pressure drop. Hence optimum blend ratio also depends on all these parameters. From figure 10, it can be seen that at 28% of GTL, the curve shows minimum. Thus 28% GTL in GTL/ANS crude oil blend is the optimum blend ratio.

#### Conclusion:

Blends of AKGTL and crude oil show Pseudo-Plastic behavior at higher temperatures (above room temperature), Newtonian behavior at intermediate temperatures (around room temperature) and Bingham Plastic behavior at lower temperatures (near zero degree Celsius and below) in the given temperature range.

The blend containing 28% GTL and 72% crude oil ratio is the optimum blend which is function of various parameters such as fluid temperature, flow behavior parameters, pipeline characteristics, and elevation changes in pipeline among others.

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#### Disclaimer:

The opinions, findings, conclusions, and recommendations expressed herein are those of the authors and do not necessarily reflect the views of the US Department of Energy and/or BP Exploration (Alaska) Inc.

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## Transportation of GTL Products From the Alaskan North Slope

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Gas-to-liquid (GTL) conversion is an emerging technology that very likely will be widely used within the next decade. With its vast natural-gas resources, the Alaskan North Slope (ANS) will be one of the first areas in the U.S. to exploit this new technology. The objective of this study is to evaluate the technical and economic feasibility of transporting GTL products through the Trans-Alaskan pipeline system (TAPS).

### Introduction

The ANS contains some of the largest hydrocarbon-gas reserves in the U.S. The proven and recoverable conventional-natural-gas reserves in developed and undeveloped fields in the ANS are estimated to be 38 Tscf, and estimates of additional undiscovered gas reserves in the Arctic fields range from 64 to 142 Tscf. Produced gas from the ANS oil fields is separated and processed in surface production facilities where natural-gas liquids (NGLs) and the components used for miscible injectant (MI) are separated from the gas stream. Some of the NGLs are mixed with crude oil for transportation through the TAPS. The remaining NGLs and MIs are used in enhanced-oil-recovery operations. Most of the lean gas is injected back into the reservoirs for pressure maintenance.

GTL technology, where gas is chemically converted to fuel-grade liquid products, was first used during World War II. In recent years, GTL technology has re-emerged as the technology for producing clean, environmentally friendly fuels. Although there are several different methods for GTL conversion, the basic GTL-conversion process considered in this study is a two-step process. In the first step, natural gas is combined with oxygen or air to form a mixture of carbon monoxide and hydrogen called synthesis gas by use of steam reforming, partial oxidation, or autothermal reforming. In the second step, synthesis gas is converted into liquid fuel, usually through the Fischer-Tropsch (FT) synthesis process. The liquid hydrocarbons produced by FT synthesis are free of impurities like sulfur and primarily consist of straight-chain hydrocarbons.

Transportation of the natural gas from the ANS is the key issue in monetization of this valuable resource. The existing infrastructure for transporting crude oil from the ANS fields is the 800-mile-long TAPS, extending from Prudhoe Bay to the marine terminal at Valdez. With declining oil production from the ANS fields, the oil throughput in TAPS is declining. Currently, 4 of the 12 pump stations are shut down because of the decline, and the pipeline is operating at one-half its design capacity. It is projected that by 2015, ANS crude-oil production will decline to such a level (200,000 to 400,000 B/D) that there will be a critical need to pump additional liquid through the pipeline. The vast natural-gas resources of the ANS can provide an adequate liquid volume for economic TAPS operation by use of GTL technology.

### Transportation Issues

Because TAPS was originally designed to carry a specific type of crude oil, the possibility of flowing GTL products through TAPS raises several questions. Operational problems associated with transporting GTL products through TAPS depend on the physical and chemical properties of the GTL products and GTL-product/ANS-crude-oil blends.

**Ability to Transport GTL Products.** TAPS was specifically designed for Prudhoe Bay crude, which is 24 to 32°API. GTL products have a much higher API gravity and physical and chemical properties significantly different from those of Prudhoe Bay crude. Thus, a thorough study of GTL-products flow hydraulics and compatibility is necessary to evaluate potential problems in GTL-products transportation through TAPS.

