Liquefied Natural Gas (LNG)

For the 2014 SPE Roughneck Camp

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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)?”

Time	Topic
7:00 AM	Check In
8:00 AM	Opening Remarks
8:10 AM	On Exploration
8:50 AM	On the Development of Oil and Gas Projects
9:30 AM	On Oil and Gas Production
10:10 AM	Ice Breakers 1
10:40 AM	On the Transportation of Oil and Gas
11:20 AM	**On liquefied Natural Gas**
12:00 PM	Lunch
12:40 PM	Open Panel Discussion on a Career in the Oil and Gas Industry

- 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)

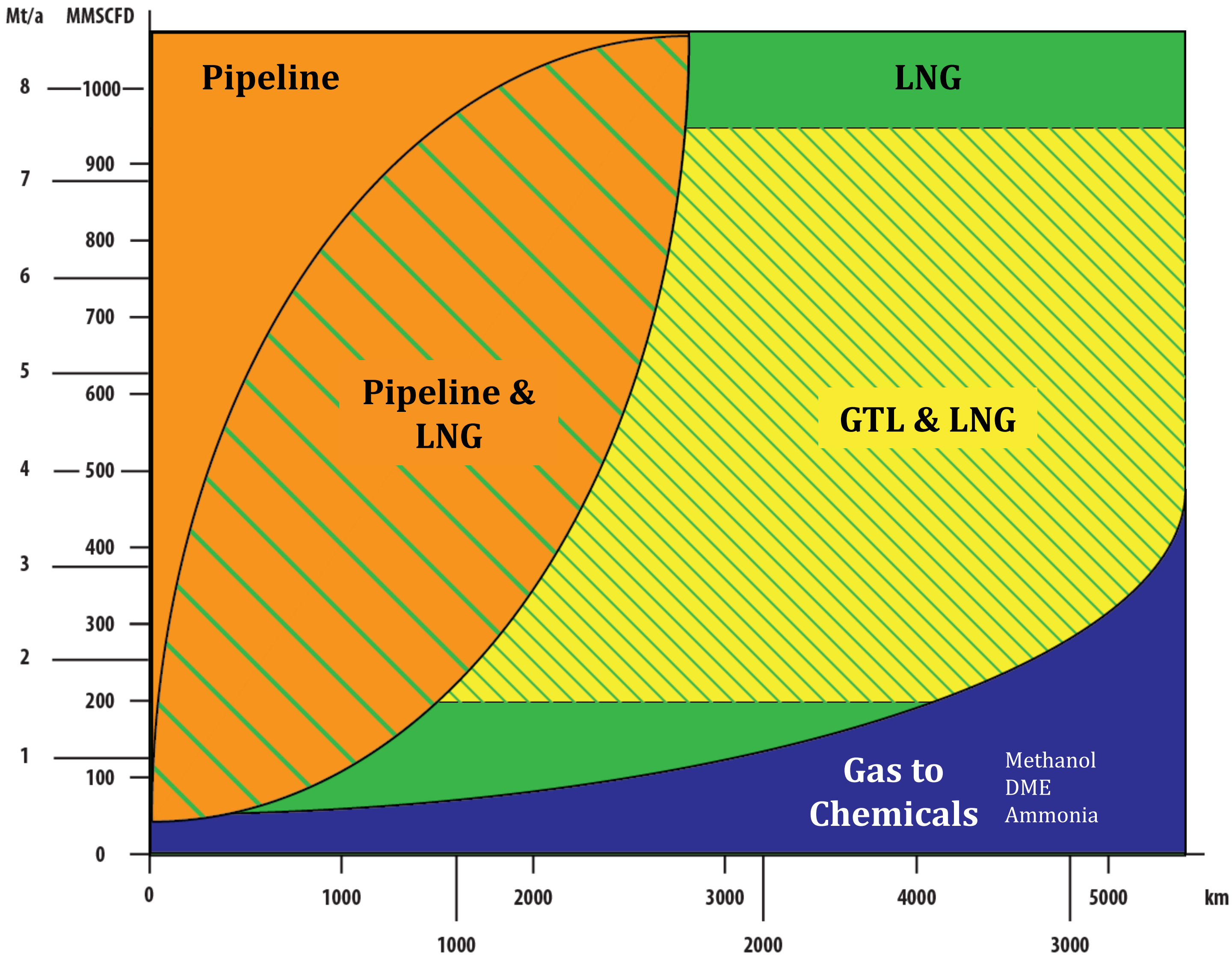
- Offshore liquefaction (FLNG) significantly increases the complexity of an LNG project

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



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 <u>**mixture**</u> of components, primarily C_1, C_2, C_3, and N_2
- Example composition of LNG (mol %):
  - 85-90 % methane (C_1)
  - 3-8 % ethane (C_2)
  - 1-3 % propane (C_3)
  - 1-2 % butanes (iso-C_4 and n-C_4)
  - 0-2 % pentanes (iso-C_5 and n-C_5)
  - 0-2 % nitrogen (N_2)

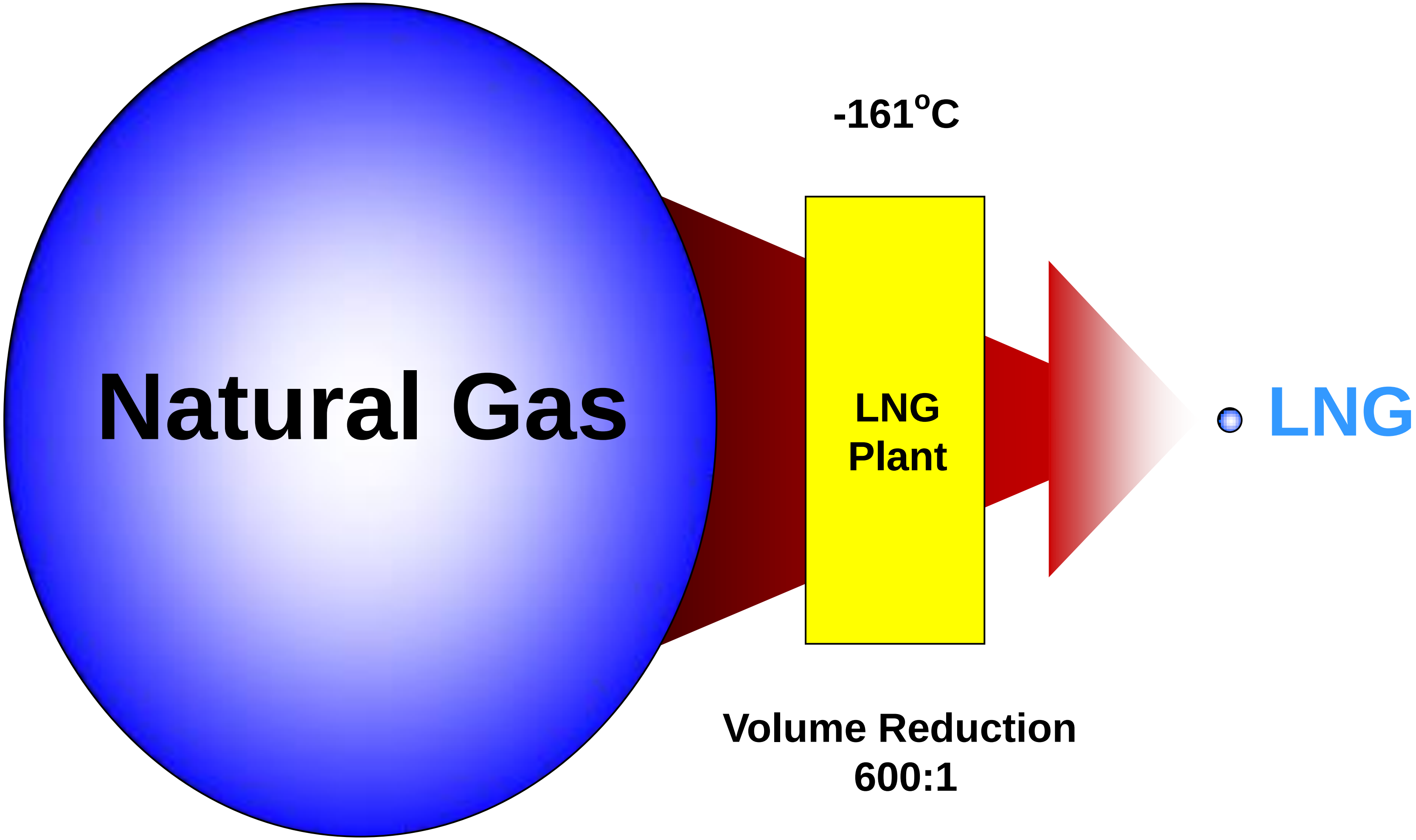
Table I – Typical LNG Compositions

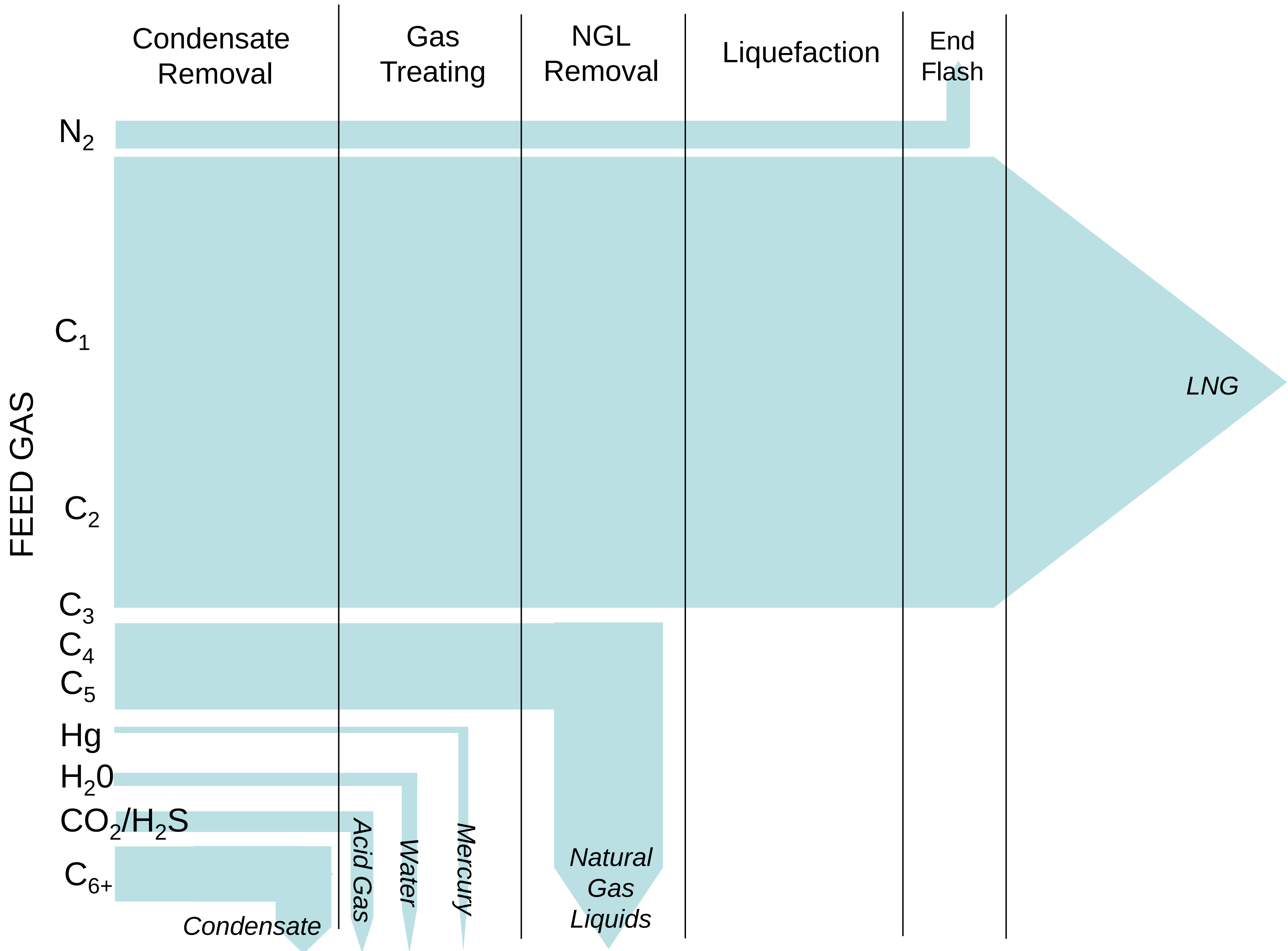
Component	Algeria	Abu-Dhabi	Australia	Malaysia	Indonesia	Brunei	Indonesia	Alaska	Algeria
Nitrogen	0.278%	0.106%	0.014%	0.320%	0.030%	0.000%	0.090%		1.400%
CH4	91.397%	87.074%	87.822%	91.151%	89.180%	89.400%	90.600%	99.800%	89.800%
C2H6	7.874%	11.410%	8.304%	4.284%	8.580%	6.300%	6.000%	0.100%	6.000%
C3H8	0.443%	1.271%	2.982%	2.873%	1.670%	2.800%	2.480%		2.200%
i-C4H10	0.004%	0.062%	0.400%	0.701%	0.240%				0.300%
n-C4H10	0.004%	0.079%	0.475%	0.661%	0.271%	1.300%	0.820%		0.300%
i-C5H12	0.000%	0.001%	0.000%	0.010%	0.020%	0.000%			0.000%
n-C5H12	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.010%		0.000%
Total	100.000%	100.003%	99.997%	100.000%	99.991%	99.800%	100.000%	99.900%	100.000%
HHV Gas, Btu/SCF	1,078.4	1,123.0	1,142.9	1,118.5	1,117.1	1,021.0	1,110.8	1,010.8	1,088.1
Wobbe Index	1,393.0	1,419.4	1,431.0	1,414.0	1,417.0	1,423.8	1,411.3	1,358.2	1,383.2
GPM C2+	2.23	3.44	3.32	2.37	2.92	2.86	2.54	0.03	2.40

