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My SPE Distinguished Lecture tour
SPE DISTINGUISHED LECTURE

The End of Stranded Gas:
The Emergence of the Gas to Products Option

Dr. Theo H Fleisch
Distinguished Advisor, BP America
Houston, TX 77079
Outline

• Problem with gas: stranded or associated
• Gas monetization options
• The case for Gas To Products (GTP)
  − What is GTP and GTL?
  − Products and markets
  − Technologies
  − Global projects
  − Economic viability
  − BP’s role in GTP
• The future of GTP
Gas resources: plentiful but...

- Gas Reserves (2005) = 6500TCF (185TCM); “under-explored”

- R/P ratio: ~70 years (versus oil at ~35)

- About 40% of gas (2500TCF) is stranded
  - (Russia, Qatar, Australia, Alaska, ...)
  - Solution: conversion of gas into transportable liquid

- Associated gas: re-injected or flared
Flaring of associated gas (in red; 15 bcfd?)
Remote and flared gas: an inexpensive feedstock

**GTP Value creation:**

*Feedstock:* $0 to 1.50/MMBTU

*Products:* $10/MMBTU

(diesel at $50 oil or methanol at $200/t)

**GTP:** Transportable, high value products

Greater netback to the feedstock

New markets for gas
# Remote Gas Monetization Options

<table>
<thead>
<tr>
<th>Methods</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipeline</td>
<td>Pushing the limits ($25B)</td>
</tr>
<tr>
<td>LNG</td>
<td>Technology of choice today</td>
</tr>
<tr>
<td>GTL (FT, Fischer-Tropsch)</td>
<td>Birth of a new industry</td>
</tr>
<tr>
<td>Methanol</td>
<td>Transition from chemical to fuel</td>
</tr>
<tr>
<td>DME</td>
<td>“SYN-LPG”, Asian Tiger awakens</td>
</tr>
<tr>
<td>CNG</td>
<td>A niche for small &amp; short (EnerSea)</td>
</tr>
<tr>
<td>Gas by Wire</td>
<td>DC transmission cost decreasing</td>
</tr>
<tr>
<td>Hydrates</td>
<td>Moving a lot of water</td>
</tr>
<tr>
<td>Gas by Bag</td>
<td>A very small niche</td>
</tr>
</tbody>
</table>
Gas by Bag
• Problem with gas: stranded or associated
• Gas monetization options
• The case for Gas To Products (GTP)
  – What is GTP, GTL, GTC, etc?
  – Products and markets
  – Technologies
  – Global projects
  – Economic viability
• The future of GTP
GTP: Inclusive term for all chemical gas conversion options (today: 20 bcf/d)

GTL PROCESS
GTC or GTFC TECHNOLOGIES

Reforming
Methane
CH4
O2
H2O
Synthesis Gas
CO + H2

PREMIUM PRODUCTS

FT
Upgrading

Diesel
Naphtha
Syn-crude

Methanol and DME
Gasoline, Hydrogen
Olefins
Ammonia and others

GTL: Gas to Liquids (FT- Fischer Tropsch)
GTC: Gas to Chemicals
GTFC: Gas to Fuels and Chemicals
Industry moves from GTP to “XTP”

Reforming

Methane, Coal, Petcoke, Biomass → Synthesis Gas → CO + H2

GTL PROCESS

FT → Upgrading

Diesel, Naphtha, Syn-crude

GTC or GTFC TECHNOLOGIES

Methanol and DME

Gasoline, Hydrogen

Olefins

Ammonia and others

Gasification/UCG “Clean Coal Technologies”
GTP offers large markets for gas

<table>
<thead>
<tr>
<th>Target Products</th>
<th>Product market size</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Comparison: LNG</strong></td>
<td>150 (actual size)</td>
</tr>
<tr>
<td>Synthetic “crude”</td>
<td>3800</td>
</tr>
<tr>
<td>GTL-FT Diesel</td>
<td>1100</td>
</tr>
<tr>
<td>Methanol, chemical</td>
<td>34</td>
</tr>
<tr>
<td>Methanol as/to gasoline</td>
<td>900</td>
</tr>
<tr>
<td>Methanol to DME (LPG)</td>
<td>215</td>
</tr>
<tr>
<td>Methanol to Olefins</td>
<td>140</td>
</tr>
<tr>
<td>Power (methanol, hydrogen)</td>
<td>Very large</td>
</tr>
<tr>
<td>Ammonia</td>
<td>130</td>
</tr>
</tbody>
</table>
Some simple conversion chemistry

