LNG (Liquefied Natural Gas)

Chapter 18

Based on presentation by Prof. Art Kidnay
Topics

Introduction
Liquefaction processes
LNG storage
Regasification
Introduction
Rationale for LNG

Liquefying natural gas greatly reduces volume

- Liquid density @ 1 atm – 26.37 lb/ft³
- Saturated vapor volume @ 1 atm – 8.8188 ft³/lb – 230X volume
- Standard ideal gas vapor volume – 24 ft³/lb – 625X volume
- Ideal gas volume @ 1000 psia & 60°F – 0.35 ft³/lb – 9X volume

Liquefaction makes it easier to...

- Store gas (peak shaving plants)
- Move gas to remote customers (base load plants)
Comparison of plants

Peak shaving plants

Relatively small (~0.1x10^6 tpy)

70+ in US (mainly in New England region)

Facility includes:

- Liquefaction plant
- Storage facilities
- Regasification facilities

Baseload plants

Large capacity – 3 to 10x10^6 tpy)

Requires large reserves to make plant economically feasible (> 1 Tscf)
Schematic of peak-shaving facility

- Natural gas pipeline
  - H$_2$S, CO$_2$ and odorant
  - H$_2$O
  - Heavy hydrocarbons

- Gas treating
- Compression liquefaction
- Storage
- Odorant injection
- Regasification

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Energy transmission efficiency over long distances

![Graph showing efficiency of different energy transmission methods over distance.](image-url)
Schematic of a baseload plant
## LNG facilities (circa 2010)

<table>
<thead>
<tr>
<th>Plant</th>
<th>Country</th>
<th>Capacity (Million tpy)</th>
<th>Number of Trains</th>
<th>Start-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arzew</td>
<td>Algeria</td>
<td>17.3</td>
<td>6</td>
<td>1964 - 1978</td>
</tr>
<tr>
<td>Skikda</td>
<td>Algeria</td>
<td>8.0</td>
<td>6</td>
<td>1972 - 1981</td>
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<td>Darwin LNG</td>
<td>Australia</td>
<td>3.0</td>
<td>1</td>
<td>2006</td>
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<tr>
<td>Northwest Shelf</td>
<td>Australia</td>
<td>20.6</td>
<td>5</td>
<td>1989 - 2008</td>
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<tr>
<td>Brunei LNG</td>
<td>Brunei</td>
<td>6.5</td>
<td>5</td>
<td>1972</td>
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<tr>
<td>Egyptian LNG</td>
<td>Egypt</td>
<td>7.2</td>
<td>2</td>
<td>2005</td>
</tr>
<tr>
<td>Segas</td>
<td>Egypt</td>
<td>4.8</td>
<td>1</td>
<td>2005</td>
</tr>
<tr>
<td>EG LNG</td>
<td>Equatorial Guinea</td>
<td>3.4</td>
<td>1</td>
<td>2007</td>
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<tr>
<td>Arun</td>
<td>Indonesia</td>
<td>6.8</td>
<td>4</td>
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</tr>
<tr>
<td>Bontang</td>
<td>Indonesia</td>
<td>21.2</td>
<td>8</td>
<td>1977</td>
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<td>Tangguh</td>
<td>Indonesia</td>
<td>7.6</td>
<td>2</td>
<td>2009</td>
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<tr>
<td>Marsa el Brega</td>
<td>Libya</td>
<td>3.2</td>
<td>4</td>
<td>1970</td>
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<tr>
<td>MLNG</td>
<td>Malaysia</td>
<td>23.5</td>
<td>8</td>
<td>1983 - 2003</td>
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<tr>
<td>Nigeria LNG</td>
<td>Nigeria</td>
<td>20.7</td>
<td>6</td>
<td>1999 - 2008</td>
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<tr>
<td>Oman LNG</td>
<td>Oman</td>
<td>7.2</td>
<td>2</td>
<td>2000</td>
</tr>
<tr>
<td>Qalhat LNG</td>
<td>Oman</td>
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<td>1</td>
<td>2005</td>
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<tr>
<td>QatarGas</td>
<td>Qatar</td>
<td>25.5</td>
<td>4</td>
<td>1996 - 2009</td>
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<tr>
<td>RasGas</td>
<td>Qatar</td>
<td>36.3</td>
<td>7</td>
<td>1999 - 2010</td>
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<td>Das Island</td>
<td>UAE</td>
<td>5.8</td>
<td>3</td>
<td>1977 - 1994</td>
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<tr>
<td>Atlantic LNG</td>
<td>Trinidad and Tobago</td>
<td>15.1</td>
<td>4</td>
<td>1999 - 2005</td>
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<tr>
<td>Sakhalin II</td>
<td>Russia</td>
<td>9.6</td>
<td>2</td>
<td>2009</td>
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<td>Hammerfest LNG</td>
<td>Norway</td>
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<td>1</td>
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<td>Kenai LNG</td>
<td>United States</td>
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<td>1969</td>
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<tr>
<td>Yemen LNG</td>
<td>Yemen</td>
<td>6.8</td>
<td>2</td>
<td>2009-2010</td>
</tr>
</tbody>
</table>
Liquefaction Processes
## Typical compositions pipeline gas vs. LNG feed

