The Gas Cycle in the 21st Century

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Schlumberger
Outline

• The Past
• The Golden Age of Oil
• The Golden Age of Gas - Now
• The Gas Cycle – What is it?
• LNG, GTL, Gas by Wire, UGS
• Conclusions
• The Past – Progression from
  - Wood to
  - Coal to
  - Oil
Decarbonization

Methane: H/C = 4
Oil: H/C = 2
Coal: H/C = 1
Wood H/C = 0.1

Source: Ausubel, American Scientist, March-April 1996
Decarbonization

- As we have progressed from wood to coal to oil, the carbon to hydrogen ratio of these fuels has decreased.
- However, more fuel is being consumed, so the amount of carbon released to the atmosphere has been increasing.
- In the future, the switch to natural gas and eventually, to hydrogen will be beneficial to the environment.
- But in the next 20 years, we will burn more oil, gas and coal than ever before.
The Golden Age of Oil
- Oil production becoming more important than exploration

![Graph showing oil discoveries and production with peak in 1962 and subsequent decline. Source: US DOE EIA - International Energy Outlook, 1999]
How Much Oil is Left in Conventional Reservoirs?
Worldwide Oil Production

- Current oil production rate:
  27 Billion STB/yr
- Cumulative production through 1996*:
  784 Billion STB
- Thus, through 2001, production is over
  900 Billion STB

* From Campbell
World Oil Reserves

- ME: 700 B BBLs
- NSA: 150 B BBLs
- AF: 100 B BBLs
- EE&FSU: 75 B BBLs
- AP: 50 B BBLs
- WE: 25 B BBLs
How Long Can We Continue Producing Oil from Conventional Reservoirs?
U.S.A.
Ultimate 210 Billion Barrels
from Campbell
Global Oil Production-Forecasts

2001 EIA Demand Forecast

Year

Billion barrels per year

Billion barrels

Source: J. MacKenzie, 1996
Will Energy Demand Keep Growing?

- Yes, on the basis of everyone’s predictions.
- World population now 6 Billion
- In 2050, the population will be 9 Billion
- World population estimates for 2050 range from 7.8 to 13 billion
- Increased population will require energy
- Will there be enough oil and gas for the expanding world population?
In the next 20 years, oil production from conventional reservoirs may begin to decline, creating a gap between supply and demand.
Gap Between Supply-Demand

EIA 2001

Gap

2200

Billion barrels per year

Year
What Can Fill The Gap?

- Gas Reservoirs Around the World
  - 5000 TCF of World Gas Reserves
- Unconventional Reservoirs
  - Heavy Oil or Tight Gas
- Renewable Resources
  - Wind or Solar
- Fuel Cells
- Nuclear Power Plants
What Will Dictate the Way Forward?

- Environmental Issues – Move to $H_2$
- Political Issues – Government Actions
- Capital Costs – High for every option
- Advances in Technology – GTL, etc.
- World Prices for Oil and Gas
- Existing Conditions – Lots of Automobiles
- Control of Terrorism
The Golden Age of Gas is Now
• Inevitable shift to gas—both exploration and production

Source: US DOE EIA - International Energy Outlook, 1999
World Natural Gas Consumption


Tcf
World Gas Reserves

Total = 5200 Tcf

EE&FSU: 2000 Tcf
ME: 2200 Tcf
NSA: 400 Tcf
AF: 200 Tcf
AP: 100 Tcf
WE: 50 Tcf

TCF
Gas Reserves by Country

- Russia
- Iran
- Saudi
- USA
- Ven
- UK
- USA-NCG

TCF
Gas Hydrates (1% Recovery)?
The Gas Cycle – What is it?
The Gas Cycle Includes Everything From

- Exploration
- Reservoir evaluation
- Reservoir description
- Reservoir development
- Production operations
- Reservoir engineering
- Gas processing facilities
- Gas transportation
- LNG processing
- GTL processing
- Burner tip use
- Gas-by-wire use
- Gas powered vehicles
- Gas as feedstock
Natural Gas Utilization Options