Component	Oman	Trinidad	Qatar	Confidential	Confidential	Indonesia	Confidential	Confidential	Confidential
Nitrogen	0.000%	0.000%	0.190%	0.050%	0.430%	1.002%	0.099%	0.015%	0.307%
CH4	87.664%	92.260%	89.870%	92.070%	84.550%	96.379%	91.425%	92.629%	91.021%
C2H6	9.716%	6.394%	6.650%	6.890%	10.930%	2.004%	7.418%	6.888%	7.534%
C3H8	2.037%	0.909%	2.300%	0.970%	3.210%	0.451%	0.872%	0.348%	0.949%
i-C4H10	0.286%	0.214%	0.410%	0.000%	0.470%	0.069%	0.075%	0.022%	0.081%
n-C4H10	0.297%	0.223%	0.570%	0.000%	0.380%	0.090%	0.088%	0.033%	0.081%
i-C5H12	0.000%	0.000%	0.010%	0.020%	0.020%	0.003%	0.012%	0.022%	0.014%
n-C5H12	0.000%	0.000%	0.000%	0.000%	0.000%	0.001%	0.012%	0.042%	0.012%
Total	100.000%	100.000%	100.000%	100.000%	99.990%	100.000%	100.000%	100.000%	100.000%
HHV Gas, Btu/SCF	1,127.6	1,082.1	1,115.6	1,077.4	1,156.7	1,025.6	1,082.9	1,070.6	1,082.8
Wobbe Index	1,421.5	1,396.9	1,412.6	1,363.6	1,432.1	1,353.1	1,396.2	1,390.5	1,393.6
GPM C2+	3.34	2.10	2.72	2.11	4.08	0.71	2.28	1.97	2.33

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

Volumetric Reduction of Natural Gas





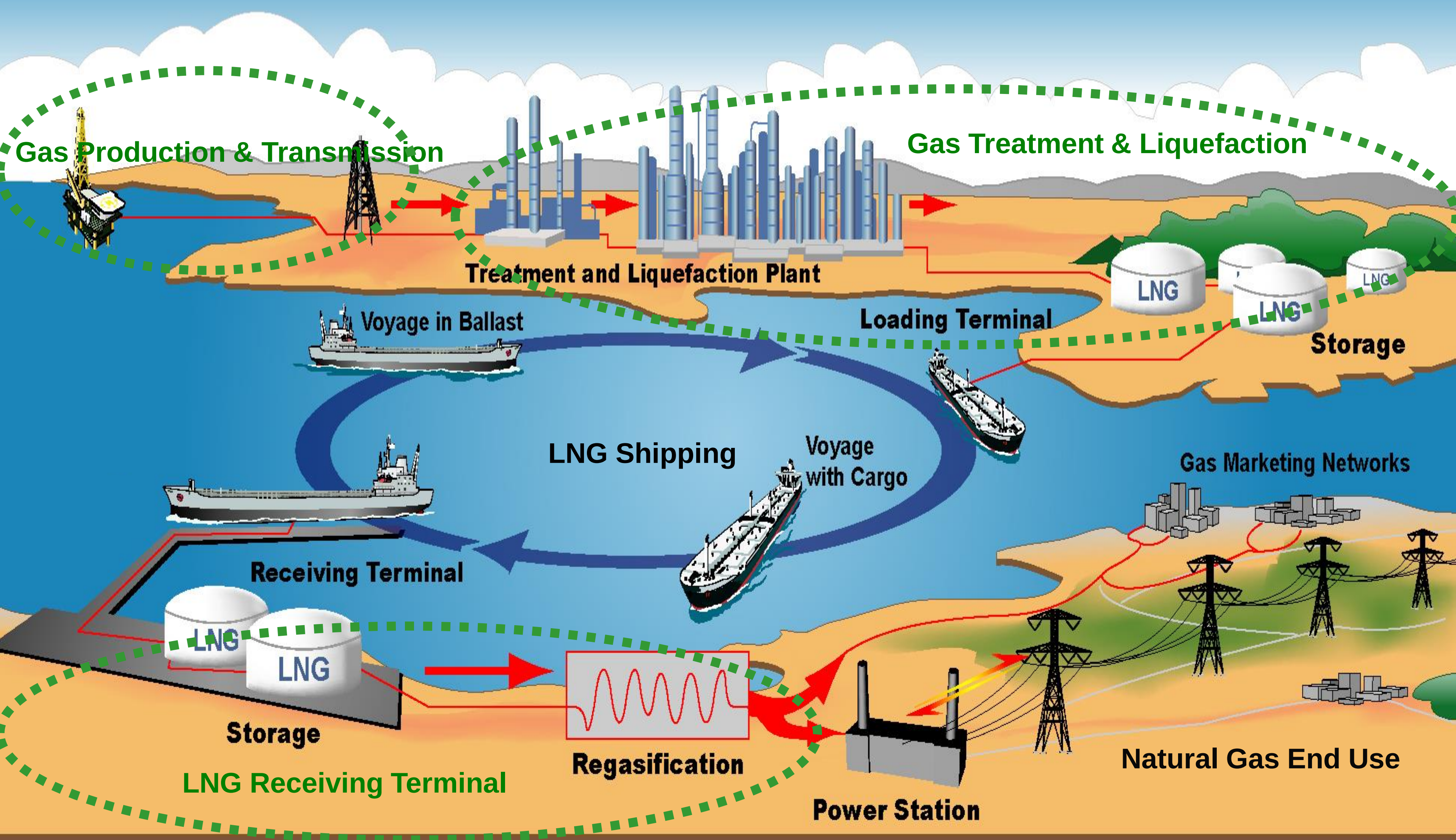
Condensate Removal
Gas Treating
NGL Removal
Liquefaction
End Flash
FEED GAS
N_2
C_1
C_2
C_3
C_4
C_5
Hg
H_20
CO_2/H_2S
C_{6+}
LNG
Condensate
Acid Gas
Water
Mercury
Natural Gas Liquids

