Natural Gas

From prospect to burner tip

J. Richard Moore
U.S. natural gas industry-segments

Gas industry function
- EXPLORATION
- PRODUCTION
- GATHERING / PROCESSING
- TRANSMISSION
- DISTRIBUTION

Gas industry segment
- Upstream
- Midstream
- Downstream

Gas industry facilities
- GAS WELLS & LEASE EQUIPMENT
- PLANTS , PIPELINES & STORAGE
- LDC PIPELINES & EQUIPMENT
- CONSUMERS
Gross withdrawals from gas and oil wells: 26.0

Vented/Flared: 0.2

Non hydrocarbon gases removed (N2, CO2, H2S, etc.): 0.7

Reservoir repressuring (used to maintain oil production): 3.5

Dry gas production: 20.6

Extraction loss (PVR): 1.0

Imports:
- Canada: 3.271
- Trinidad: 0.236
- Other: 0.243

Additions: 3.4

Withdrawals: 3.0

Natural gas storage facilities

Lease, P/L, plant fuel, misc., bal. (gas industry): 1.9

Residential: 4.8

Commercial: 3.1

Industrial: 6.2

Vehicle Fuel: 0.03

Electric power: 6.9

Source: EIA Natural Gas Annual 2009
Seasonality of natural gas storage balances supply & consumption

Supply (Dry gas production plus net imports)

Withdraw from Storage

Inject into Storage

Consumption
Natural Gas Formation & Exploration
**Geology and formation of natural gas**

### GEOLOGIC TIME

<table>
<thead>
<tr>
<th>Years Ago</th>
<th>Headlines</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Man Appears</td>
</tr>
<tr>
<td>65 Million</td>
<td>Horses Appear, Dinosaurs Disappear</td>
</tr>
<tr>
<td>225 Million</td>
<td>Dinosaurs Appear</td>
</tr>
<tr>
<td>570 Million</td>
<td>First Abundant Fossil Record</td>
</tr>
<tr>
<td>4,600 Million</td>
<td>Ozone Layer Formed, Big Bang Heard</td>
</tr>
<tr>
<td></td>
<td>Rock Layers Deposited Over Time</td>
</tr>
</tbody>
</table>

### OIL AND GAS FORMATION

<table>
<thead>
<tr>
<th>Depth</th>
<th>Pressure &amp; Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface</td>
<td>SUCCEEDING LAYERS OF ROCK</td>
</tr>
<tr>
<td>5,000’</td>
<td>PRESSURE ON EARLIER LAYERS</td>
</tr>
<tr>
<td>10,000’</td>
<td>Heat and Pressure Convert Organic Debris to Oil &amp; Gas</td>
</tr>
<tr>
<td>Surface</td>
<td>“BASEMENT” ROCK</td>
</tr>
</tbody>
</table>
# Natural gas reservoir requirements

## Reservoir Rocks (Sedimentary)

<table>
<thead>
<tr>
<th>Name</th>
<th>Example</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source</td>
<td>Limestone</td>
<td>Porosity and Permeability</td>
</tr>
<tr>
<td>Reservoir</td>
<td>Sandstone</td>
<td></td>
</tr>
<tr>
<td>Cap/Trap</td>
<td>Shale</td>
<td>Impermeability</td>
</tr>
</tbody>
</table>

## Reservoir Requirements

- **RESERVOIR ROCK (WATER)**
- **SOURCE ROCK**
- **IMPERMEABLE CAPPING LAYER**
  - **(GAS)**

![Diagram of natural gas reservoir requirements](image)
Porosity and permeability

Conventional formation

Unconventional formation

Source: Natural Gas.org, USGS
1. Identify Prospect
   A. Seismic
   B. Log Correlation
2. Obtain Mineral Lease
3. Obtain Drilling Permit
4. Prepare Site

Preliminary

1. Drilling Contract
   A. Rate: Day, Footage, Turnkey
   B. Equipment & Start Date
2. Design Casing Program
3. Evaluate Surface Equipment Requirements

Contract & Design Issues

1. Well Control - Blow Outs / Lost Holes
2. MWD - Directional Wells
3. Logging and Analysis
4. Decision to Complete
5. Tight Hole - Confidential

Activities While Drilling

Major Rig Systems

1. Hoisting - Mast & Drawworks
2. Rotating - Turntable / Top Drive and Drill String
3. Circulating - Pumps and Mud
4. Power - Engines (Diesel / Electric)

Drilling a well
Horizontal drilling benefits

- Improved project economics
  (> production rates = > PV)
- Reduced total field CAPEX
  (fewer wells/locations required)
- Reduced environmental disturbance
  (fewer sites/wells/roads)
Completion & Production Operations
Completion activities

**Typical Steps**
- Perforate
- Fracture
- Stimulate ("Frac")
- Recover frac load/flow well

**Issues**
- Benefits
- Controversies
- Costs
“Fracing” & water quality concerns

Water for human consumption is taken from top 1000 feet of the earth.