- Domestic Gas
- LNG
- Power Generation
- Ammonia
- Urea
- Methanol / MTBE
- Dimethyl Ether
- Fischer-Tropsch Products
- CNG
**Imports**
- Canada: 3.4 Tcf
- Algeria: 0.076 Tcf
- Mexico: 0.055 Tcf
- Trinidad: 0.051 Tcf
- Qatar: 0.02 Tcf
- Australia: 0.012 Tcf
- UAE: 0.003 Tcf
- Malaysia: 0.003 Tcf

**Exports**
- Canada: 3.4 Tcf
- Mexico: 0.055 Tcf
- Japan: 0.064 Tcf

**Gross Production**
23.8 Tcf

**Vented**
0.2 Tcf

**Injected**
3.3 Tcf

**Non-hydrogen Gas**
0.6 Tcf

**Gas Plants**
18.7 Tcf

**Dry Gas Production**
22.15 Tcf

**Loss/Use**
0.9 Tcf

**Storage**
22.36 Tcf

**Residential**
4.72 Tcf

**Commercial**
3.07 Tcf

**Industrial**
7.95 Tcf

**Electricity**
3.78 Tcf

**Fuel**
1.87 Tcf

**Transportation**
0.02 Tcf

**Discrepancy**
0.946 Tcf

**In**
2.7 Tcf

**Out**
2.9 Tcf
Natural Gas Logistics

- Natural gas is more difficult to transport than oil
- Most gas use is in the USA and Europe where systems of pipelines are used to transport natural gas
- In remote parts of the world, gas must be transported
  - As LNG, which requires high Capex, or
  - GTL which is an emerging technology, or
  - Gas-by-wire, which is electric power generation, or
  - New, expensive pipelines will have to be constructed
LNG Trade
LNG Properties

- Stored as a liquid at minus 260°F under pressure
- Occupies 1/600 (0.00167) the volume of natural gas at standard temperature and pressure
- Mostly methane with very few heavy components
- LNG is
  - Odorless
  - Non-corrosive
  - Colorless
  - Non-toxic
LNG Facts

- Australia has 100 Tcf looking for a market
- Shell is looking at a floating LNG plant in Timor Sea
- Others looking at LNG for Alaska’s 35 Tcf
- New Sources from Nigeria and Venezuela
- Large expansion will require more tankers
Major trade movements
Trade flows worldwide (billion cubic metres)

Natural gas ➔ LNG

USA ➔ Canada ➔ Mexico ➔ S. & Cent. America ➔ Europe ➔ Former Soviet Union ➔ Middle East ➔ Africa ➔ Asia Pacific

36 SPE/Holditch
LNG Trade Movements

Middle East 54 million boe

Malaysia 122 million boe

Brunei 50 million boe

NW Shelf 60 million boe

Indonesia 218 million boe
## LNG Movement in 1999

<table>
<thead>
<tr>
<th>Major Importer</th>
<th>Volume (Tcf)</th>
<th>Major Exporter</th>
<th>Volume (Tcf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Japan</td>
<td>2.440</td>
<td>Indonesia</td>
<td>1.273</td>
</tr>
<tr>
<td>South Korea</td>
<td>0.617</td>
<td>Algeria</td>
<td>0.907</td>
</tr>
<tr>
<td>France</td>
<td>0.361</td>
<td>Malaysia</td>
<td>0.724</td>
</tr>
<tr>
<td>Spain</td>
<td>0.252</td>
<td>Australia</td>
<td>0.355</td>
</tr>
<tr>
<td>USA</td>
<td>0.161</td>
<td>Brunei</td>
<td>0.296</td>
</tr>
<tr>
<td>Belgium</td>
<td>0.142</td>
<td>Qatar</td>
<td>0.286</td>
</tr>
<tr>
<td>Others (3)</td>
<td>0.307</td>
<td>Others (5)</td>
<td>0.439</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>4.280</strong></td>
<td><strong>Total</strong></td>
<td><strong>4.280</strong></td>
</tr>
</tbody>
</table>
## LNG Capacity in the U.S.