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



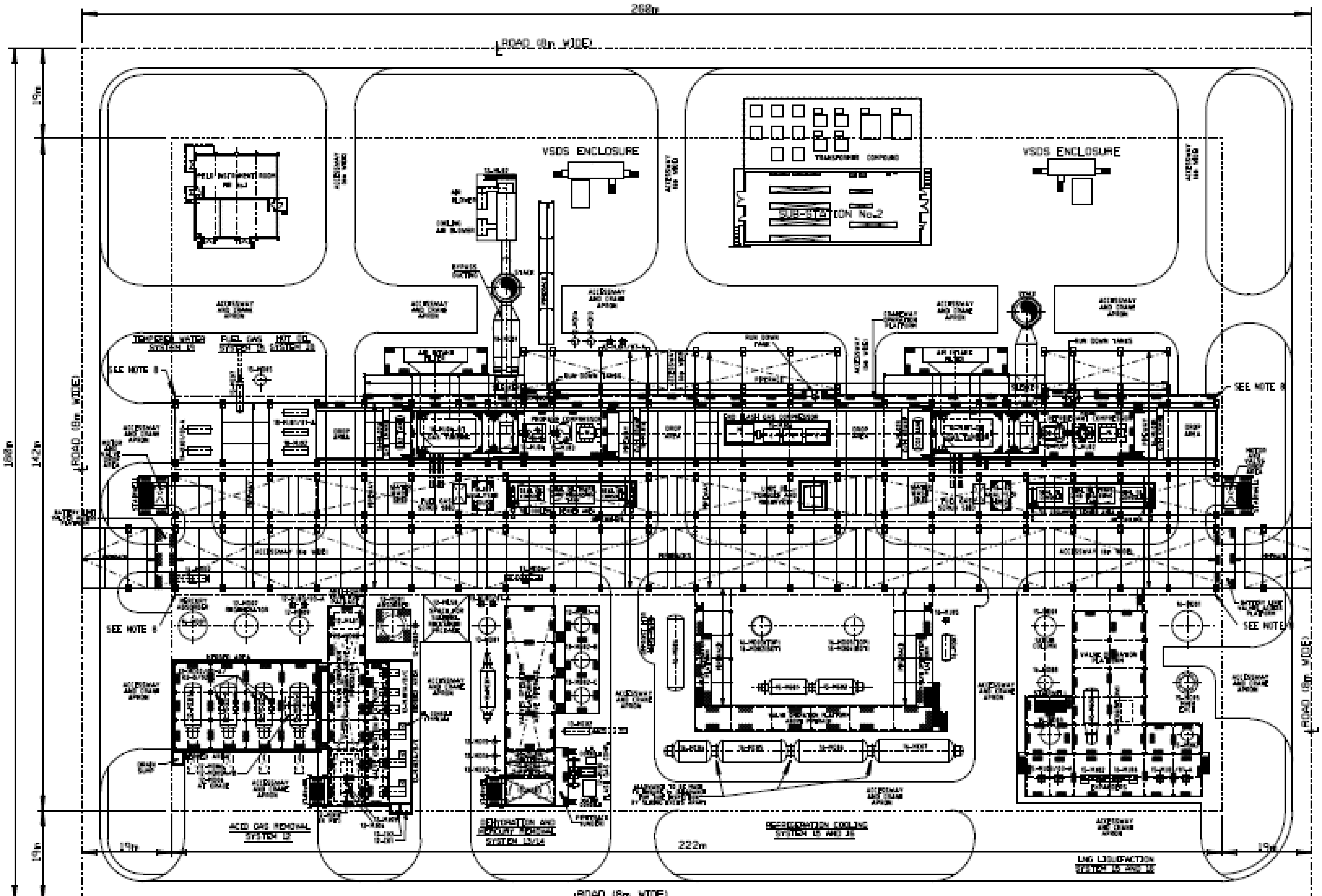
LNG Facilities Are Remote

NIGERIA LNG SITE – early 1990's

LNG Facilities Are Complex

NIGERIA LNG FACILITY

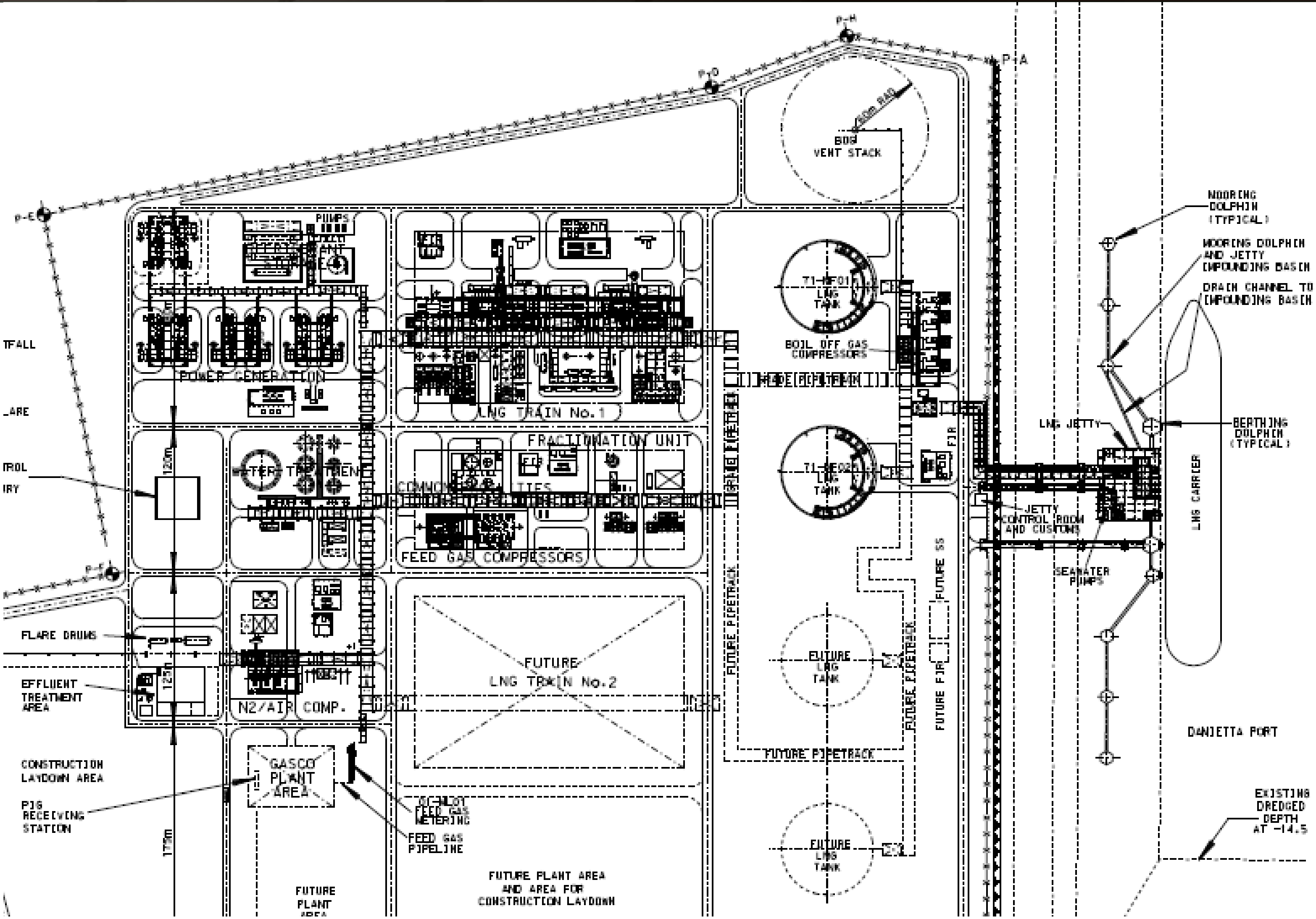
What Does an LNG Train Look Like?



SEGAS LNG

First single train of 5 Mt/a

What Does an Complete LNG Facility Look Like?



LNG Facility Example: SEGAS LNG


NWS LNG
Train 3: 2.5 Mt/a
Train 4: 4.4 Mt/a
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Image © 2008 DigitalGlobe
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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

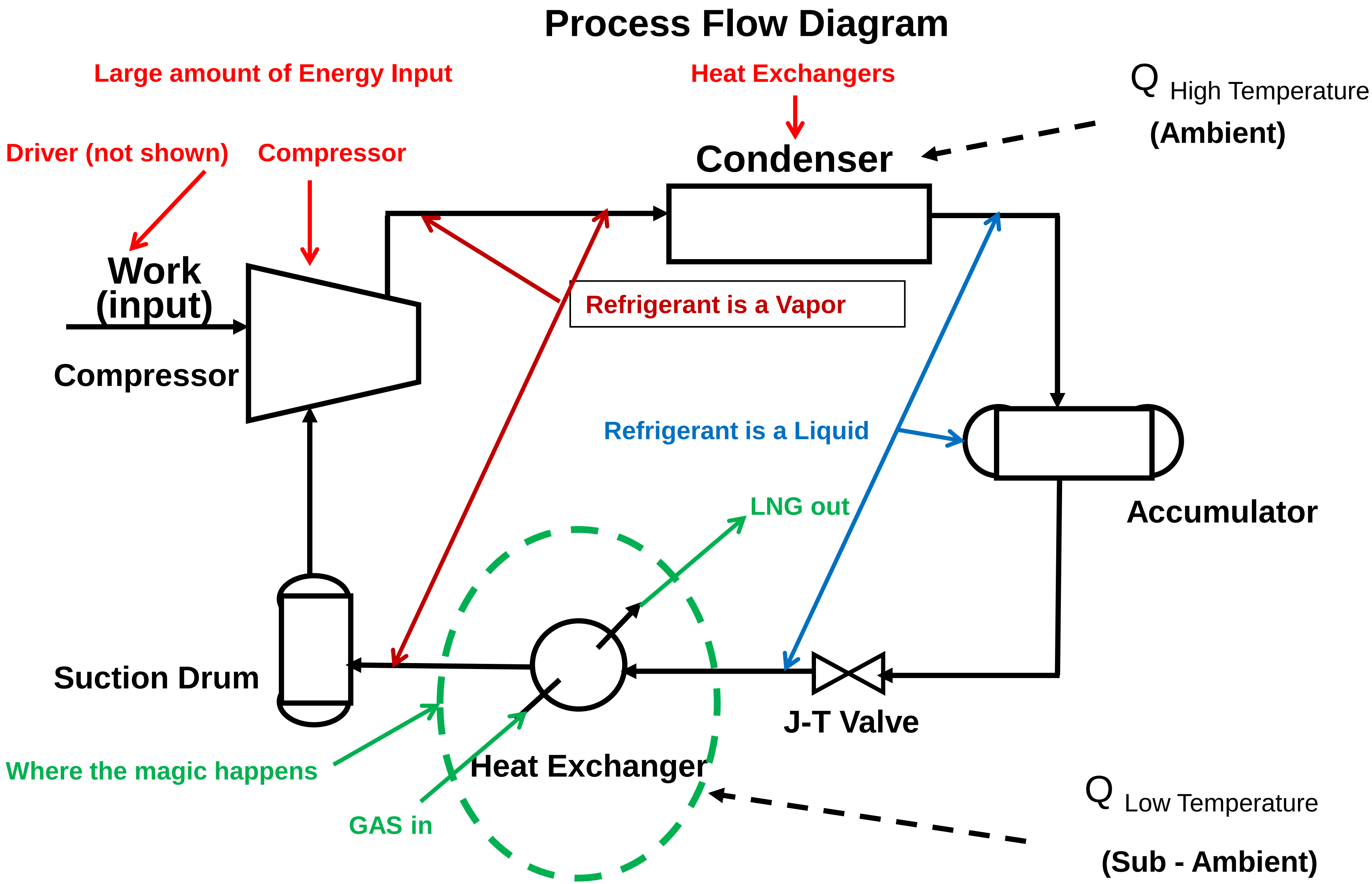
  1.5% Total Butane+

  1.0% Carbon Dioxide

  Trace: H_2S, Hg, RSH, COS, BTX

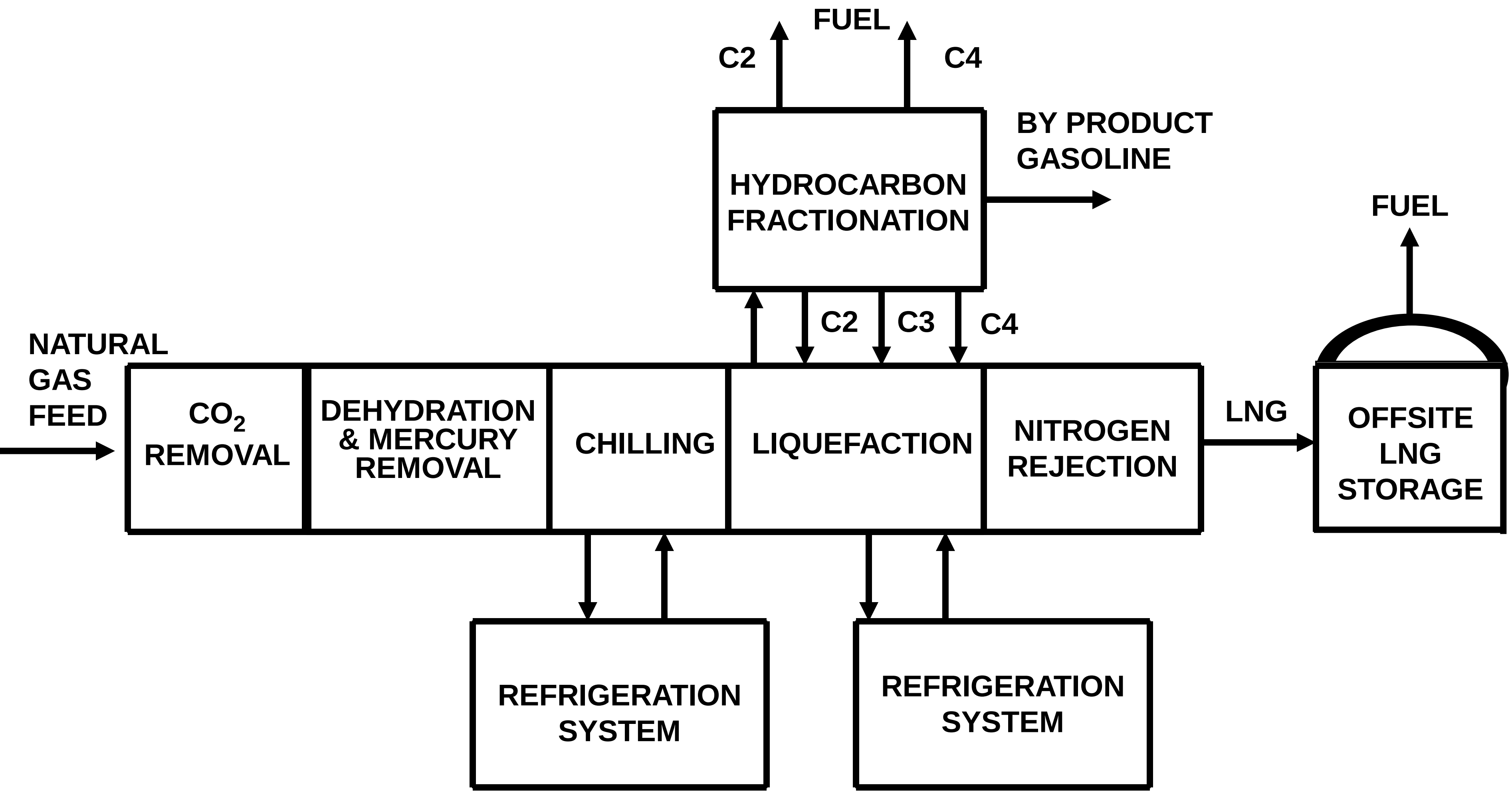
- In reality, there is no such thing as a typical inlet gas composition
  - Coal seam methane reserves can have > 98% methane
  - Acid gas content (CO2) as high as 15% in Australia and potentially much higher (over 50%) in stranded fields
  - Associated gas reservoirs could have waxes (e.g. C_{20+})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