Dimethyl-ether (DME)

Methanol

"Diesel"

Hydrogen  Carbon  Oxygen
About DME

- Easily made from methanol
- Physical properties: like LPG
- Clean bill of health
- Multi-purpose fuel
  - LPG extender (commercial)
  - Ultimate Diesel fuel (fleet demos)
  - Power production (CCGT)
  - Other: olefins, hydrogen, gasoline
- International DME Association (IDA)
- www.aboutdme.org
Methanol/DME in China

2020: 60/30

<table>
<thead>
<tr>
<th>Year</th>
<th>Thousands MT/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>40</td>
</tr>
<tr>
<td>2005</td>
<td>155</td>
</tr>
<tr>
<td>2006</td>
<td>275</td>
</tr>
<tr>
<td>2007</td>
<td>935</td>
</tr>
<tr>
<td>2008</td>
<td>1555</td>
</tr>
<tr>
<td>2009</td>
<td>4155</td>
</tr>
<tr>
<td>2010</td>
<td>8355</td>
</tr>
</tbody>
</table>

- **Shandong Jiutai Chemical Industry**
  - 1 million T/yr - 2009
  - Xinao Group
  - 400,000 T/yr - under construction
  - Mengda Group
  - 1 million T/yr – under planning
  - Luthianhua Group
  - 200,000 T/yr – under planning
  - Xinao Group
  - 400,000 T/yr - under construction

- **Shanxi Lanhua Sci-Tech**
  - 100,000 T/yr – under construction, 2007
  - (Jincheng)

- **Lanhu Group**
  - 1,000,000 T/yr – under planning

- **Shenhua Ningxia Coal Industry Group**
  - 210,000 T/yr - 2007
  - To 830,000 T/yr - 2008

- **Yankuang Group**
  - 200,000 T/yr - 2009

- **Yuannan Jiehua Chem. Group**
  - 150,000 T/yr – 2007
  - Under construction

- **Hubei Zhongjie Petrochem. Group**
  - 100,000 T/yr – under const. - 2007

- **Hubei Biocause Pharmaceutical**
  - 100,000 T/yr – under planning -2007

- **Shandong Jiutai Chemical Industry**
  - 1 million T/yr - 2009

- **Xinao Group**
  - 100,000 T/yr – under construction

- **Mengda Group**
  - 1 million T/yr – under planning

- **Luthianhua Group**
  - 10,000 T/yr – 2003
  - 110,000 T/yr – 2006

- **Shanghai Coking/Huayi Company**
  - 5000 T/yr – Apr.2006

- **Xinao Group**
  - 10,000 T/yr – Jan. 2006

- **Luthianhua Group**
  - 200,000 T/yr – under planning

- **Shenhua Ningxia Coal Industry Group**
  - 210,000 T/yr - 2007
  - To 830,000 T/yr - 2008

- **Yuannan Jiehua Chem. Group**
  - 150,000 T/yr – 2007
  - Under construction

- **Hubei Zhongjie Petrochem. Group**
  - 100,000 T/yr – under const. - 2007

- **Hubei Biocause Pharmaceutical**
  - 100,000 T/yr – under planning -2007

Memo: This is a work in progress, Ron Sills, Sept. 19, 2006

1 MT DME requires 1.4 MT methanol
Automotive fuel demand scenario to 2100

Energy Demand ($10^{18} J$)

- Diesel / Gasoline
- Electricity
- Gas
- Hydrogen
- Synthetic fuels and biofuels
- Liquid Fuels
- Gaseous Fuels

Source: IEA

Data source: WEC; with modification
The dangers of technical prediction

• **Nuclear-powered vacuum cleaners will probably be a reality in 10 years** - Alex Lewyt, president of vacuum cleaner company Lewyt Corp., 1955

• **There is no reason anyone would want a computer in their home** - Ken Olson, president of Digital Equipment Corp. 1977

• **Drill for oil? You mean drill into the ground to try and find oil? You're crazy.** - Drillers who Edwin L. Drake tried to enlist in 1859

• **Radio has no future. Heavier-than-air flying machines are impossible. X-rays will prove to be a hoax** - William Thomson, Lord Kelvin, 1899
Role of GTP in host countries

• Gas resource holder increasingly value GTP
  - GTP: Requirement for gas access and country entry
  - Algeria: Tinnirhert GTL bid
  - Qatar: “GTL Capital of the World”
  - Trinidad: “GTP Capital of the World”
  - No more flaring policies

• Key advantages
  - Diversity of products and markets
  - Country industrialization (investments, jobs)
  - Acceleration of gas monetization
  - New “unconstrained” markets for gas
GTL (and some other GTP) markets are virtually unconstrained.