**Gelling and Cold-Restart Issues.** Because FT-based GTL products are paraffinic, they tend to form gels at low temperatures. This can be a particularly troublesome issue for TAPS because of the extremely cold Arctic environment. In an extended TAPS emergency shutdown in the winter, the fluids inside the pipeline will gradually cool and form a gel. The pressure required to break the gel and restart the pipeline could be greater than the pump and pipeline capacities. Thus, pipeline throughput must be tested to ensure that a cold restart after a shutdown is possible.

**Effect of Solids Precipitation.** Presence of GTL products may increase solids precipitation (wax and/or asphaltene) significantly within the pipeline. Buildup of such deposits may impede fluid flow to the extent that the deposits have to be removed mechanically.

#### Objectives

The first objective of this study was to address the cold restart of TAPS by measuring the gel strength of FT-based GTL products and GTL-product/crude-oil blends. Because restart feasibility depends on the cold-temperature gel strength of the transported fluid, gel strength is the key parameter determining feasibility of transporting a given GTL product through TAPS. The second objective of the study was to conduct a preliminary economic analysis of GTL-product transportation through TAPS, considering the fluid properties and flow hydraulics.

#### Gel-Strength Measurements

Gel strength gives an indication of the cold-restart pressure at which the liquid in the pipeline will yield. Thus, gel strengths of various GTL products and GTL-product/ANS-crude blends were determined by the rotating-vane technique at different temperatures.

**Sample Preparation.** FT-based GTL products obtained from two different sources were used to simulate the variation in GTL products that could be produced at an ANS facility. The first GTL product used in this study, GTL1, was a light-hydrocarbon liquid. The second GTL product, GTL2, was a diesel fuel obtained from FT synthesis. In addition, heavy alkanes were separated from a wax sample by a vacuum-distillation process to produce only the 20% overhead fraction. This wax distillate was gravimetrically mixed with GTL1 to create GTL samples with varying wax content. Because gel strength is a function of wax content, samples were made with varying wax content so the limiting conditions for flow through TAPS could be estimated. GTL2 was not mixed with the wax distillate to represent the scenario where clean diesel is produced and transported through TAPS.

**Measurement Procedure.** Test temperatures were selected on the basis of cold ramping the GTL-product/crude-oil blends from 90 to -20°F over a 21-day period. The temperature-decay curve used for sample conditioning and test-temperature selection was based on TAPS cold-restart data supplied by the pipeline operator. The temperature ramp simulates fluid cooling inside TAPS under winter-shutdown conditions.

Gel strength of the samples was determined by the rotating-vane method. This method uses commercial rotary viscometers and vane spindles, which extend horizontally through a sample to minimize slippage at the spindle wall. This method determines the minimum torque necessary to initiate oil movement at low shear and subsequent gel breakdown after flow initiation. Gel strengths were measured at predetermined temperatures along the cooling ramp.

**Results and Discussion.** In several cases, gel strength was beyond the maximum torque capacity of the viscometer. Gel strengths of GTL1/crude-oil blends are generally low at 40 to 60°F, but increase rapidly as temperature drops to 20°F. Gel strength can increase significantly in the presence of even moderate amounts of wax components in the GTL product.

The results for GTL2 also show that gel strength increases rapidly with decreasing temperature. The pure form of GTL2 showed high gel strength at 20°F; however, gel strength at 20°F decreased markedly when GTL2 was blended with crude oil. For the GTL2/crude-oil blends, gel strengths at 0°F were quite high.

Results indicate that gel strength of GTL products or GTL-product/crude-oil blends can increase abruptly once the temperature falls below a threshold. The threshold temperature can be as high as 20°F and depends on wax content. This may pose a serious problem for pipeline cold restart. To be transported through TAPS, the GTL products manufactured at ANS must be relatively free of wax components. This may require the products from FT synthesis to be hydrocracked to remove the higher paraffins before entering the pipeline.