Basic Refrigeration - Simple PFD



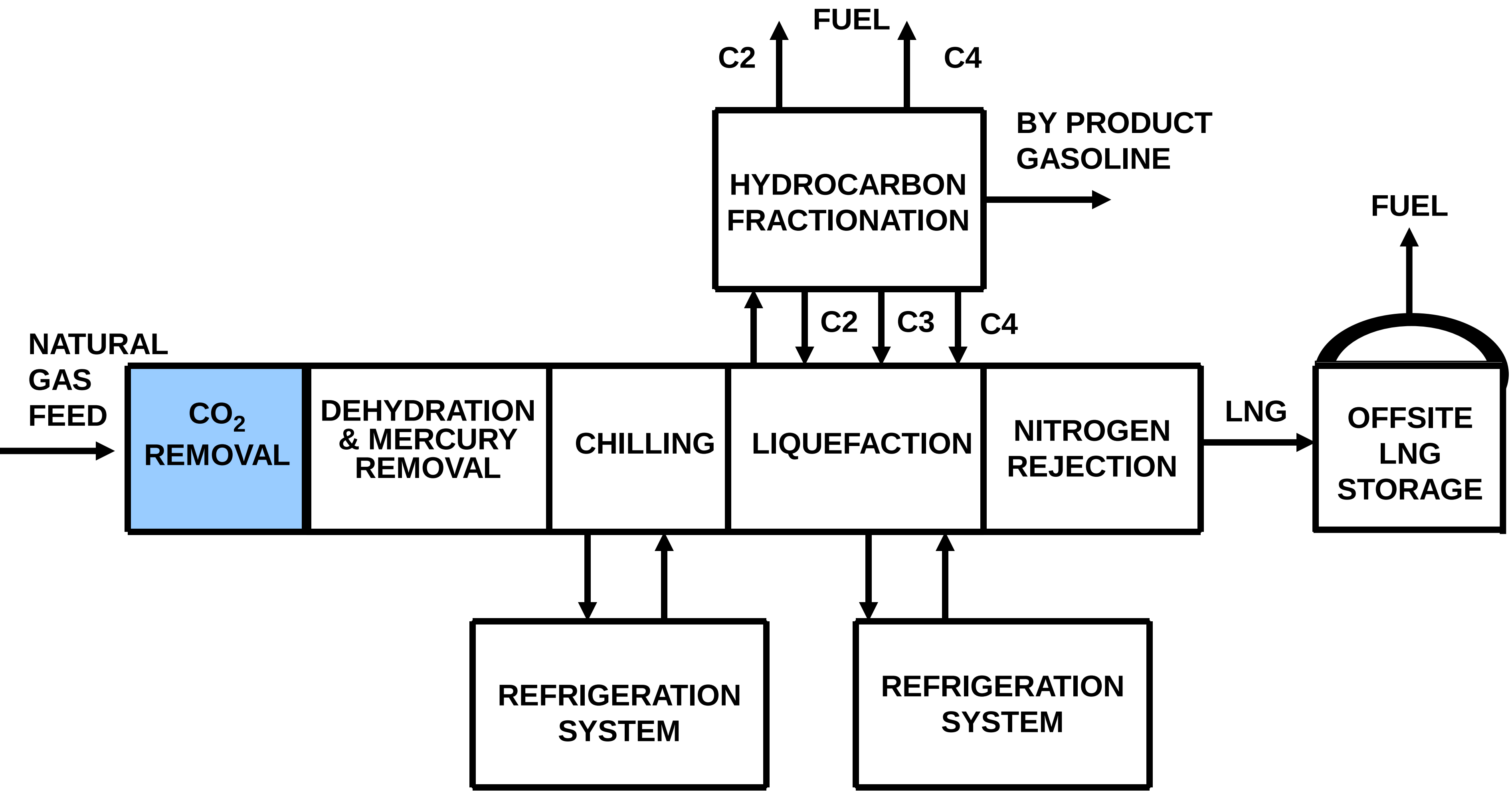
Rough "rule of thumb": 35 MW of shaft power per Mt/a for "efficient" liquefaction processes

Typical Block Diagram – Liquefaction Plant



A two-stage refrigeration cycle is used in this example

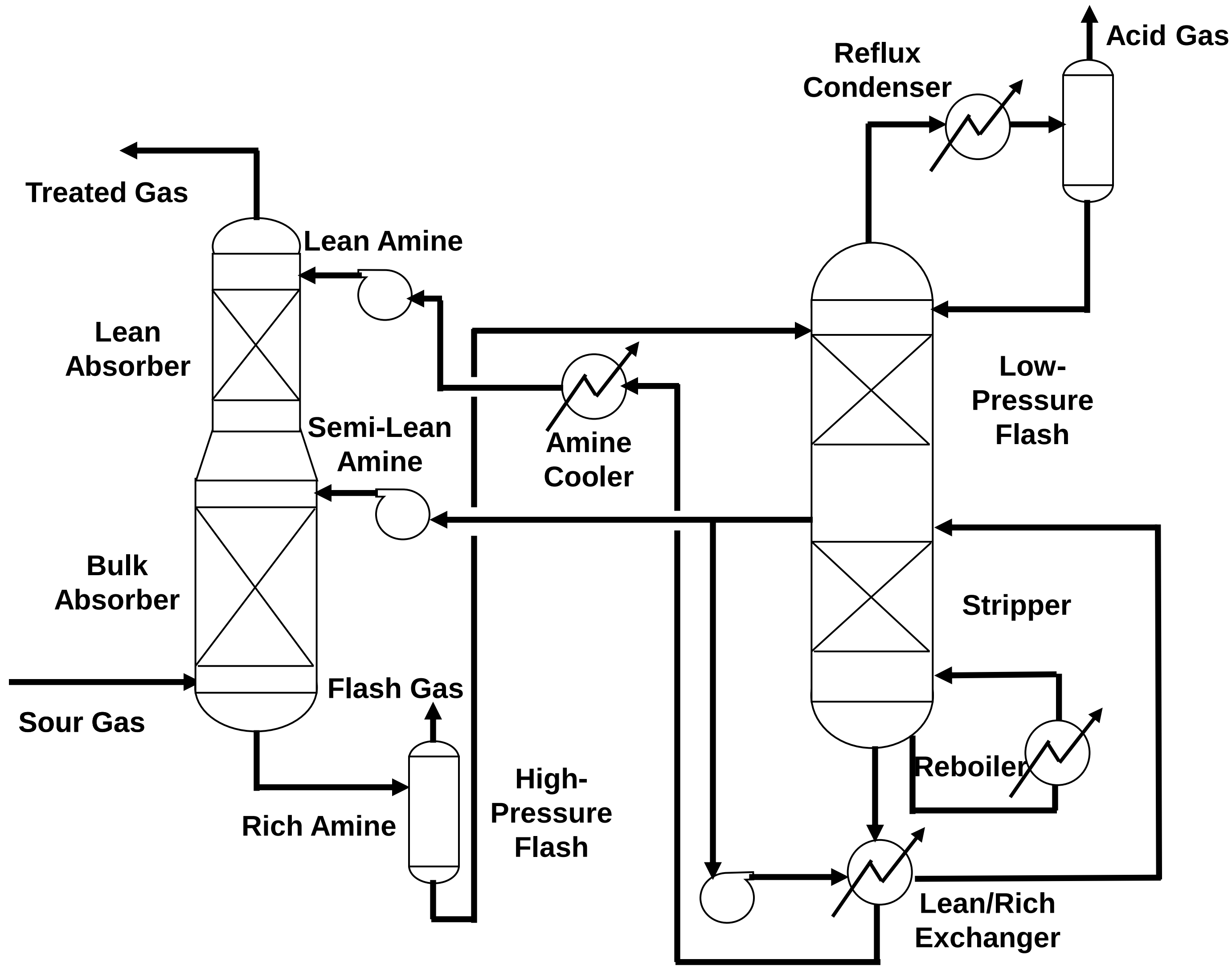
Typical Block Diagram - Liquefaction Plant



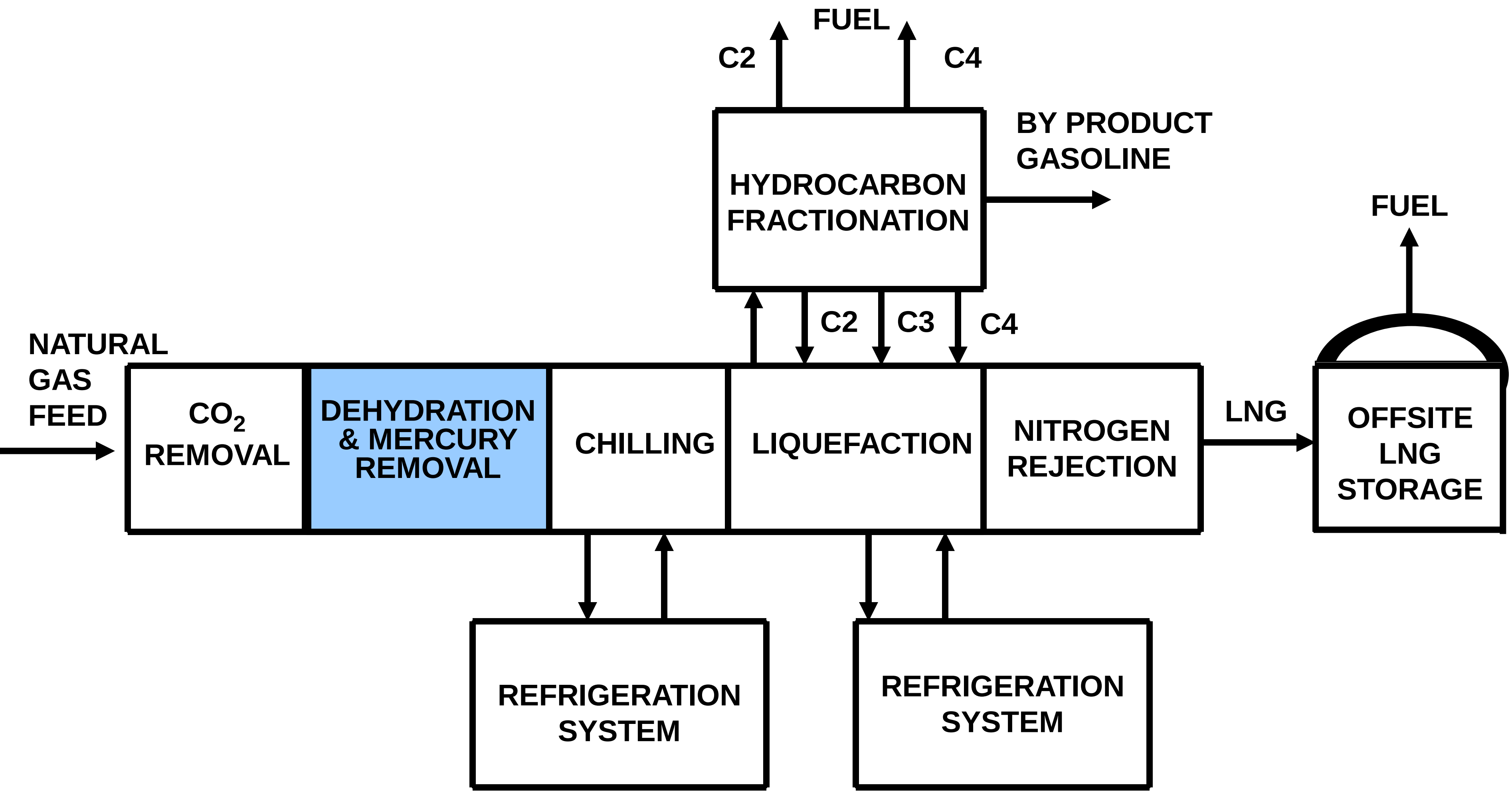
Acid Gas Removal Requirements

- 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_2S (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