GTP is an excellent complement to LNG.
Gas resource consideration

- LNG: massive scale; multiple trains
  - >10 tcf resource requirement

- GTP: massive scale AND smaller scale
  - World scale methanol/DME plant: 150mmscf/d, <2 tcf
  - World scale GTL plant: 300mmscf/d, ~3tcf
Summary: Products and markets

• XTP offers a broad product portfolio
  – Improved conventional fuels (diesel, gasoline, jet fuel, etc)
  – New “designer” fuels and fuel additives (methanol, DME, hydrogen, ethanol, etc)
  – New large volume chemicals (olefins)

• Fuel properties
  – Greatly improved performance and emissions
  – Preferred (early) applications: blends

• XTP is a must have tool in the tool box
Problem with gas: stranded or associated
Gas monetization options
The case for Gas To Products (GTP)
  - What is GTP and GTL?
  - Products and markets
  - Technologies
  - Global projects
  - Economic viability
The future of GTP
GTL technology challenges

Gas Plant

CH₄

Co+H₂

(-CH₂-)ₙ

Reformer

FT Plant

Upgrading

O₂

ASU

Naphtha

Diesel
GTL projects: the birth of an industry

World GTL
Trinidad
4kbpd

Tinrhet
Algeria
35kbpd

Heritage Plants
Shell Bintulu
PetroSA Mossgas

BP
“Colombia Condor”
~35kbpd

Sasol
“Oryx”
35kbpd (70kd/d train 2)

Shell
“Pearl”
140kbpd (Nov. 2003)

ExxonMobil
160kbpd (July, 2004)
PP: Feb. 2007

Marathon/Syntroleum
ConocoPhillips
SasolChevron
POSTPONED

Many other proposed projects
Methanol/DME projects: transition from chemicals to fuels

- Iran DME: 2500 TPD
- Iran Methanol: 1-5 5,000 TPD
- Oman Methanol: 3,000 TPD
- Qatar Methanol: 6,750 TPD
- Methanol Holdings in Trinidad: (2) 5,000 TPD
- Methanol in Egypt
- Nigeria/Eurochem MTO: 7,500 TPD
- Qatar DME Int’l Corp.: 2,500-4,500 TPD
- Japan DME Ltd: 3,000 TPD
- Oman Methanol
- Qatar Methanol
- Iran DME
- Methanol Holdings in Trinidad
- Methanol in Egypt
- Methanol for Fuel, Power/Olefins
- DME

Memo: Not including <5,000 MTPD methanol plants
As we stand here today to celebrate the inauguration of Oryx GTL, we are changing the world’s energy paradigm with gas-to-liquids (GTL) technology.

- His Excellency Abdullah Bin Hamad Al-Attiyah, Second Deputy Premier, Minister of Energy and Industry, Qatar, and Qatar Petroleum chairman.

**Plant Statistics**

- 34,000 bpd capacity
- 24,000 bpd Diesel
- 9,000 bpd Naphtha
- 1,000 bpd LPG

Construction Start – Dec 2003

Project Completion – March 2007

Believed to have cost $1.2 Billion
Atlas Plant (Trinidad): Pioneer methanol plant

- 5000tpd (160MMscfd); equivalent to 15,000bpd GTL
- Operated by Methanex, BP is 40% equity partner
- World’s largest single train reformer
GTP Economics: summary

• 2000: GTL reached parity with LNG in economic returns
  − Robust economics at $20 crude and Capex of $25k/bbl (2000)
  − But EPC cost increases: >$50k/bbl (2006)

• 2006: Relative economic viability
  − GTL (~$35/bbl), CTL (~$50 - 60/bbl), BTL (~$85/bbl)
  − Higher crude prices favor GTP over LNG

