Liquefied Natural Gas (LNG)

For the 2014 SPE Roughneck Camp

Chris Caswell, Director – LNG and FLNG

KBR

July 17, 2014
How to Plan a 30 Minute Discussion on LNG

• SPE Objective:
  – “What happens after gas is produced and before it becomes a marketable product – (For liquid natural gas transportation, specifically)?”

<table>
<thead>
<tr>
<th>Time</th>
<th>Topic</th>
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<tbody>
<tr>
<td>7:00 AM</td>
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<td>8:00 AM</td>
<td>Opening Remarks</td>
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<td>8:10 AM</td>
<td>On Exploration</td>
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<tr>
<td>8:50 AM</td>
<td>On the Development of Oil and Gas Projects</td>
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<tr>
<td>9:30 AM</td>
<td>On Oil and Gas Production</td>
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<td>10:10 AM</td>
<td>Ice Breakers 1</td>
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<td>10:40 AM</td>
<td>On the Transportation of Oil and Gas</td>
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<tr>
<td>11:20 AM</td>
<td>On liquefied Natural Gas</td>
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<td>12:00 PM</td>
<td>Lunch</td>
</tr>
<tr>
<td>12:40 PM</td>
<td>Open Panel Discussion on a Career in the Oil and Gas Industry</td>
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• Presentation Strategy:
  – Short list of key messages
  – Cover primarily the liquefaction link of the LNG chain
  – Encourage questions
Key Messages for Today

• Produced gas (even when separated or treated near the reservoir) requires extensive and mandatory conditioning to make LNG

• LNG projects are large complex projects, often in remote locations
  – Process design is not simplistic,
  – Scope is highly civil/mechanical,
  – Projects are capital intensive, and
  – Not all LNG plants are created equal (NALPACE)

• Offshore liquefaction (FLNG) significantly increases the complexity of an LNG project
Items Not Addressed Today

• LNG transfer, storage, regasification, and LNG shipping
  – Regas: more simplistic than liquefaction, but important
  – Shipping: decades of efficient manufacturing methods

• Economics:
  – Capital cost estimates and schedules (e.g. US$ per ton of LNG)
  – Onshore LNG vs. FLNG, baseload plants vs. tolling facilities

• Market views / growth of LNG
  – Industry statistics, project forecasts, and LNG news

• Review of liquefaction projects and process technologies
  – History, size, and growth of LNG trains and complexes
  – Licensor share, process selection, cycle efficiency, equipment, etc.
  – Permitting, siting, approval process in the USA
  – Terminal (regas) conversions to liquefaction (export)
  – Ownership of projects and the contracting community
Why LNG: Long Distance Transportation of Natural Gas
The Transportation of Natural Gas

Pipeline

LNG

Pipeline & LNG

GTL & LNG

Gas to Chemicals

Methanol
DME
Ammonia
What is LNG? Typically, LNG is:

- “Cool” natural gas at essentially atmospheric pressure
- Liquefied at -161º C (-256º F) and slightly subcooled
- Colorless, odorless, non-corrosive, and non-toxic
- A mixture of components, primarily C₁, C₂, C₃, and N₂
- Example composition of LNG (mol %):
  - 85-90 % methane (C₁)
  - 3-8 % ethane (C₂)
  - 1-3 % propane (C₃)
  - 1-2 % butanes (iso-C₄ and n-C₄)
  - 0-2 % pentanes (iso-C₅ and n-C₅)
  - 0-2 % nitrogen (N₂)
### Table I – Typical LNG Compositions

<table>
<thead>
<tr>
<th>Component</th>
<th>Algeria</th>
<th>Abu-Dhabi</th>
<th>Australia</th>
<th>Malaysia</th>
<th>Indonesia</th>
<th>Brunei</th>
<th>Indonesia</th>
<th>Alaska</th>
<th>Algeria</th>
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<td>0.106%</td>
<td>0.014%</td>
<td>0.320%</td>
<td>0.030%</td>
<td>0.000%</td>
<td>0.090%</td>
<td>0.000%</td>
<td>1.400%</td>
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<tr>
<td>CH4</td>
<td>91.397%</td>
<td>87.074%</td>
<td>87.822%</td>
<td>91.151%</td>
<td>89.180%</td>
<td>89.400%</td>
<td>90.600%</td>
<td>99.800%</td>
<td>89.800%</td>
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<td>4.284%</td>
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<td>1.670%</td>
<td>2.800%</td>
<td>2.480%</td>
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<td>i-C4H10</td>
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<td>0.062%</td>
<td>0.400%</td>
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<td>0.240%</td>
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<td>0.000%</td>
<td>0.010%</td>
<td>0.020%</td>
<td>0.000%</td>
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<tr>
<td>n-C5H12</td>
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<td>0.000%</td>
<td>0.000%</td>
<td>0.000%</td>
<td>0.000%</td>
<td>0.010%</td>
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<td>Total</td>
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<td>100.003%</td>
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<td>99.991%</td>
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<td>Btu/SCF</td>
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<td>Wobbe Index</td>
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<td>0.190%</td>
<td>0.050%</td>
<td>0.430%</td>
<td>1.002%</td>
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<td>CH4</td>
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</table>

Source: GAS CONDITIONING FOR IMPORTED LNG by D. McCartney for 82nd annual GPA Convention, March 2002.
Volumetric Reduction of Natural Gas

Natural Gas

LNG Plant

Volume Reduction
600:1

-161°C
What are the End Uses for LNG?