EPA says 20 Billion* barrels of sewage (containing toxins and diseases) leak annually from US sewage systems. Leaks are into top of water supply zone and can go down through entire zone. (Daily volume is: (1) > than 10 times the total BP Macondo well spill (2) equal to total fluid needed for 550 to 1100 frac jobs)

Which is the greater threat?

Typical frac job 50-100k barrels—thousands of feet below water supply

*Source: www.epa.gov/npdes/pubs/csosso_RTC_factsheet.pdf
“Fracing” & water supply concerns

Some facts:

1. Water used to frac one horizontal well = 50k -100k bbls

2. Golf course water consumption in U.S.*
   • Average golf course in U.S. consumes 50K bbls per week
   • Average U.S. golf course consumes 2.5 million bbls per year
   • U.S. has 16,000 golf courses
   • Annual U.S. golf course water consumption = 40 billion bbls

   U.S. golf courses consume enough water every year to frac 400,000 to 800,000 wells--shall we ban golf?

Source: May 2008 Golf Digest (“How green is my golf?”), EIA
Natural Gas Gathering and Processing
Typical natural gas stream

FROM WELLHEAD SEPARATORS

PIPELINE

TO GAS PROCESSING PLANTS

HYDROGEN SULFIDE
METHANE
PROPANE
NITROGEN HELIUM
NATURAL GASOLINE
NORMAL BUTANE
ISO-BUTANE
ETHANE
DIRT & RUST
CARBON DIOXIDE
WATER

RECOVERABLE HYDROCARBONS
RESIDUE GAS
NON-HYDROCARBONS AND CONTAMINANTS
Gas well surface flow schematic

- Condensate Line
- Heater
- Separator
- Treating (CO$_2$, H$_2$S)
- Dehydration Unit
- Sales Gas
- Gas
- Condensate
- Liquid Sales
- Water
- To Disposal
Natural gas gathering and processing

Place in physical distribution network

Site / Facilities

- Wellhead
- Compressor
- Pig Launcher/Retriever
- High Pressure Gathering Line
- Medium Pressure Gathering Line
- Low Pressure Gathering Line
- Gas Transmission Pipeline

Functions / Activities

- Gathering – Connects Wells to Transmission Pipeline System
- Treating – Removes Impurities
- Processing – Removes NGLS
Natural Gas Transmission
Natural gas transmission pipelines
Place in physical distribution network

SITE / FACILITIES

- Supply Source (S)
- Market (M)
- Gathering Lines
- Intrastate Transmission Pipeline
- Interstate Transmission Pipeline “A”
- Interstate Transmission Pipeline “B”
- City Gate (CG)
- Local Distribution Company Pipelines (C)
- Compressor
- Underground Storage (US)

FUNCTIONS / ACTIVITIES

- Provide high pressure / long distance transportation of gas
- Pipeline uses pressure from reservoir or compressors (pumps) to move gas
- Pipeline uses storage facilities and line pack to meet supply / demand swings
- Safety & environmental regulation - DOT, OSHA, EPA, DOI
- Intrastate rate regulation - state agencies
- Interstate rate regulation - FERC
Natural Gas Distribution
Natural gas distribution
Place in physical distribution network

Local Distribution Utilities*

<table>
<thead>
<tr>
<th>Miles of Main</th>
<th>Type</th>
<th>Number</th>
<th>Regulation</th>
<th>LDC Deliveries</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Steel - 551,000</td>
<td>Investor Owned 260</td>
<td>State</td>
<td>Residential 4.9 Trillion BTU</td>
</tr>
<tr>
<td></td>
<td>Plastic - 621,000</td>
<td>Municipal 930</td>
<td>Local</td>
<td>Commercial 3.1 Trillion BTU</td>
</tr>
<tr>
<td></td>
<td>Other - 38,000</td>
<td></td>
<td></td>
<td>Industrial 3.9 Trillion BTU</td>
</tr>
<tr>
<td></td>
<td>Total - 1,210,000</td>
<td></td>
<td></td>
<td>Elec. Gen. 1.8 Trillion BTU</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Total 13.7 Trillion BTU</td>
</tr>
</tbody>
</table>

*Source: AGA AGA
Natural gas consumption
(22.9 tcf consumed-21.0 tcf by consumers)

- Most natural gas is consumed as fuel
- Lease, P/L and plant fuel = 1.9 TCF (8% of total consumption)
- R&C = 7.9 TCF (37% of consumer use)
- Electric power generation = 6.9 TCF (33% of consumer use)
- Industrial = 6.2 TCF (30% of consumer use)

