Plant Block Schematic

Gas & liquids from wells
  → Field liquids removal
  → Field acid gas removal
  → Field dehydration
  → Field compression

Inlet receiving → Inlet compression → Gas Treating

Hydrocarbon recovery
  → Nitrogen rejection
  → Helium recovery

Dehydration

Outlet compression → Liquifaction

CO₂

Sulfur recovery → Elemental Sulfur

Water & solids

Liquids processing

Crude Helium
Sales gas
LNG
NGLs
Natural gasoline
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 ($\sim 0.1 \times 10^6$ tpy)
70+ in US (mainly in New England region)
Facility includes:
- Liquefaction plant
- Storage facilities
- Regasification facilities

Baseload plants
Large capacity – 3 to $10 \times 10^6$ tpy
Requires large reserves to make plant economically feasible (> 1 Tscf)
Schematic of peak-shaving facility
Energy transmission efficiency over long distances

![Graph showing efficiency over distance for LNG, Pipeline, Gas-to-Liquids, and Electricity](image)
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>
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<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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<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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<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>
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<td>Arun</td>
<td>Indonesia</td>
<td>6.8</td>
<td>4</td>
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<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>
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<td>Marsa el Brega</td>
<td>Libya</td>
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<td>4</td>
<td>1970</td>
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<td>MLNG</td>
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<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>
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<td>Qalhat LNG</td>
<td>Oman</td>
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<td>1</td>
<td>2005</td>
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<td>QatarGas</td>
<td>Qatar</td>
<td>25.5</td>
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<td>1996 - 2009</td>
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<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>
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<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>
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<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>1</td>
<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>
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</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

Diagram showing the flow of gas through various components such as compressors, coolers, and separators, with labels for each part.

Graph showing the relationship between total compressor power and vapor quality after JT valve.
JT liquefaction cycle with intermediate flash
Simple closed-cycle liquefaction process
Open-cycle expander plant

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

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

Natural Gas

Mixed Refrigerant

GPSA Engineering Data Book, 14th ed.

Updated: December 27, 2017
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Fig. 16-37, GPSA Engineering Data Book, 14th ed.
Cascade Refrigeration Process

Fig. 16-32, GPSA Engineering Data Book, 14th ed.

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

- Carbon Steel Roof
- Suspended Deck
- Carbon Steel Outer Tank
- Electrical Heating Elements
- Perlite Insulation
- 9% Nickel Steel Inner Tank
- 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