Because the pure GTL sample gels at a higher temperature than GTL-product/crude-oil blends, batching of GTL products could be more troublesome than commingled flow. Rigorous studies are needed to identify the upper limit for the paraffin quantity and molecular weight that is acceptable in GTL products for TAPS flow.

#### Economics of GTL Transportation

There are two possible ways to transport GTL products through TAPS: (1) batch or slug mode, where GTL products and crude oil flow as alternate slugs, and (2) commingled or blended mode, where GTL products and crude oil are mixed to form a single phase. In either mode, the feasibility and economics of moving GTL products through TAPS depend on the physical properties of the GTL products and GTL-product/crude-oil mixtures. Table 3 in the full-length paper lists the economic assumptions.

The GTL products are assumed to have a premium of 125% over the crude-oil price. Also, it is assumed that GTL-product quality is maintained in the batch mode. For the commingled mode, the

GTL-product/ crude-oil mixture is assigned a premium of U.S. \$1 over the crude-oil price to account for the increased gasoline or diesel yield after refining.

The results of the economic analysis are presented in the form of rate of return (ROR). The ROR increases with decreasing capital expenditure (CAPEX) for both modes of transportation. The CAPEX, expressed in U.S. dollars per daily barrel (U.S. \$/Dbbl), represents initial investment for the ANS GTL plant only and does not include the additional capital investment necessary in the batch mode for liquid storage. The batch mode shows higher ROR than the commingled mode (Fig. 1), although the batch mode had higher initial expense than the commingled mode. The difference in ROR of the two modes decreases with decreasing CAPEX, indicating that the two modes may become equally economical if the CAPEX is sufficiently small.

**Fig. 1—ROR for batch and commingled modes.**

The U.S. \$1 premium of the GTL-product/crude-oil mixture used in the base case of commingled mode is entirely arbitrary because it is very difficult to quantify the increase in product value achieved by adding a GTL product to the crude oil. Therefore, a sensitivity analysis was performed by varying the premium applied to the commingled mode from U.S. \$1 to \$3 more than the crude-oil price. For a fixed CAPEX of \$25,000/Dbbl, as the mixture premium increases from \$1 to \$3, the ROR of the commingled mode approaches that of the batch mode.

**Conclusions**

This study indicates that transportation of GTL products through TAPS may pose significant problems from the cold-restart point of view. From the preliminary economic analysis, batch-mode transportation appears to be more economical than commingled mode. However, the difference may lose significance as CAPEX decreases and/or the premium for the commingled product stream improves. Because blending GTL products with crude oil tends to lower gel strength significantly and aid restart, the commingled mode may emerge as a more viable option than the batch mode from a technical standpoint.

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This article, written by Assistant Technology Editor Karen Bybee, contains highlights of paper SPE 86931, "Technical and Economic Issues in Transportation of GTL Products From Alaskan North Slope to the Markets," by Santanu Khataniar, SPE, Godwin A. Chukwu, SPE, Shirish L. Patil, SPE, and Abhijit Y. Dandekar, SPE, U. of Alaska Fairbanks, prepared for the 2004 SPE International Thermal Operations and Heavy Oil Symposium and Western Regional Meeting, Bakersfield, California, 16-18 March.