<table>
<thead>
<tr>
<th>Location</th>
<th>Owner</th>
<th>Capacity</th>
<th>Rate</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Everett MA</td>
<td>Cabot</td>
<td>3.5</td>
<td>435</td>
<td>1971-1985; 1987 - present</td>
</tr>
<tr>
<td>Lake Charles</td>
<td>CMS</td>
<td>6.3</td>
<td>700</td>
<td>1982-1983; 1989-present</td>
</tr>
<tr>
<td>Cove Point</td>
<td>Williams</td>
<td>5.0</td>
<td>1000</td>
<td>1978-1980; 1985- present</td>
</tr>
<tr>
<td>Elba Island</td>
<td>El Paso</td>
<td>4.2</td>
<td>675</td>
<td>1978-1980</td>
</tr>
<tr>
<td>Puerto Rico</td>
<td>Enron</td>
<td>3.5</td>
<td>186</td>
<td>2000 – present</td>
</tr>
</tbody>
</table>
GTL Technology
What is GTL?

- Gas to Liquids is the conversion of natural gas to high value liquid fuels, such as
  - Methanol
  - Dimethyl Ether (DME)
  - Middle distillates
  - Specialty chemicals and waxes
- Fischer-Tropsch Chemistry began in 1920’s and was used in WWII by Germans
GTL Chemistry

Methane $\rightarrow$ CH$_4$ + O$_2$ + H$_2$O $\rightarrow$ CO + H$_2$ $\rightarrow$ n(CH$_2$) + nH$_2$O $\rightarrow$ Liquid Fuels
Methanol

Fuel Cells
DME
Gasoline

Ammonia/Urea

Diesel
Naphtha
LPG
Wax/Lubes

Natural Gas

Syngas Production

Fischer Tropsch Process
## Commercial GTL Plants

<table>
<thead>
<tr>
<th>Operator</th>
<th>Location</th>
<th>Bbls/day</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sasol – 1955</td>
<td>South Africa</td>
<td>124,000</td>
<td>Light olefins and gasoline</td>
</tr>
<tr>
<td>Mossgas – 1991</td>
<td>South Africa</td>
<td>22,500</td>
<td>Gasoline and diesel</td>
</tr>
<tr>
<td>Shell – 1993</td>
<td>Malaysia</td>
<td>12,500</td>
<td>Waxes, chemicals and diesel</td>
</tr>
</tbody>
</table>
## Proposed GTL Plants

<table>
<thead>
<tr>
<th>Operator</th>
<th>Location</th>
<th>Bbls/day</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rentech</td>
<td>USA</td>
<td>1200</td>
<td>Waxes and fuels</td>
</tr>
<tr>
<td>Syntroleum</td>
<td>Australia</td>
<td>10,000</td>
<td>High margin products</td>
</tr>
<tr>
<td>Sasol</td>
<td>Qatar</td>
<td>34,000</td>
<td>Liquid fuels</td>
</tr>
<tr>
<td>ExxonMobil</td>
<td>Qatar</td>
<td>100,000</td>
<td>Liquid fuels</td>
</tr>
<tr>
<td>SasolChevron</td>
<td>Nigeria</td>
<td>33,000</td>
<td>Liquid fuels</td>
</tr>
<tr>
<td>BP</td>
<td>Alaska</td>
<td>100,000</td>
<td>Liquid fuels</td>
</tr>
<tr>
<td>Sicor</td>
<td>Ethiopia</td>
<td>20,000</td>
<td>Liquid fuels</td>
</tr>
<tr>
<td>PDVSA</td>
<td>Venezuela</td>
<td>15,000</td>
<td>Liquid fuels</td>
</tr>
</tbody>
</table>
# Feasibility Studies for GTL