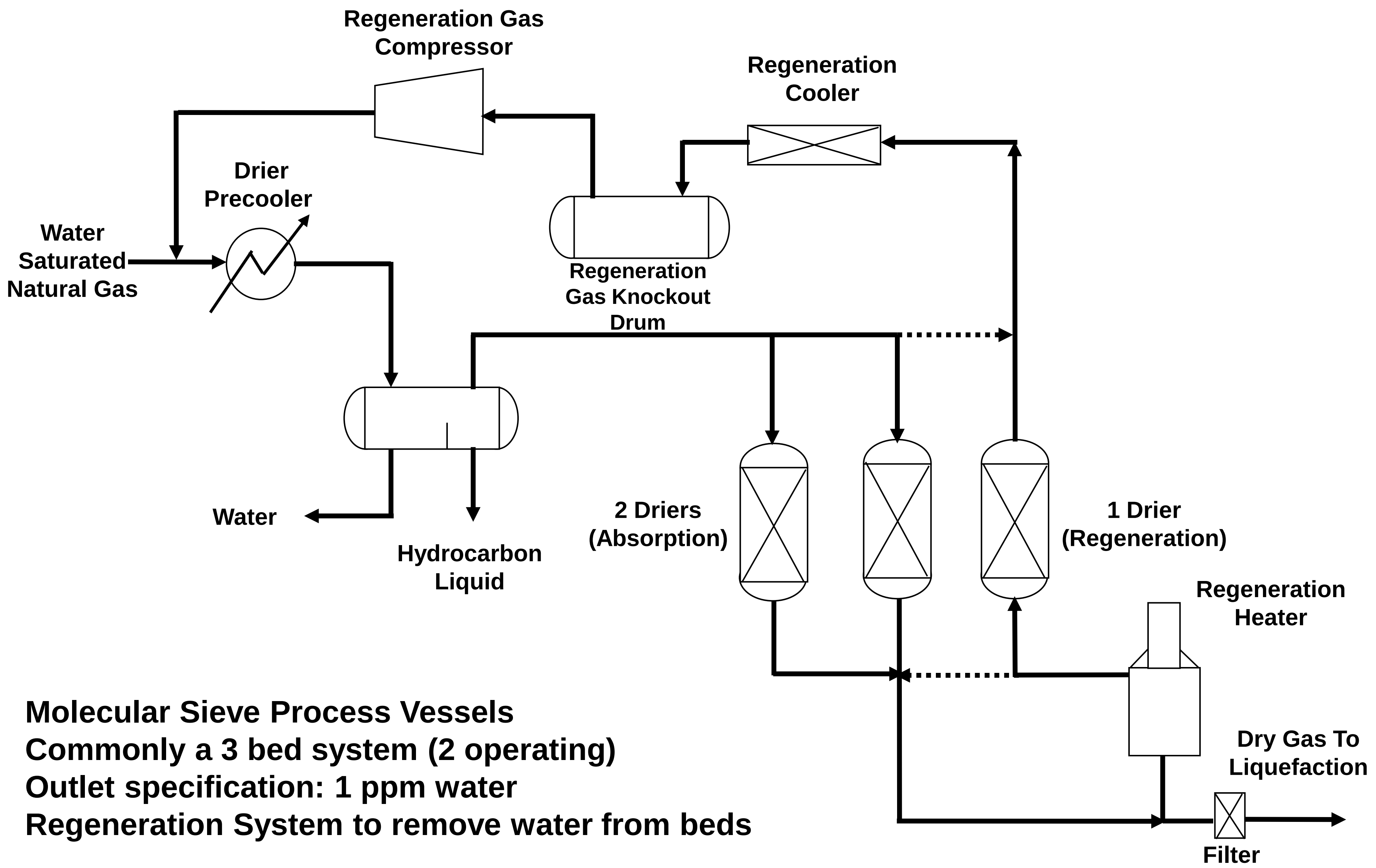
Typical Acid Gas Removal Scheme Process Flow



Typical Block Diagram - Liquefaction Plant



Typical Dehydration Scheme Process Flow

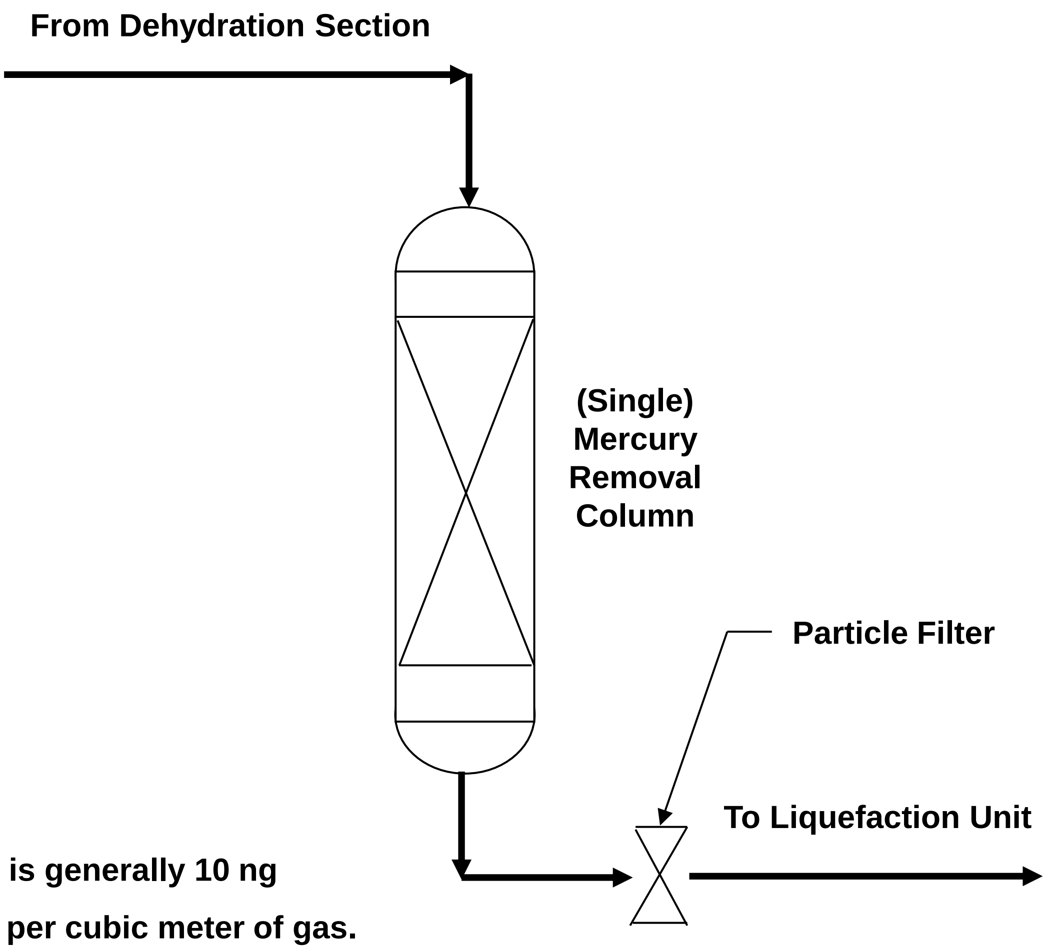


Molecular Sieve Process Vessels
Commonly a 3 bed system (2 operating)
Outlet specification: 1 ppm water
Regeneration System to remove water from beds

Mercury Removal Unit

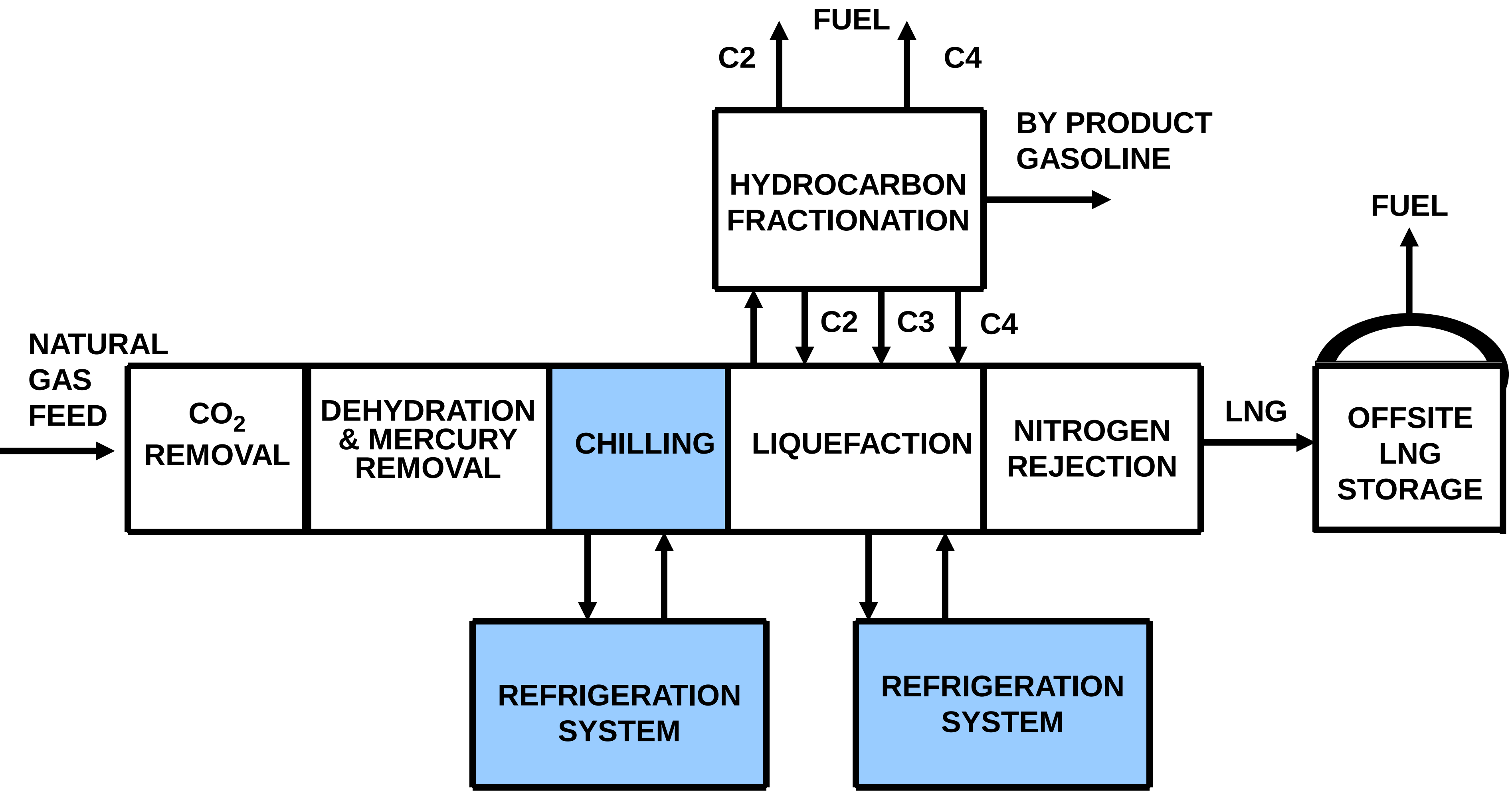
- Mercury has to be removed from natural gas to prevent corrosion in aluminum equipment
  - E.g. the Main Cryogenic Heat Exchanger
- Removal of mercury by:
  - Adsorption via sulfur impregnated bed in vessel – common
  - As part of dehydration with added mol sieve – less common
- Replacement of Hg removal beds is necessary for maintenance
  - No regeneration like in dehydration
  - If integrated with dehydration, Hg is with water on regeneration

Typical Mercury Removal Scheme Process Flow



Outlet Gas Specification is generally 10 ng (nanograms) of mercury per cubic meter of gas.