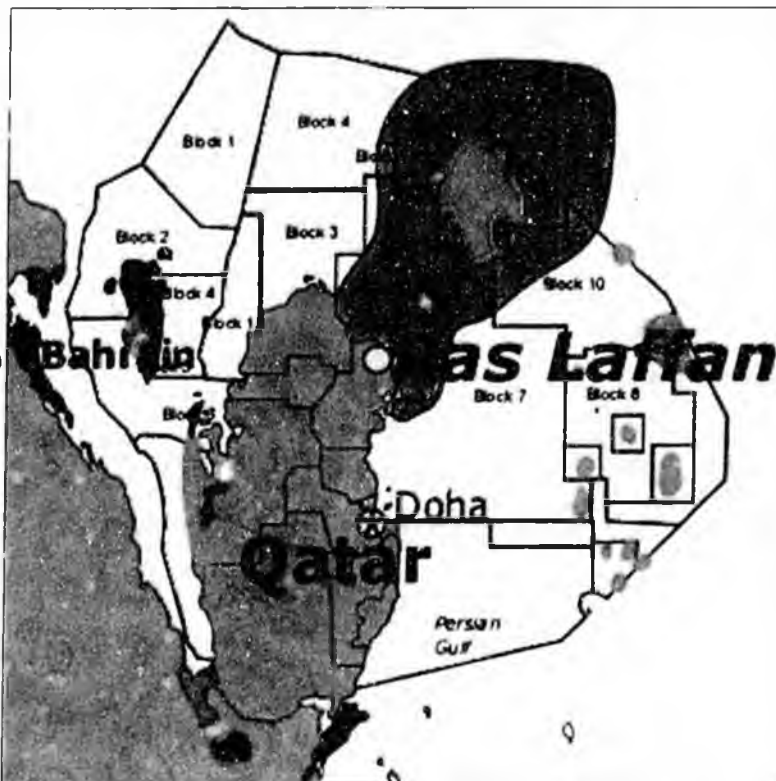
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## Gas-to-Liquids (GTL) Projects

Qatar Petroleum is actively pursuing a number of world-scale gas-to-liquids conversion projects for the production of synthetic fuels and base oil stocks. The projects are all integrated with offshore development to supply the large amounts of gas needed for these projects. These are active business opportunities that are being pursued, but the status of each of the projects is still at the preliminary stage. A brief summary for each project is given.

### Oryx GTL Project

All major project agreements have been signed with the relevant parties. Oryx GTL Ltd. was established at the end of January 2003 as a JV company between Qatar Petroleum (51%) and Sasol (49%). The design capacity of the project is 34,000 BPD of gas-to-liquid fuel. The EPC contract was awarded to Technip and the 33-month contract is being executed from their Rome office. The project reached financial close on 18 March 2003 with EPC contract effective from 19 March 2003.



His Highness Sheikh Tamim Bin Hamad Al Thani, the Heir Apparent, on 7 December 2003 laid the Foundation Stone for the Middle East's first gas-to-liquids plant.

The GTL plant will be ready for start-up in December 2005 and first product will enter the international market during the second quarter of 2006.

QP and Sasol Chevron have signed a Memorandum of Understanding (MOU) for the Oryx GTL Expansion project and have discussed the technical and business principles that will support the planned increase in the output of the foundation plant to 100,000 bbl/day. This will involve defining the feasibility of a three (3) train, 65,000 bbl/day facility with an expected start up by 2009.

### Pearl GTL

Shell's GTL is an integrated project which will develop about 1.6 BSCFD of North Field gas to produce approximately 140,000 BPD of synthetic fuels and base oils. The project will be developed in two phases with the first phase operational in 2009, producing around 70,000 bpd of GTL products with the second phase to be completed less than two years later. Qatar Petroleum and Qatar Shell GTL Limited (Shell) signed the Development and Production Sharing Agreement (DPSA) for Pearl GTL in July 2004.

The first of two appraisal wells in the North Field were drilled in February 2004 and the Front End Engineering and Design (FEED) contract was awarded to JGC Inc. of Japan in March 2004.

#### **Sasol Chevron**

Sasol Chevron submitted a Project Profile Proposal to QP in July 2002 for an integrated upstream/downstream GTL project to produce 120,000 BPD of GTL product in two phases. The project will produce naphtha and diesel as the primary products. A Statement of Intent was signed for this project in November 2002.

As part of its ongoing project work, Sasol Chevron submitted a Scoping Study to QP in June 2003. Progress has yet to be made on commercial issues to enable further progress with the technical development of the project.

Initial indications were for startup of the project by 2010, but a revised startup date will be produced when the next round of negotiations with Sasol Chevron commences.

QP and Sasol Chevron have also signed a Letter of Intent (LOI) to examine GTL Base Oils opportunities in Qatar.