• Methanol and DME can be delivered at $5-7/MMBTU and become viable as fuels above $30 crude
  − Fuel methanol and DME are commercial realities in China
  − Olefin projects underway (new low cost technology)
Important factors for economics

1. Feedstock cost

2. Capital cost
   - Location factor
   - Boundary conditions
   - Inflation

3. Product prices
GTL Cost Trends

- Relatively few commercial-scale projects to date
- Significant scope, scale and location-specific differences
- Estimates based on published data
LNG Liquefaction Cost Trends

Drivers:
- Economies of scale (e.g. liquefaction, storage & shipping)
- Increased competition (e.g. licensors, contractors, suppliers)
- New technology (e.g. cryogenic pipelines; flexible hoses)

Drivers:
- EPC demand and supply imbalance
- Materials and labour costs
- Vendors and manufacturing (e.g. exchangers, turbines, compressors)
- LNG shipping and yard availabilities
- Increase in schedules
LNG and GTL comparison: boundary conditions

**Fixed Chain**
- **600 MMSCF/D**
- LNG Plant: ~4 mtpa
- Shipping: ~3500 nm, 3 x 130,000 m3
- Regasification

**Unconstrained Market**
- **600 MMSCF/D**
- GTL Plant: 75,000 bbl/day
- Product carriers: spot/term
- Distribution/Blending

Shell
Impact of product prices (USA)

US Energy Costs ($/Million BTU)

Diesel > Natural gas/LNG > Coal

Liquid fuels >> natural gas
Economics of GTL vs. LNG

Key Issues:
- Oil:gas price relationship; gas capped by coal
- LNG capex: plant only or value chain capex?
- Strategic value:
  - Revenue diversification
  - Value added in-country
  - LNG and GTP

Net Present Value

Oil Price ($/bbl)

LNG Price ($/mmbtu)
### Summary: Pros and cons of GTP

**PROS**
- Large new markets
- Host country appeal
- Premium "designer" products
- Robust economics
- Proven technologies
- Scaleability

**CONS**
- Capital intensive
- Scale-up risks
- Aversion to new products
- Poor efficiencies
## Process carbon efficiencies

<table>
<thead>
<tr>
<th>Benchmark:</th>
<th>Carbon efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LNG and refineries</td>
<td>85 - 90</td>
</tr>
<tr>
<td>GTL today</td>
<td>75 – 80</td>
</tr>
<tr>
<td>Goal</td>
<td>~/&gt;85</td>
</tr>
<tr>
<td>Methanol/DME today</td>
<td>80 – 83</td>
</tr>
<tr>
<td>Goal</td>
<td>85 - 90</td>
</tr>
</tbody>
</table>
The future in GTP

- On-going R&D and value engineering
  - lower cost plants
  - Higher efficiencies
- Floating applications
  - Marinization of GTL FT
  - Micro-channel technologies (Velocys, CompactGTL)
- New products from syngas
- Gas refinery
  - Integration of different plants
  - Further conversion of primary products into consumer products (plastics)
Technology Benchmark: Syntroleum FPSO

16,300 bpd GTL
150 mm-scfd Gas
$1.2b EPC
20,150 M²
Integrated Gas Refinery Concept

Feedgas Supply → NGL Extraction → NGLs

NGLs → Ethane → PetChem e.g. ATC

NGLs → Methane → Syngas Hub

Syngas Hub → GTL Diesel → Core GTP Offer

Syngas Hub → DME Plastics

Syngas Hub → Methanol (Acetic Acid)

Syngas Hub → Ammonia (Urea)

Syngas Hub → Power Plant

Syngas Hub → LNG

Integration Options
BP GTP Profile

- World class R&D group (~60 people)
- Relationship with Berkeley, Caltech, DICP (~60)
- Broad GTP product portfolio (CR, FT, alcohols,...)
- Atlas methanol plant (with Methanex)
- Portfolio of project options
- Decarbonized fuel projects
- Jan 2007: Transition to XTP
Hydrogen power projects: “DF2” – Carson Refinery

Gasification: C + H2O = CO + H2
Syngas cleanup
Shifting: CO + H2O = CO2 + H2
Separation: CO2 and H2
Summary

- GTP and XTP are here to stay: new options for resource holders
- Oryx and Atlas: pioneer plants for new GTL and methanol/DME business
- Target feedstocks: stranded gas, flares, domestic coal
- Products: high performing, low emitting fuels
- No more stranded gas