• Imported LNG can support the following activities:
  – Augmenting baseload pipeline supply
  – Support peak-shaving activities (peak demand periods)
  – Fuel for nearby power plants
  – Feedstock for industrial use (Ammonia, Ethylene)
  – Fuel substitution (natural gas for diesel) at reduced cost
How LNG is Made: The Traditional LNG Value Chain

Key Issue - Integrating all links in the chain

Gas Production & Transmission
Gas Treatment & Liquefaction
LNG Receiving Terminal
LNG Shipping
Natural Gas End Use

Storage
Gas Marketing Networks

Regasification
Power Station
LNG Facilities Are Remote

NIGERIA LNG SITE – early 1990’s
LNG Facilities Are Complex

NIGERIA LNG FACILITY
What Does an LNG Train Look Like?
SEGAS LNG
First single train of 5 Mt/a
What Does an Complete LNG Facility Look Like?
LNG Facility Example: SEGAS LNG
Train 3: 2.5 Mt/a
Train 4: 4.4 Mt/a
Design of an LNG Plant

Australia Northwest Shelf LNG Plant – 1989, 1993
Design Factors Affecting Overall Cost

- Targeted Plant Capacity
- Number/size of Process Trains
  - Series or parallel within train
  - Large vs. small train
  - Common Areas / Utilities
- Availability / Reliability
  - Sparing, maintenance, startup/shutdown
  - OPEX costs
- Modular Concepts
  - Constructability
- Site Selection
  - Marine access, soils, earthquake
- Design Margins
- Plant Layout
- Project Execution
- Schedule (life cycle)

“NALPACE” – Not all LNG Plants are Created Equal
- Because of site-specific criteria, it is unwise to compare one plant to another based solely on capacity and capital cost (US$ per Mt/a)
Natural Gas Data – Feed Gas to LNG Plant

• Typical inlet Composition? No, but an example:
  2.0% Nitrogen, 86.0% Methane
  6.0% Ethane, 3.0% Propane
  1.5% Total Butane+
  1.0% Carbon Dioxide
  Trace: H₂S, Hg, RSH, COS, BTX

• In reality, there is no such thing as a typical inlet gas composition
  – Coal seam methane reserves can have > 98% methane
  – Acid gas content (CO2) as high as 15% in Australia and potentially much higher (over 50%) in stranded fields
  – Associated gas reservoirs could have waxes (e.g. C_{20+}) that affect flow assurance
Basic Refrigeration - Simple PFD

Process Flow Diagram

- Work (input)
- Compressor
- Condenser
- Heat Exchangers
- Accumulator
- J-T Valve
- Suction Drum
- LNG out
- GAS in
- Rough "rule of thumb": 35 MW of shaft power per Mt/a for "efficient" liquefaction processes
A two-stage refrigeration cycle is used in this example.
Acid Gas Removal Requirements

- Removal of CO$_2$ to 50 parts per million (ppm)
  - CO$_2$ would freeze at cryogenic temperatures
  - Safely below solubility limit of CO$_2$ in LNG

- Removal of H$_2$S (to end-user pipeline specifications)
  - Specification is often total weight of sulfur in LNG product
  - Targeted removal of Mercaptans and COS

- Acid Gas Disposal (after capture)
  - Venting (in small quantities), thermal oxidation (burning), or
  - Sequestration (large quantities, e.g. Gorgon LNG)

- About 80% of AGRU Cost is associated with Solvent Regeneration System
  - AGRU absorber is heaviest vessel (but not largest) in the plant
Typical Dehydration Scheme Process Flow

Molecular Sieve Process Vessels
Commonly a 3 bed system (2 operating)
Outlet specification: 1 ppm water
Regeneration System to remove water from beds
• Mercury has to be removed from natural gas to prevent corrosion in aluminum equipment
  – E.g. the Main Cryogenic Heat Exchanger

• Removal of mercury by:
  – Adsorption via sulfur impregnated bed in vessel – common
  – As part of dehydration with added mol sieve – less common

• Replacement of Hg removal beds is necessary for maintenance
  – No regeneration like in dehydration
  – If integrated with dehydration, Hg is with water on regeneration
Outlet Gas Specification is generally 10 ng (nanograms) of mercury per cubic meter of gas.
Typical Block Diagram - Liquefaction Plant