QP and Sasol Chevron have agreed to pursue the opportunity to develop a 130,000 bbl/day upstream/downstream integrated GTL project based on the Sasol Slurry Phase Distillate Process and utilizing resources from the North Field. This will involve defining the feasibility of a six (6) train facility with an expected start up by 2010. These efforts will lead to the establishment of a Heads of Agreement (HOA) for the project.

#### **ExxonMobil**

ExxonMobil GTL project is for the production of synthetic GTL products in excess of 150,000 BPD. Feedstock for the GTL Plant will be provided from two wellhead platforms; approximately 1.8 BSCFD will be required to yield the target GTL production. The project will produce base oil stocks in addition to the synthetic fuels.

Onshore gas treatment and NGL recovery plants will benefit, to the maximum extent possible, from the existing RasGas infrastructure to reduce the overall project cost. LPG, condensate and sulphur storage/loading will most likely be shared with other ongoing projects at Ras Laffan.

The HOA signed in July 2004 specifies the principal terms for the project that will be defined in a Development and Production Sharing Agreement (DPSA). The term of the DPSA will be 25 years from the start of production, which is expected to commence in 2011.

ExxonMobil will drill an appraisal well for the GTL project in 2004, and will supplement the extensive preliminary front-end engineering and design (pre-FEED) undertaken earlier. FEED is expected to begin upon execution of the DPSA.

#### **Marathon**

The Marathon GTL project will produce approximately 120,000 BPD of naphtha and diesel. The project will consist of two trains of equal capacity. Phase I first commercial production is planned for 2010. Offshore development is based on two unmanned wellhead platforms and two wet scheme pipelines configuration.

Marathon is considering introducing shareholders to the project; shareholders will include PetroCanada, Occidental and the Offset Group. Details regarding the venture partners will probably be concluded during 2004.

The project will be executed on a Production Sharing Agreement basis. Marathon's pre-FEED work was completed during the last quarter of 2003 and it is expected that commercial negotiations will commence during early 2004.

### **ConocoPhillips**

ConocoPhillips is planning to develop its GTL project in two phases, each producing approximately 80,000 BPD of GTL products - naphtha and diesel using CoPOX technology. Two wellhead platforms with adequate number of wells will provide the required feedstock for the GTL plant.

The company completed a feasibility study that was submitted to QP mid 2003. A Statement of Intent to proceed with the project was signed with QP in December 2003. The company intends to proceed with pre-FEED work during 2004. Startup of the first phase of the plant is scheduled for 2010. The project is structured on the basis of a Production Sharing Agreement, as with all other large-scale GTL projects.

The company has successfully completed the construction of a 400 BPD semi-works plant at its refinery in Ponca City, Oklahoma and commissioning of the plant was well underway at the end of December 2003. ConocoPhillips will demonstrate its process during 2004 and it expects to be able to commence commercial negotiations in 2004 also.

## **Petrochemicals**

### **Cracker at Ras Laffan**

A Joint Venture Agreement (JVA) was signed on 13 June 2002 between Q-Chem II (53.31%), Qatofin (45.69%) and QP (1%) to establish a steam cracker at Ras Laffan with design capacity of 1,300,000 MMTA of ethylene.

An ethylene pipeline from Ras Laffan to Mesaieed will supply ethylene to Q-Chem II and Qatofin plants.

### **Qatofin**

Qatofin is a JV between QAPCO (63%), Atofina (36%) and QP (1%) for production of 450,000 MTPA of LLDPE adjacent to QAPCO site. Feasibility study was completed in December 2002. ITB document for EPC contract was sent to bidders on 22 July 2003. Negotiations continued on several project agreements. The estimated start-up of the project is third quarter 2008.

### **Q-Chem II Project**

An amended JVA was signed on 13 June 2002 between QP (51%) and Chevron Phillips (49%) to establish an ethylene derivatives plant at Mesaieed, adjacent to the Q-Chem plant, with a design capacity of 350,000 MTPA of HDPE and 350,000 MTPA normal alfa olefins.

Feasibility study was completed in December 2002. FEED contract was awarded to Aker-Kvaerner. The estimated start-up of the project is third quarter 2008.