<table>
<thead>
<tr>
<th>Operator</th>
<th>Location</th>
<th>Bbls/day</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shell</td>
<td>Indonesia</td>
<td>75,000</td>
<td>Liquid fuels</td>
</tr>
<tr>
<td>Shell</td>
<td>Australia</td>
<td>75,000</td>
<td>Liquid fuels</td>
</tr>
<tr>
<td>Shell</td>
<td>Malasia</td>
<td>75,000</td>
<td>Liquid fuels</td>
</tr>
<tr>
<td>Shell</td>
<td>Egypt</td>
<td>75,000</td>
<td>Liquid fuels</td>
</tr>
<tr>
<td>Shell</td>
<td>Iran</td>
<td>75,000</td>
<td>Liquid fuels</td>
</tr>
<tr>
<td>Shell</td>
<td>Argentina</td>
<td>75,000</td>
<td>Liquid fuels</td>
</tr>
<tr>
<td>Shell</td>
<td>Trinidad</td>
<td>75,000</td>
<td>Liquid fuels</td>
</tr>
<tr>
<td>SasolChevron</td>
<td>Australia (2)</td>
<td>30-100,000</td>
<td>Liquid fuels</td>
</tr>
</tbody>
</table>
# Economies of Scale

<table>
<thead>
<tr>
<th>Plant Size</th>
<th>Capacity (BPD)</th>
<th>Capex (US$/BPD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>&lt; 10,000</td>
<td>40,000</td>
</tr>
<tr>
<td>Medium</td>
<td>10,000 – 35,000</td>
<td>40,000 – 22,000</td>
</tr>
<tr>
<td>Large</td>
<td>&gt; 35,000</td>
<td>19,000 – 22,000</td>
</tr>
</tbody>
</table>
Approximate GTL Plant Costs

- Oxygen Plant and Gas Purification 35%
- Synthesis Gas Generation 25%
- Fischer-Tropsch Processes 30%
- Product Upgrades 10%
Gas by Wire
World Electricity Consumption

Billion Kilowatthours


- Develop
- FSU/EE
- Indus
World Electricity Generation

Quadrillion BTU

- Renewable
- Nuclear
- Coal
- Gas
- Oil

USA Electricity Consumption

Billion Kilowatthours


Indus
Comm
Resid
USA Natural Gas Consumption

Major Increase is in Electricity Generation

Tcf

- Fuel
- Elec
- Indus
- Comm
- Resid

USA Natural Gas Demand

- Demand to increase 10 Tcf per year by 2015
- Virtually all the increase will be in electricity generation
- Sources of new gas
  - LNG
  - Alaska/Canada pipeline
  - New Drilling
- Need $3+/Mcf for any of these options
Sources of New Gas

• Imported Liquified Natural Gas (LNG)
  – Current 5 terminals can supply 1 Tcf/yr
  – 10 more terminals are being planned
  – Will take time and more tankers

• Alaska/Canada Pipeline
  – May cost $18-20 billion
  – May take 6-7 years
  – Will deliver 1-2 Tcf/yr
New Drilling

- Offshore – recovery is 5-10 bcf per well but costs are very high
- Onshore – recovery is 1-2 bcf per well with lower costs than offshore
- For 1 Tcf/yr of new gas onshore, it will require,
  - Hundreds of new rigs
  - Thousands of new wells
  - Thousands of people (40 people for each new rig)
  - Lost of new $$$
U.S. Dry Gas Production (Tcf)

Source: DOE/EIA
U.S. Production History

* Representing 93% of US Production
### Total Natural Gas Resources – U.S. (TCF)