Gas as feedstock = <10% of industrial use or < 3% of total (MECS)

Source: EIA Natural Gas Annual 2009
Natural Gas Supply
Conventional & unconventional gas
### U.S. natural gas supply-potential sources

<table>
<thead>
<tr>
<th>Area/Source</th>
<th>Technically recoverable gas resource (TCF)</th>
<th>Issues</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Natural gas resource</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alaska</td>
<td>302</td>
<td></td>
</tr>
<tr>
<td>Lower 48 Onshore (non-associated)</td>
<td>1,382</td>
<td>Access / Transport / Economics</td>
</tr>
<tr>
<td>Lower 48 Offshore (non-associated)</td>
<td>296</td>
<td>Access / Pipeline / Economics (Unconventional Gas)</td>
</tr>
<tr>
<td>Associated</td>
<td>138</td>
<td>Access / Pipeline</td>
</tr>
<tr>
<td>US recoverable resource (2010AEO)</td>
<td>2119*</td>
<td>Access (leases)</td>
</tr>
<tr>
<td>Shale gas resource increase (2011)</td>
<td>480</td>
<td></td>
</tr>
<tr>
<td>Updated US resource estimate</td>
<td>2,599</td>
<td></td>
</tr>
<tr>
<td>US proved reserves</td>
<td>238</td>
<td></td>
</tr>
<tr>
<td>Hydrates (U.S.)</td>
<td>200,00 -320,00</td>
<td>Technology / Economics</td>
</tr>
</tbody>
</table>

Source: AEO 2010 (as of 1/1/2008*) and AEO 2011
# U.S. dry natural gas supply/forecasted sources

<table>
<thead>
<tr>
<th>Source</th>
<th>2010</th>
<th>%</th>
<th>2025</th>
<th>%</th>
<th>2035</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>U. S. Dry Production</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower 48 - Onshore</td>
<td>18.6</td>
<td>77</td>
<td>21.0</td>
<td>84</td>
<td>23.0</td>
<td>87</td>
</tr>
<tr>
<td>Lower 48 - Offshore</td>
<td>2.4</td>
<td>10</td>
<td>2.4</td>
<td>10</td>
<td>2.9</td>
<td>11</td>
</tr>
<tr>
<td>Alaska</td>
<td>0.3</td>
<td>1</td>
<td>0.2</td>
<td>1</td>
<td>0.2</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total U. S. Dry Production</strong></td>
<td>21.3</td>
<td>88</td>
<td>23.6</td>
<td>95</td>
<td>26.1</td>
<td>99</td>
</tr>
<tr>
<td><strong>Imports (Net)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pipeline</td>
<td>2.4</td>
<td>10</td>
<td>1.0</td>
<td>4</td>
<td>0.2</td>
<td>1</td>
</tr>
<tr>
<td>LNG</td>
<td>0.4</td>
<td>2</td>
<td>0.3</td>
<td>1</td>
<td>0.1</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total Imports</strong></td>
<td>2.8</td>
<td>12</td>
<td>1.3</td>
<td>5</td>
<td>0.3</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total U. S. Dry Supply</strong></td>
<td>24.1</td>
<td>100</td>
<td>24.9</td>
<td>100</td>
<td>26.4</td>
<td>100</td>
</tr>
<tr>
<td><strong>Lower 48 year end reserves</strong></td>
<td>264</td>
<td></td>
<td>287</td>
<td></td>
<td>266</td>
<td></td>
</tr>
</tbody>
</table>

- Unconventional gas (Tight Gas, Shale, CBM) growth more than offsets decline in conventional lower 48 onshore production
- 2010 AEO Alaska gas pipeline begins operation in 2023. **2011 AEO: no AGP**

Source: EIA Annual Energy Outlook (AEO) 2011
Unconventional Natural Gas Supply
# Unconventional gas sources

<table>
<thead>
<tr>
<th>Category</th>
<th>Extraction Difficulty</th>
<th>Solution</th>
<th>Recoverable TCF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep Gas (15,000’ +)</td>
<td></td>
<td>Technology / Higher Gas Prices</td>
<td>90 (30% of US resource)</td>
</tr>
<tr>
<td>“Tight” Gas</td>
<td>Drilling Cost</td>
<td></td>
<td>254 (6000)</td>
</tr>
<tr>
<td>Shale</td>
<td>Low Production Rates</td>
<td>Fracture / Acid Stimulation</td>
<td></td>
</tr>
<tr>
<td>Coal Bed Methane</td>
<td>Low Production Rates</td>
<td>Horizontal Wells</td>
<td>827 (650-1135)</td>
</tr>
<tr>
<td>Geo-Pressurized Zone (10,000 – 25,000 Ft)</td>
<td>Low Production Rates/Water Disposal</td>
<td>Fracture Stimulation &amp; Horizontal Drilling</td>
<td></td>
</tr>
<tr>
<td>Methane Hydrates</td>
<td>Depth and High Pressure</td>
<td>Improved Drilling &amp; Production Technology CO2 Injection</td>
<td>163</td>
</tr>
<tr>
<td></td>
<td>• Extracting Methane from Ice Crystal Lattice</td>
<td>Improved Drilling &amp; Production Technology</td>
<td>1,100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Not Yet Known</td>
<td>(5,000-49,000)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>?(200,000-320,000)</td>
</tr>
</tbody>
</table>