- Natural Gas Feed
- CO₂ Removal
- Dehydration & Mercury Removal
- Chilling
- Liquefaction
- Nitrogen Rejection
- Hydrocarbon Fractionation
- Offsite LNG Storage
- Refrigeration System
- Fuel
- C₂
- C₃
- C₄
- By Product Gasoline
- Fuel
- C₂
- C₃
- C₄
- Gasoline
- C₂
- C₄
APCI Propane Pre-cooled MR Process

Simplified version

Figure 3: The C3MR Process
APCI Propane Pre-cooled MR Process

- Treated Feed Gas
- DEHY/Hg Removal
- SCRUB COLUMN
- LPG REINJECTION
- To FRACTIONATION
- Low BTU Fuel Gas
- LNG RUNDOWN
- LNG PRODUCT PUMP
- MCHE
- LNG EXP
- REFLUX DRUM
Typical Block Diagram - Liquefaction Plant

- **CO\(_2\)** REMOVAL
- **DEHYDRATION & MERCURY REMOVAL**
- **CHILLING**
- **LIQUEFACTION**
- **REFRIGERATION SYSTEM**
- **REFRIGERATION SYSTEM**
- **HYDROCARBON FRACTIONATION**
- **NITROGEN REJECTION**
- **BY PRODUCT GASOLINE**
- **FUEL**
- **OFFSITE LNG STORAGE**

- **C\(_2\)**
- **C\(_3\)**
- **C\(_4\)**

**Natural Gas Feed**

**Liquefaction Plant**
APCI Propane Pre-cooled MR Process

Red lines denote the feed gas path through liquefaction and the path of NGLs (natural gas liquids)

Benzene comes out here by cold reflux
Typical Block Diagram - Liquefaction Plant

- Natural Gas Feed
- CO₂ Removal
- Dehydration & Mercury Removal
- Chilling
- Liquefaction
- Nitrogen Rejection
- Hydrocarbon Fractionation
- Refrigeration System
- Offsite LNG Storage

Flow Diagram:
- FUEL (C2, C4)
- By Product Gasoline
- LNG
- Fuel (C2, C4)
Nitrogen Removal

- The higher the nitrogen content of LNG, the lower its gross heating value
  - Therefore, why transport an undesirable component in the LNG?
  - Balance cost of removal vs. influence on heating value

- However, some nitrogen in LNG can reduce the boil off of more valuable components during transport
  - Nitrogen vaporizes first, before methane

- Modest concentrations of N2 can be reduced by a flash drum
  - Deeper removal by a N2 removal column/process

- Nitrogen specification in LNG is commonly 1% max
**Typical Block Diagram - Liquefaction Plant**

- **NATURAL GAS FEED**
  - **CO₂ REMOVAL**
  - **DEHYDRATION & MERCURY REMOVAL**
  - **CHILLING**
  - **LIQUEFICATION**
  - **NITROGEN REJECTION**

- **HYDROCARBON FRACTIONATION**
  - **C2**, **C4**
  - **BY PRODUCT GASOLINE**

- **OFFSITE LNG STORAGE**
  - **LNG**
  - **FUEL**

- **REFRIGERATION SYSTEM**
  - **C2**, **C3**, **C4**

- **REFRIGERATION SYSTEM**
  - **FUEL**
Propane Pre-cooled MR Process

DEHY/Hg REMOVAL

TREATED FEED GAS

HP C₃, MP C₃, LP C₃, LLP C₃

To FRACTIONATION

MCHE

NRU

LNG EXP

LNG RUNDOWN

LNG PRODUCT PUMP

REFLUX DRUM

LNG EXP

LPG REINJECTION

HP MR, MP MR, LP MR

DEHY/Hg REMOVAL

HP C₃, MP C₃, LP C₃, LLP C₃

SCRUB COLUMN

LNG PRODUCT

LOW BTU FUEL GAS
Typical Fractionation Scheme Process Flow

• Uses of Fractionation Unit:
  – Make liquid products for sale (LPG and Condensate help econ)
  – Make refrigerants (MR make-up or high purification C3)
  – Stabilize NGLs for reinjection

HO: Hot Oil (or other heat),  SW: Seawater (or other cooling)
“Complex project at a challenging location”

“Moderate size project at industrial location”

“Using efficient fabrication methods”
The Full Floating LNG Chain

FPSEO or FLNG

KBR FLNG Training

FSRU

Complex Project, Efficient Fabrication, with Marine Installation
New Complexities for Designing Offshore LNG

- Marinization of Process Design
  - Layout, equipment selection, and equipment spacing

- Modularization
  - Strategy, weight/size, fabrication and assembly plan

- Safety, Accommodation, Spill protection, LNG Storage

- Turret and mooring systems
  - Towing / transportation to site

- Hookup, Commissioning, and Startup
  - Pre-commissioning prior to tow, isolation offshore
  - Turnaround and Maintenance Operations

- Execution strategy and contracting strategy
  - Cost competitiveness, internal rate of return, comparison to onshore LNG