### **DME Project with MGC**

A letter of intent was signed on 10 June 2003 with Mitsubishi Gas Chemicals (MGC) and ITOCHU to establish a project for the production of Di-Methyl-Ether (DME) at Ras Laffan in Qatar.

The production capacity of the project is 1.7 MMTPA of DME. The project is planned to start-up around fourth quarter 2008.

### **Fuel Grade-Methanol Project**

Heads of Agreement (HoA) was signed with Petroworld Ltd on 14 September 2003 for the development of a large scale fuel grade methanol project targeting on out put of 12,000 to 15,000 MTPD at Ras Laffan. The partners expect the proposed project to come on stream by 2008.

### **Sport**



### **Qatar International Racetrack**

With over 1.5 million on-site attendees to the GrandPrix (GP) in 2002 plus television viewers from more than 200 countries every year for a total annual audience of 5,200 million, it is no wonder that Qatar is building a MotoGP Racetrack. Over 320 million spectators watch each GP!

The Qatar MotoGP Grand Prix will take place on 2 October 2004, and building has started on the track located on the outskirts of the desert country's capital city, Doha.

For more information click on [www.qmmf.com](http://www.qmmf.com) or contact [investorsrelations@qatartourism.gov.qa](mailto:investorsrelations@qatartourism.gov.qa).

### **Asian Games 2006**

As part of the infrastructural obligations for hosting the Asian Games, construction of the Asian Games City has begun. Once completed, over 30 sports facilities will be in place. Existing buildings are being renovated as new ones being built, including Al Sadd Stadium, Al Rayyan Sports Centre, Al Ilihad Sports Centre, Al Arabi Sports Centre, Swimming Centre (Aquatic) and Khalifa Stadium.

For more information, click on [www.qatarolympics.org](http://www.qatarolympics.org).

[www.dohasiangames.org](http://www.dohasiangames.org) or contact [investorsrelations@qatartourism.gov.qa](mailto:investorsrelations@qatartourism.gov.qa).



### **Doha Golf Club**

Doha Golf Club will undergo extensive renovations and expansions after a customer

survey revealed the need for increased amenities, including a play area for kids and swimming pool. The renovation and expansion includes a ground floor dining hall, new bar area, professional shop, members' bag store, male and female locker areas, ground floor kitchen, service yard, first floor kitchen, restaurant, and bar. New construction projects include swimming pool with Jacuzzi, fitness centre, ground floor main office in a new building, buggy barn, function hall, two staff residential buildings, new academy building, television building, and a nine-hole golf course. For more information, go to [www.dohaclub.com](http://www.dohaclub.com) or contact [investorsrelations@qatartourism.gov.qa](mailto:investorsrelations@qatartourism.gov.qa).

#### Pearl of the Gulf



#### **\$2.5bn 'Pearl of the Gulf' man-made island project set to take off**

By late 2006, the first of some 30,000 residents should be living on a man-made island 350 meters off the coast of Doha's West Bay Lagoon.

The ambitious 'Pearl of the Gulf' project was the recent subject of a presentation to the Qatar Tourism Authority (QTA), and features in its new project development and investment opportunities newsletter. Marketing is expected to begin next month.

The \$2.5bn project is the brainchild of United Development Company (UDC), Qatar's largest private-sector shareholding company, and is being developed on a fast-track basis with "full government support", say officials.

The master plan and environmental impact study have apparently already received official approval, and a financial advisor is to be appointed soon. It is understood that detailed infrastructure and landscaping design has already been tendered.

Apart from over 7,500 high-quality dwelling units, the island development will also have three luxury hotels offering around 900 rooms between them, retail units covering approximately 60,000 square meters, and community infrastructural facilities such as entertainment centers, restaurants and parks.

The island is even expected to have its own private schools. An 'island city within a city' Pearl of the Gulf is to have ten distinct, but inter-related precincts. Officials say that under an agreement signed between UDC and the Government of Qatar almost a year ago, UDC would be granted freehold title to the island, together with the right to sub-divide and re-sell the property.