<table>
<thead>
<tr>
<th>Impurity</th>
<th>Pipeline Gas</th>
<th>LNG Feed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>150 ppmv (7.0 lb/MMsc)</td>
<td>&lt; 0.1 ppmv</td>
</tr>
<tr>
<td>Hydrogen sulfide</td>
<td>0.25 gr/100 scf (4.0 ppmv)</td>
<td>&lt; 0.25 gr/100 scf (4.0 ppmv)</td>
</tr>
<tr>
<td>Total sulfur (H2S, COS, …)</td>
<td>5–20 gr/100 scf</td>
<td>&lt; 20 ppmv</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>2–3 mol%</td>
<td>&lt; 50 ppmv</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>&lt; 3 mol%</td>
<td>&lt; 1 mol%</td>
</tr>
<tr>
<td>Mercury</td>
<td>N/A</td>
<td>&lt; 0.01 μg/Nm3</td>
</tr>
<tr>
<td>Butanes</td>
<td>N/A</td>
<td>&lt; 2 mol%</td>
</tr>
<tr>
<td>Pentanes+</td>
<td>N/A</td>
<td>&lt; 0.1 mol%</td>
</tr>
<tr>
<td>Aromatics</td>
<td></td>
<td>&lt; 2 ppmv</td>
</tr>
</tbody>
</table>
Simple JT liquefaction cycle

\[ f = \frac{\dot{m}_2}{\dot{m}_1} = \frac{\hat{H}_3 - \hat{H}_1 - q_L}{\hat{H}_3 - \hat{H}_2} \]
Simple JT liquefaction cycle – 500 psia inlet gas
JT liquefaction cycle with intermediate flash
Simple closed-cycle liquefaction process
Open-cycle expander plant

\[
f = \frac{\dot{m}_2}{\dot{m}_1} = \frac{\hat{H}_3 - \hat{H}_1 - q_l}{\hat{H}_3 - \hat{H}_2} + \frac{e \left( \hat{H}_4 - \hat{H}_6 \right)}{\hat{H}_3 - \hat{H}_2}
\]
C3 Precooled Mixed Refrigerant

FIG. 16-34
Single Mixed Refrigerant Liquefaction Process with Precooling

Natural Gas

Mixed Refrigerant

GPSA Engineering Data Book, 14th ed.

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AP-X LNG Process

Fig. 16-37, GPSA Engineering Data Book, 14th ed.
Cascade Refrigeration Process

Fig. 16-32, GPSA Engineering Data Book, 14th ed.
LNG storage
Storage of LNG

Tanks can be
- Aboveground
- Below ground

Tank material is
- Steel
- Prestressed concrete
- Hybrid (combination of both)

Typical types
- Single-containment
- Double-containment
- Full containment
- Prestressed concrete
- Frozen-earth underground storage
Single-containment tank

- Carbon Steel
  - Roof
  - Outer Tank
- Suspended Deck
- Electrical Heating Elements
- Reinforced Concrete Pad
- Perlite Insulation
- 9% Nickel Steel Inner Tank
- Base Insulation
Double-containment tank

- Carbon Steel Roof
- Suspended Deck
- Carbon Steel Outer Tank
- Perlite Insulation
- 9% Nickel Steel Inner Tank
- Electrical Heating Elements
- Reinforced Concrete Pad
- Concrete Outer Shell
- Base Insulation
Full-containment tank

- Concrete Roof
- Suspended Deck
- Carbon Steel Outer Tank
- Electrical Heating Elements
- Perlite Insulation
- 9% Nickel Steel Inner Tank
- Concrete Outer Shell
- Base Insulation
- Reinforced Concrete Pad
Prestressed Concrete Tank

- Concrete
- Select Fill
- Earth Berm
- Insulation and Liner
- Spring-loaded Trusses
- Insulated Roof
- Ballast
Figure 13.23  Frozen-earth storage container
Regasification
LNG regasification (simplified)

~ 40 % of HHV required to heat LNG to ambient temperatures
Summary
Summary

Natural gas can be liquefied to greatly decrease its volume & make for easier long-distance transportation

Gas to be liquefied must be further processed from typical pipeline quality

Two separate steps

- Liquefaction
  - Proper heat integration necessary to minimize compression power
- Regasification