Typical Block Diagram - Liquefaction Plant



APCI Propane Pre-cooled MR Process

Simplified version

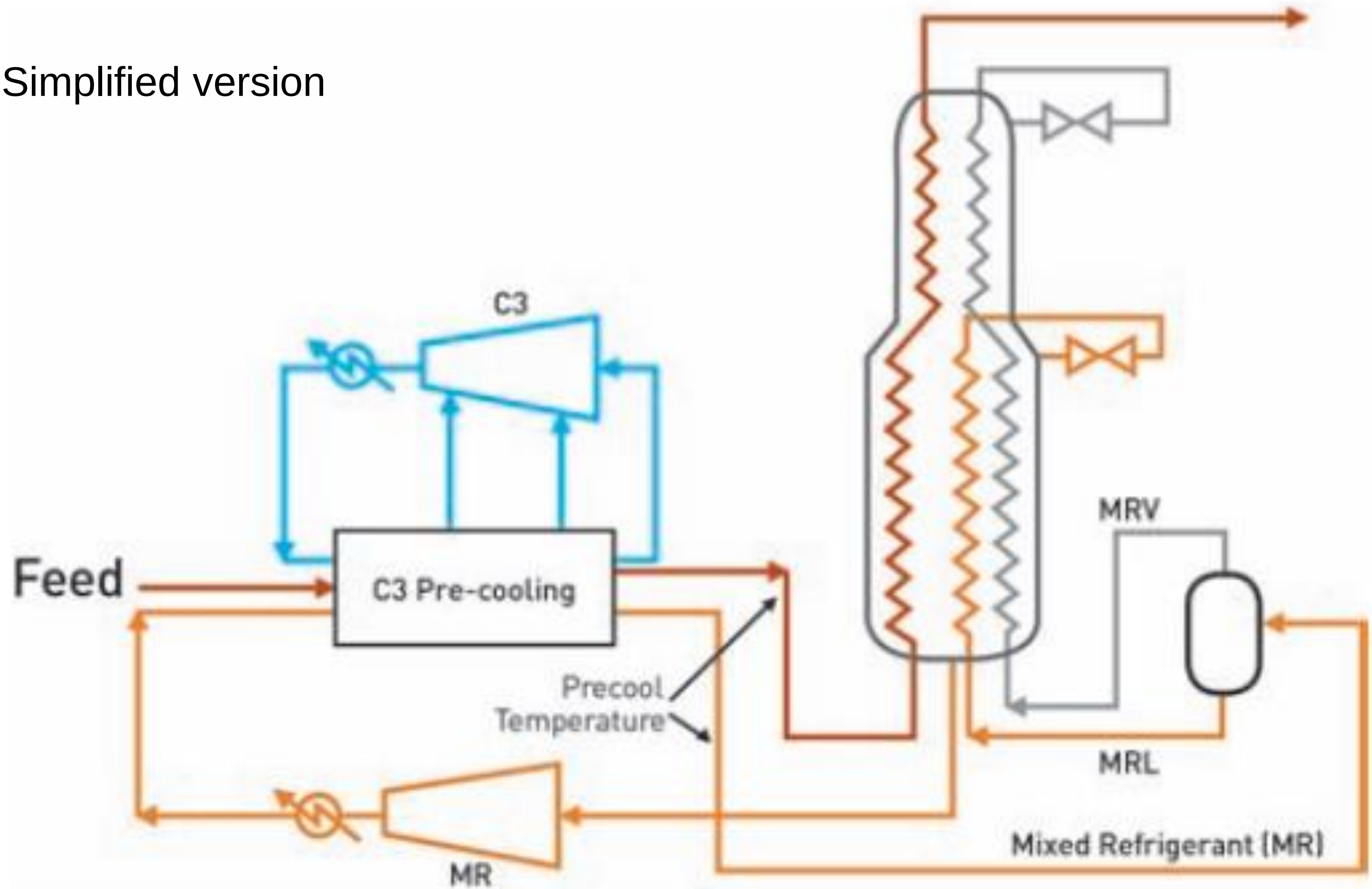
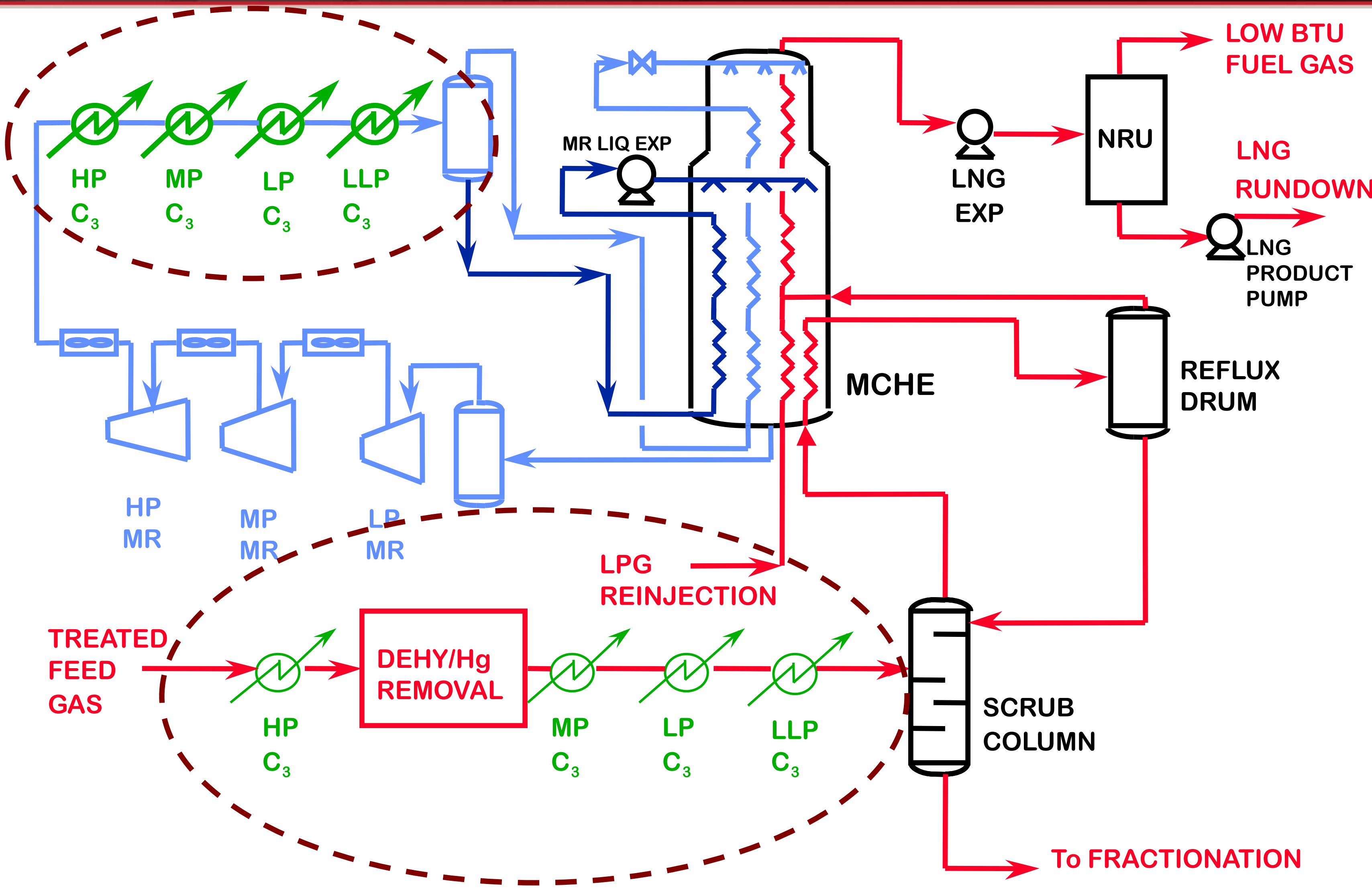
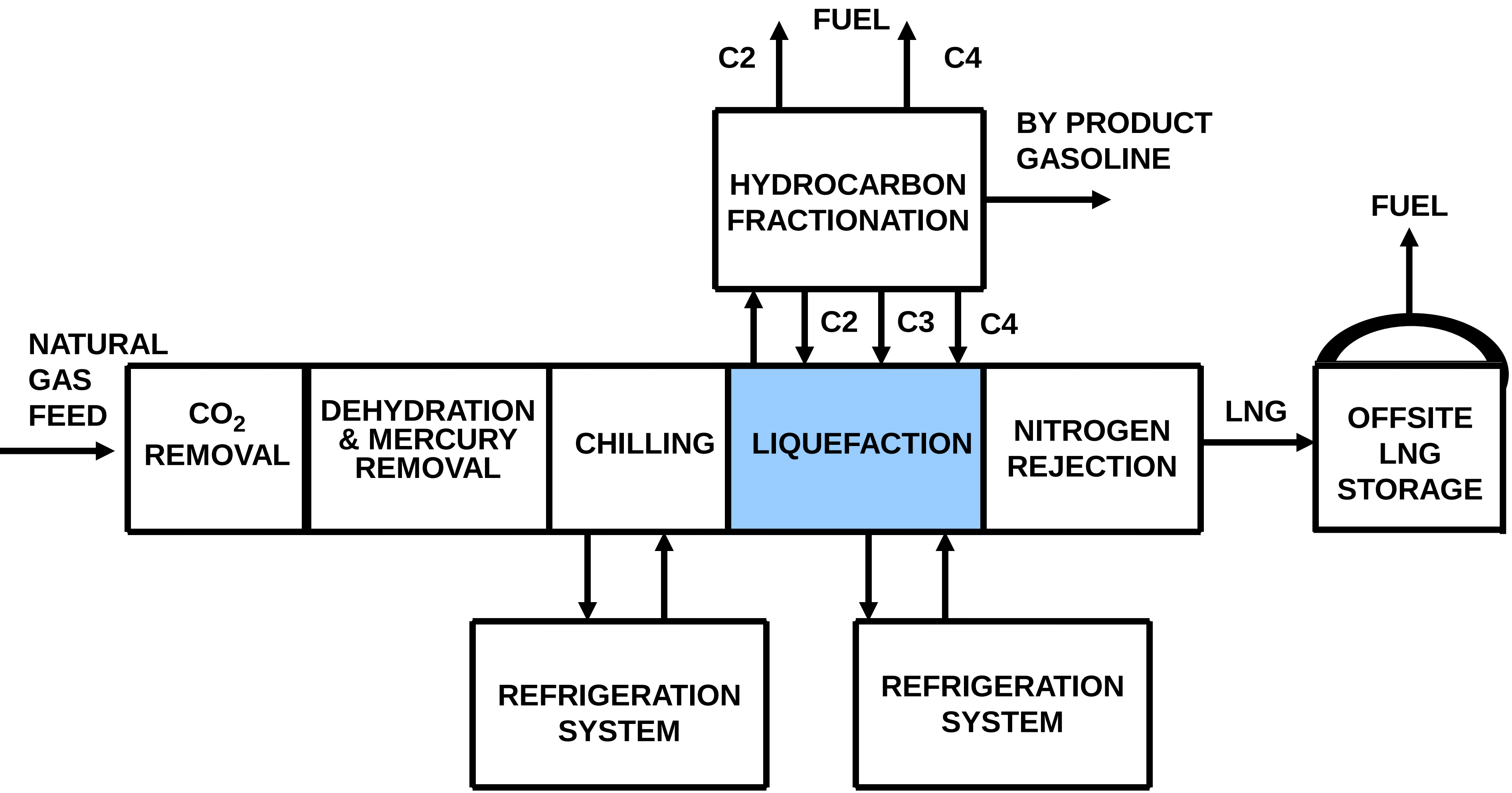