Source: 2011 NETL, USGS, NG.org websites
Shale gas refers to natural gas that is trapped within shale formations. Shales are fine-grained sedimentary rocks that can be rich sources of petroleum and natural gas. Long known as source rock, shale’s limited permeability has rendered the resource uneconomic until recently.
Worldwide shale gas resource

• 48 shale basins (70 formations) in 32 countries
• 5,670 TCF of recoverable resource (plus 862 TCF in US)
• Conservative. Excluded; offshore, Russia, Middle East

Source: EIA, “World shale gas resources” 4/5/11
Why is shale gas important?

US shale resource:
• Abundance of gas will hold down US energy costs
• Lower energy costs improve US competitiveness
• Expand US employment/taxes/royalties
• Environmental benefits: low emissions
• Reduce imports and improve energy supply security
• Reduce cash flow and influence of enemies of US

Worldwide resource: (shale located in 688 formations in 142 basins)
{i.e. China=540 TCF, Europe=108 TCF, Canada=72 TCF with resource likely to expand with drilling)

• Reduce energy cost and emissions worldwide
• Improve living standards and promote trade
• Reduce potential for conflict
Liquefied Natural Gas (LNG)
• **US 2009 Imports of LNG = 479 BCF = 6% of 8.6 TCF World LNG Market (2007 = 771 BCF = 10%)**

• **Worldwide Proved Gas Reserves = 6,647 TCF (57 times projected 2011 Worldwide Consumption of 117 TCF)**

Source: FERC, EIA, IEO 09, O&GJ 12/06/10, LNG World News
LNG shipping

- 333 Vessels in LNG Trade, 34 Ships on Order (03/06/10 www.shipbuildinghistory.com)
- LNG Transported at -163 C (-260 F) and Atmospheric Pressure (1/600 Reduction)
- Ship Fuel may be Cargo “Boil Off” = 0.15% Per Day or Dual Fuel (diesel)
- Standard Vessel is Increasing from 125,000 m³ / 138,000 m³ (3 BCF) to 145,000 m³ / 250,000 m³

Source: EIA, FERC, web
Natural Gas Storage
Underground gas storage facilities

Underground Natural Gas Storage Facilities in the lower 48 States

Consuming West

Consuming East

Producing

Depleted Fields
Salt Caverns
Aquifers

Source: EIA
**Underground gas storage facilities**

### Statistics

<table>
<thead>
<tr>
<th>Type</th>
<th>Sites</th>
<th>Working Gas Capacity</th>
<th>Daily Deliverability</th>
<th>Working Gas / Deliverability Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>#</td>
<td>%</td>
<td>BCF</td>
<td>%</td>
</tr>
<tr>
<td>Depleted Gas / Oil</td>
<td>326</td>
<td>81</td>
<td>3,528</td>
<td>86</td>
</tr>
<tr>
<td>Aquifer</td>
<td>43</td>
<td>11</td>
<td>390</td>
<td>10</td>
</tr>
<tr>
<td>Salt Cavern</td>
<td>31</td>
<td>8</td>
<td>173</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>400</td>
<td>100</td>
<td>4,091</td>
<td>100</td>
</tr>
</tbody>
</table>

Source: EIA
## US underground gas storage facilities

### Characteristics (generalization)

<table>
<thead>
<tr>
<th>Type</th>
<th>Cost To Build</th>
<th>Base Gas Requirement</th>
<th>Working Gas Capacity</th>
<th>Daily Deliverability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depleted Reservoir</td>
<td>Least</td>
<td>Higher</td>
<td>Larger</td>
<td>Less</td>
</tr>
<tr>
<td>Aquifer</td>
<td>More</td>
<td>Higher</td>
<td>Larger</td>
<td>Less</td>
</tr>
<tr>
<td>Salt Dome</td>
<td>Most</td>
<td>Low</td>
<td>Smaller</td>
<td>Greatest</td>
</tr>
</tbody>
</table>
Thank You

jrichardmoore@sbcglobal.net