<table>
<thead>
<tr>
<th>Category</th>
<th>Resource Type</th>
<th>Total (TCF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Natural Gas Resources</td>
<td></td>
<td>1281</td>
</tr>
<tr>
<td>Proved Reserves</td>
<td></td>
<td>164</td>
</tr>
<tr>
<td>S.</td>
<td></td>
<td>33</td>
</tr>
<tr>
<td>Alaska</td>
<td></td>
<td>129</td>
</tr>
<tr>
<td>Associated-Dissolved</td>
<td></td>
<td>393</td>
</tr>
<tr>
<td>Unconventional</td>
<td></td>
<td>278</td>
</tr>
<tr>
<td>Tight Gas</td>
<td></td>
<td>62</td>
</tr>
<tr>
<td>CBM Shale</td>
<td></td>
<td>53</td>
</tr>
<tr>
<td>Inferred Reserves</td>
<td></td>
<td>244</td>
</tr>
<tr>
<td>Offshore</td>
<td></td>
<td>52</td>
</tr>
<tr>
<td>Onshore</td>
<td></td>
<td>192</td>
</tr>
<tr>
<td>Onshore (Deep)</td>
<td></td>
<td>152</td>
</tr>
<tr>
<td>Onshore (Shallow)</td>
<td></td>
<td>118</td>
</tr>
<tr>
<td>Onshore (CBM)</td>
<td></td>
<td>85</td>
</tr>
<tr>
<td>Onshore (Shale)</td>
<td></td>
<td>83</td>
</tr>
<tr>
<td>Onshore (Other)</td>
<td></td>
<td>167</td>
</tr>
</tbody>
</table>
More gas storage will be needed
The Gas Cycle from E&P to Distribution

Incremental consumer cost ($)

Source: IEA, GRI
European UGS Outlook

Source: International Energy Agency
UGS projects in Europe: 2000-2010

- **97 existing UGS**
- **44 new projects**
- **40 expansions**

Total UGS Work Gas in Europe:
Today = 57 Bcm → 2015 = 126 Bcm

Source: UN
Optimization of the Gas Cycle

Software
Data Management
Networking
Metering
Automation

Incremental consumer cost ($)

E&P  Compress  Interstate  UGS  Pipeline  Distribution
Summary and Conclusions
World Energy Generation

Quadrillion BTU

- 1990
- 1999
- 2005
- 2010
- 2015
- 2020

- Other
- Nuclear
- Coal
- Gas
- Oil
## Summary of World Increases

<table>
<thead>
<tr>
<th>Item</th>
<th>2000</th>
<th>2020</th>
<th>% Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population (billion)</td>
<td>6.1</td>
<td>7.6</td>
<td>25</td>
</tr>
<tr>
<td>Energy (Quadrillion BTU)</td>
<td>385</td>
<td>607</td>
<td>58</td>
</tr>
<tr>
<td>Oil Production (billion bbls)</td>
<td>27</td>
<td>43</td>
<td>60</td>
</tr>
<tr>
<td>Gas Production (Tcf)</td>
<td>86</td>
<td>162</td>
<td>88</td>
</tr>
<tr>
<td>Electricity (Quadrillion BTU)</td>
<td>150</td>
<td>225</td>
<td>50</td>
</tr>
</tbody>
</table>
Conclusions

• The world population (25%) and energy needs (60%) will grow substantially in the next 20 years.

• Production from conventional oil reservoirs will peak and begin to decline in the next 20 years.

• There will be a gap between demand for oil and production from conventional oil reservoirs during the next 20 years.

• Other resources (gas) will have to be developed to meet the world energy demands by 2020.
Conclusions

- The world currently has the oil and gas resources required to meet demand in the next 20 years.
- Liquids from conventional natural gas, plus unconventional oil and gas can fill the gap once conventional oil production begins to decline.
- Opportunity exists for the next 1-2 generations of young professionals to have a successful career in the global E&P Oil and Gas Industry.
Conclusions

• To meet the growing world energy needs
  – Liquified Natural Gas (LNG),
  – Gas to Liquids Technology (GTL),
  – New Gas Pipelines, and
  – Gas by Wire (electric generation)
  – New Underground Gas Storage

will be required to transport the world’s natural gas energy from the field to the end user

• Significant capital investment and new technology are required to bring more gas to market