Figure 3: The C3MR Process

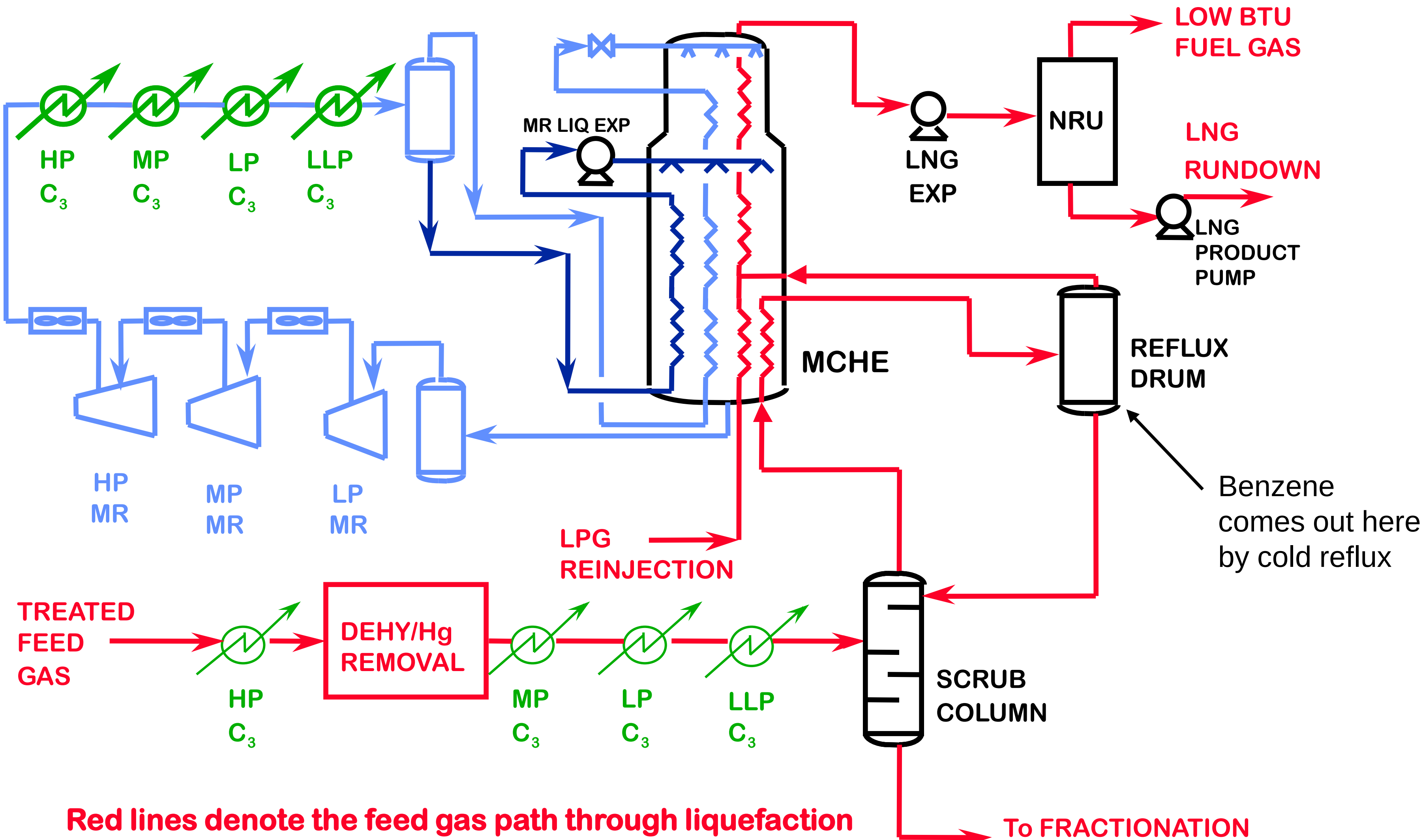
APCI Propane Pre-cooled MR Process



Typical Block Diagram - Liquefaction Plant

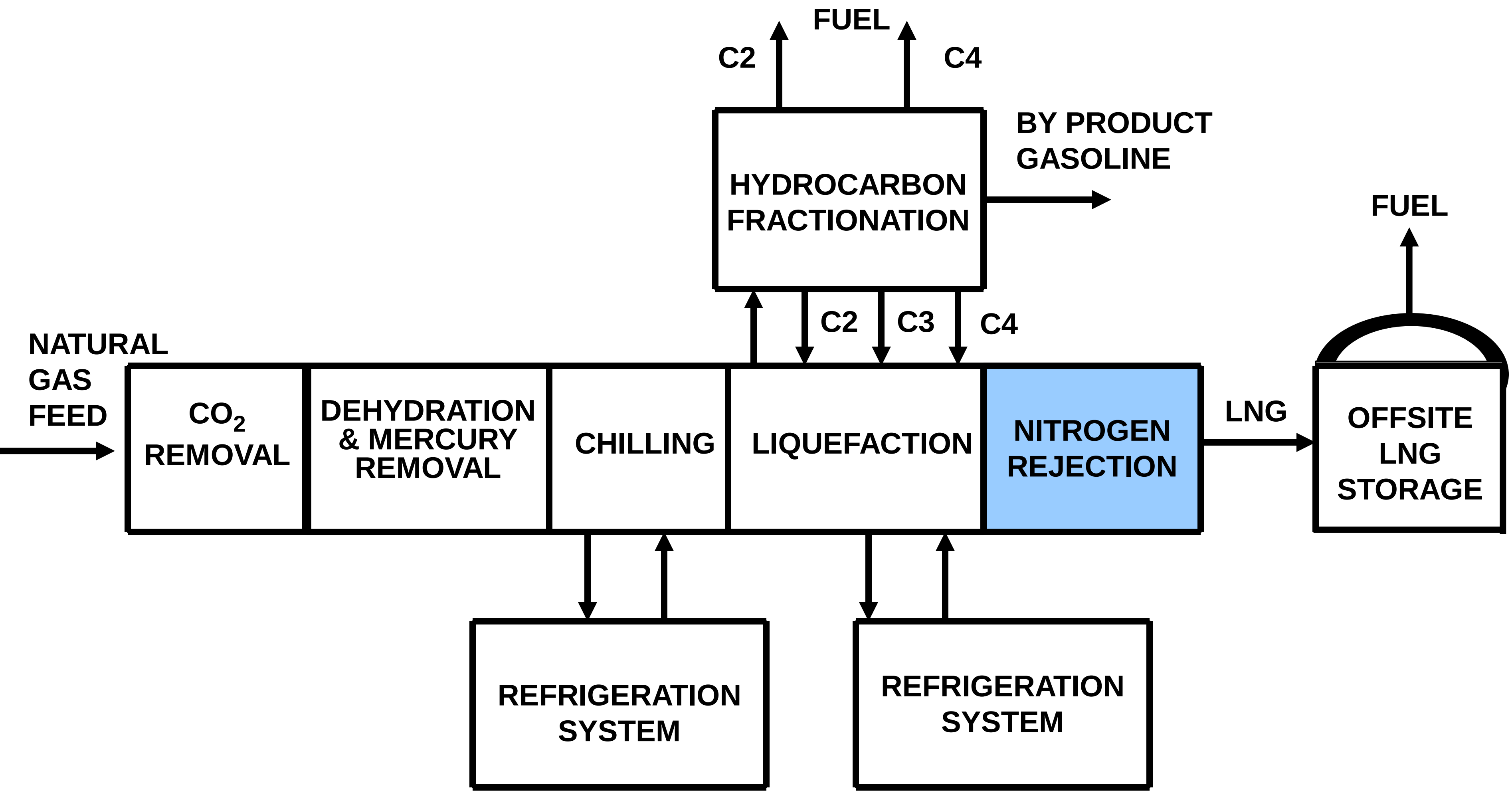


APCI Propane Pre-cooled MR Process



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

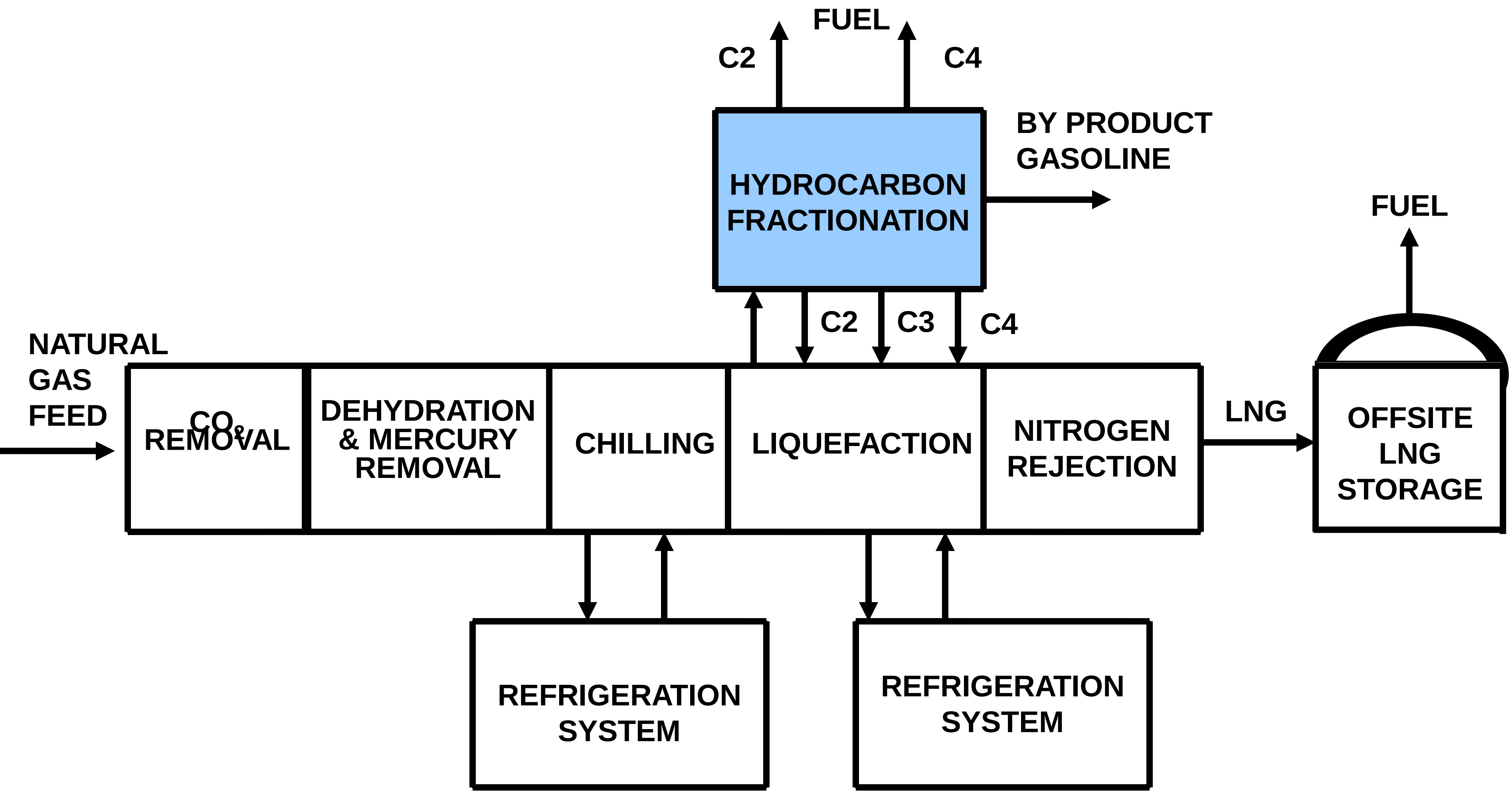
Typical Block Diagram - Liquefaction Plant