With three huge bays, designed to maximize its water-frontage, the island will, according to the Master Plan, also have four marinas to accommodate up to 700 boats. The first occupants are expected to take possession at the beginning of the fourth quarter of 2006.

UDC has emphasized that "through the process of an international design competition, a Master Plan and an Environmental Impact Study prepared by international consultants, the island has been positioned with the greatest respect to marine environment and topography in order to achieve both environmental integrity and construction practicality."

#### **Peninsula**

source : [www.penninsula.com](http://www.penninsula.com)

For more information, click on [www.udcqatar.com](http://www.udcqatar.com) or contact [investorsrelations@qatartourism.gov.qa](mailto:investorsrelations@qatartourism.gov.qa).

**North Beach Development**

# **PROSPECTS FOR DEVELOPMENT OF ALASKA NATURAL GAS: A REVIEW**

*As of January 2001*

*by*

*Kirk W. Sherwood and James D. Craig*

**U.S. Department of the Interior**

**Minerals Management Service**

**Resource Evaluation Office  
Anchorage, Alaska**

This report is available online at <http://www.mms.gov/alaska/re/reports/rereport.htm>

A Compact Disk version of the report (in PDF format) may be obtained by contacting Rance Wall, Regional Supervisor for Resource Evaluation, Minerals Management Service, 949 E. 36<sup>th</sup> Ave., Rm. 308, Anchorage, AK 99508-4362, or at Ph. 907 271 6078, or at e-mail [rance.wall@mms.gov](mailto:rance.wall@mms.gov)

## 1. EXECUTIVE SUMMARY

### Alaska Gas: Key Drivers and Issues

- The first gas production from northern Alaska will focus on the proven, low-cost reserves at Prudhoe Bay (26 tcf).
- The most likely scenario for exports of northern Alaska gas is a gas pipeline down existing highways from Prudhoe Bay to Alberta, Canada. No decision has yet been announced. The State of Alaska, Yukon Territory, and most stakeholders advocate a highway route. Existing regulatory permits and international treaties, subject to review, authorize the highway route.
- Phillips Alaska estimates that prices above \$3.50/mcf at Chicago city gate are needed for economic success. Chicago city gate prices were approximately \$8/mcf in January 2001.
- Gas delivery to U.S. via gas pipeline from Prudhoe Bay is not expected before years 2007-2010. Regulatory delays or litigation could delay it.
- The gas pipeline will be sized for efficient transportation of the known gas reserves at Prudhoe Bay. For a 4.0 billion cubic feet per day pipeline, excess capacity would become available in year 2023 (assuming a 2007 start up).
- Cook Inlet remaining natural gas reserves (2.56 tcf) will be depleted by year 2012. New gas sources must be located soon to supply the majority of the State's population which lives in the area around Cook Inlet.
- The most attractive gas province in the Bering Sea is North Aleutian basin,

which is closed by moratorium until year 2012.

- LNG export models are required for future Bering Sea gas production. Potential gas resources cannot be taken to the U.S. West Coast because there are no LNG receiving facilities. The most likely LNG export models deliver gas to Japan or other Asian Pacific Rim countries.
- Alaska has a huge resource base of discovered and undiscovered gas (217.91 tcf), but 88 percent of this gas is undiscovered. Expensive and time-consuming exploration programs will be required to identify new commercial gas fields.

### Summary

Alaska contains 39.88 trillion cubic feet (tcf) of gas remaining in developed and known undeveloped fields. Some of this gas is in fields too small or remote to justify economic development. Of the known gas reserves, 26.92 tcf may be considered available for export at appropriate market prices and pending construction of new gas transportation systems. Most of this gas is in onshore fields and mostly beneath State of Alaska surface or submerged lands. No Federal offshore gas reserves are considered to be readily available for export at present.

Three percent (0.92 tcf) of Alaska's exportable gas reserves occur within fields in the Cook Inlet basin of southern Alaska and are at present dedicated to future LNG exports to Japan. Cook Inlet has 2.56 tcf in total remaining gas reserves, most of which is used locally or converted to fertilizer feedstock. At present rates of consumption,