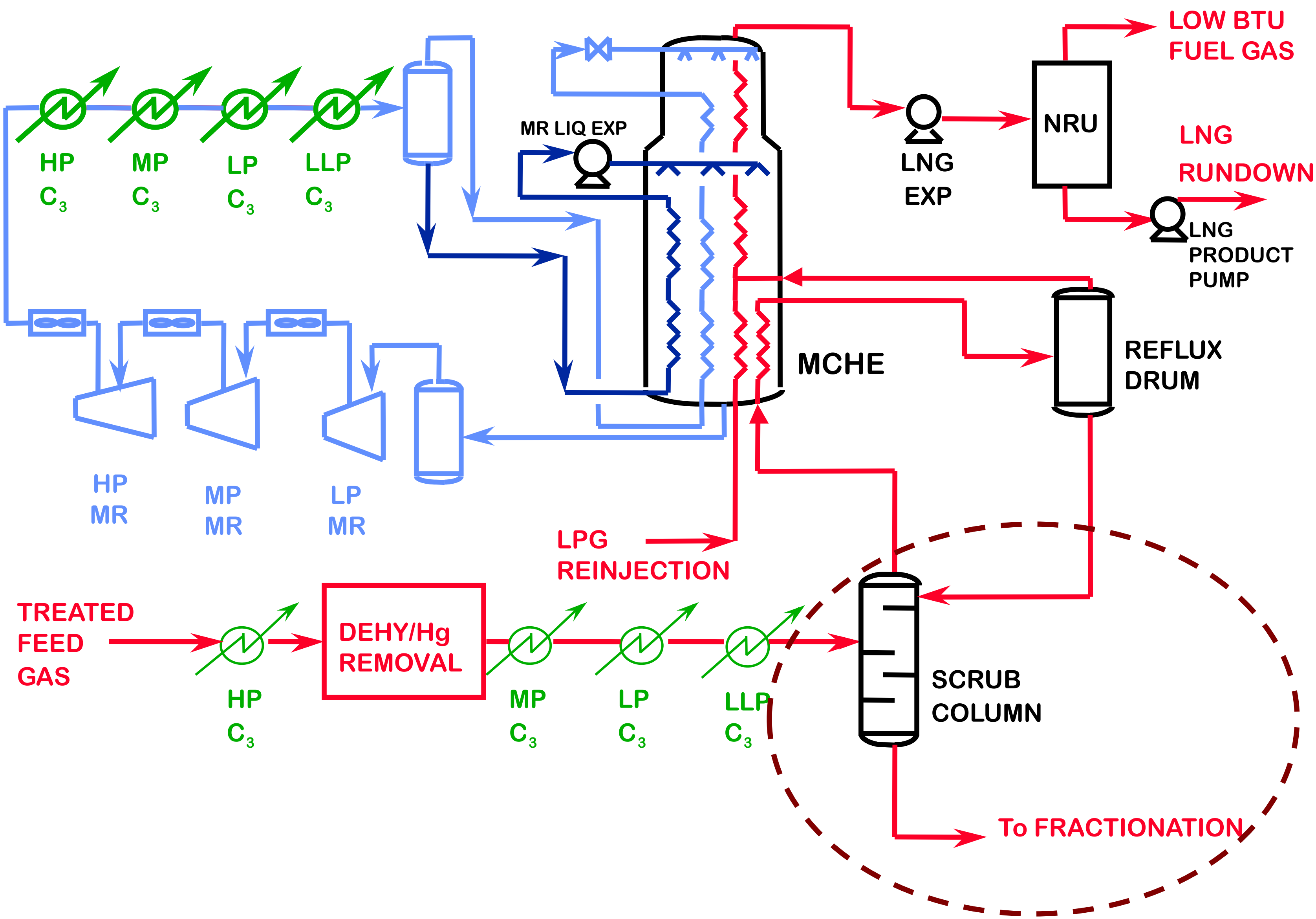
Nitrogen Removal

- 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

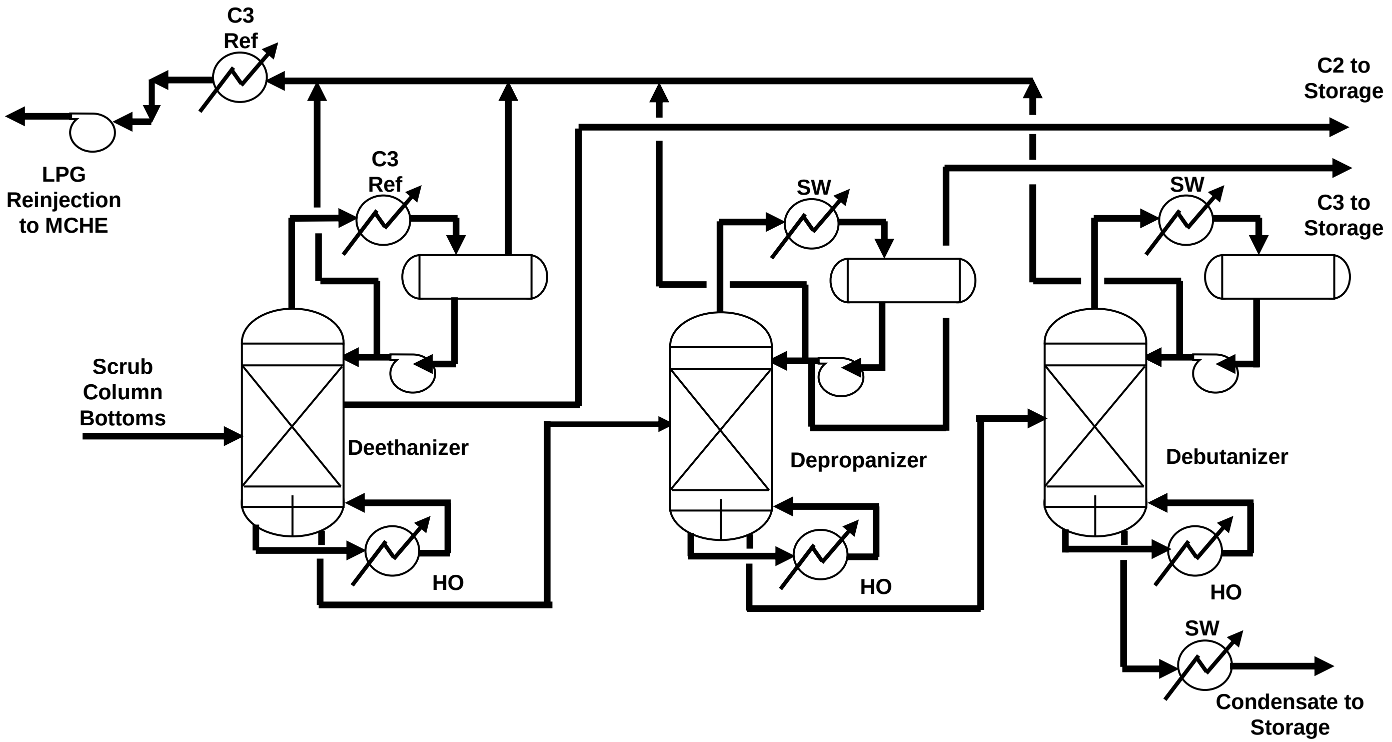


Propane Pre-cooled MR Process



Typical Fractionation Scheme Process Flow

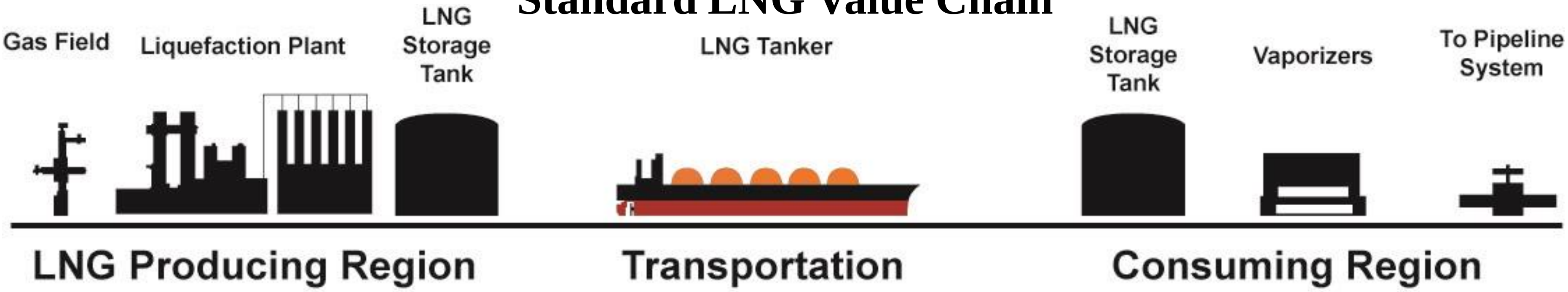
- Uses of Fractionation Unit:
  - Make liquid products for sale (LPG and Condensate help econ)
  - Make refrigerants (MR make-up or high purification C3)
  - Stabilize NGLs for reinjection



HO: Hot Oil (or other heat), SW: Seawater (or other cooling)

A Few Words on Floating LNG

Standard LNG Value Chain



LNG Liquefaction Facility

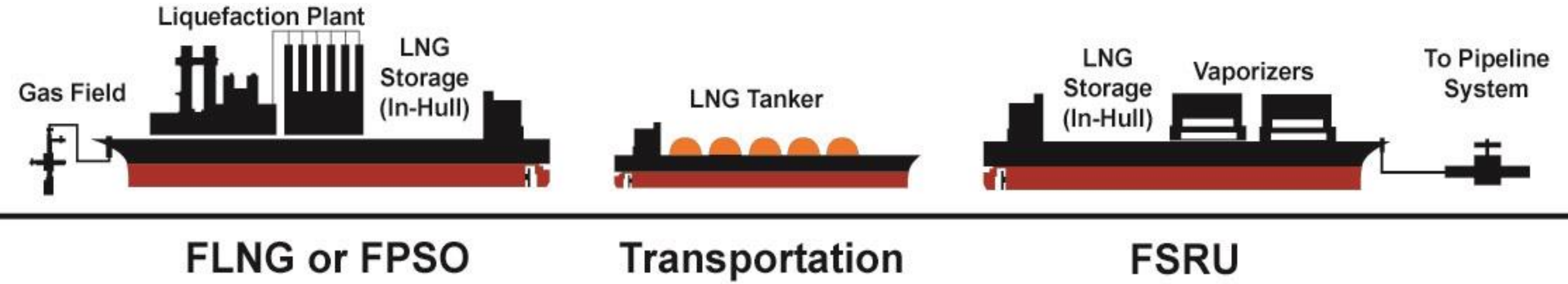
“Complex project at a challenging location”

LNG Receiving Terminal

“Moderate size project at industrial location”

“Using efficient fabrication methods”

The Full Floating LNG Chain



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

Questions