KUALA LUMPUR 2012 WORLD GAS CONFERENCE

25th world gas conference

"Gas: Sustaining Future Global Growth"

Improve Efficiency in LNG Production for Baseload LNG Plants

Chen-Hwa Chiu, Tat Tsang,

Meredith Chapeaux, Christopher Chen

Chevron Energy Technology Company

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Importance of Efficiency

- Baseload LNG production, with its large scale, is energy intensive
- Improvements in energy efficiency can:
  - Reduce fuel consumption
  - Increase LNG production, where feed supply is constrained
  - Reduce Greenhouse Gas (GHG) emissions
- LNG industry has continued to make efficiency gains in many areas
  - Gas treating
  - Heat exchange design and integration
  - **Refrigerant compressor drivers**
  - **“Waste heat” recovery**
  - **Cryogenic liquid expansion**
  - **Integration of LNG production and NGL recovery**
- What would you choose?
  - Improve efficiency by 1 % or produce 1 extra cargo every 8 months?

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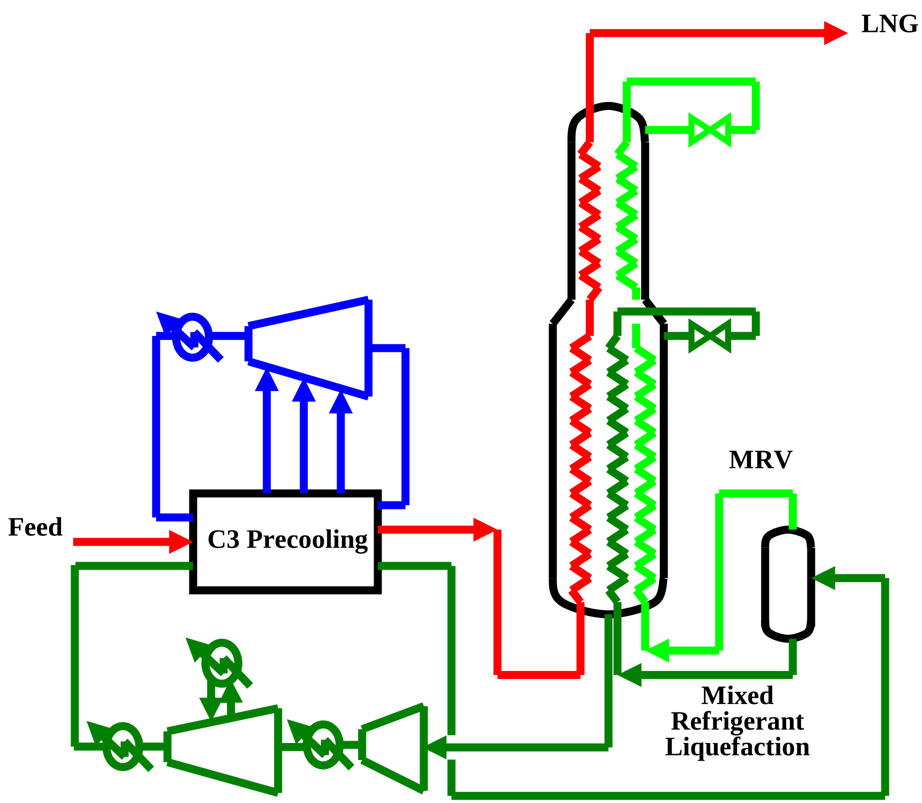
Optimization of Compressors and Drivers
C_3MR/SplitMR TM

- The C_3MR LNG process utilizes Propane (C_3) pre-cooling and Mixed Refrigerant (MR) for natural gas liquefaction
- Propane refrigeration duty
  - Feed gas pre-cooling temperature is limited to liquid propane temperature
  - Duty is about half that of the MR refrigeration duty
- Generally prefer that compression trains have matched turbines
  - Ease of procurement
  - Simpler maintenance logistics and sparing
- SplitMR TM process accomplishes this by power balancing
  - Shifts portion of MR compression driver duty to C3 compression driver



C_3MR Process

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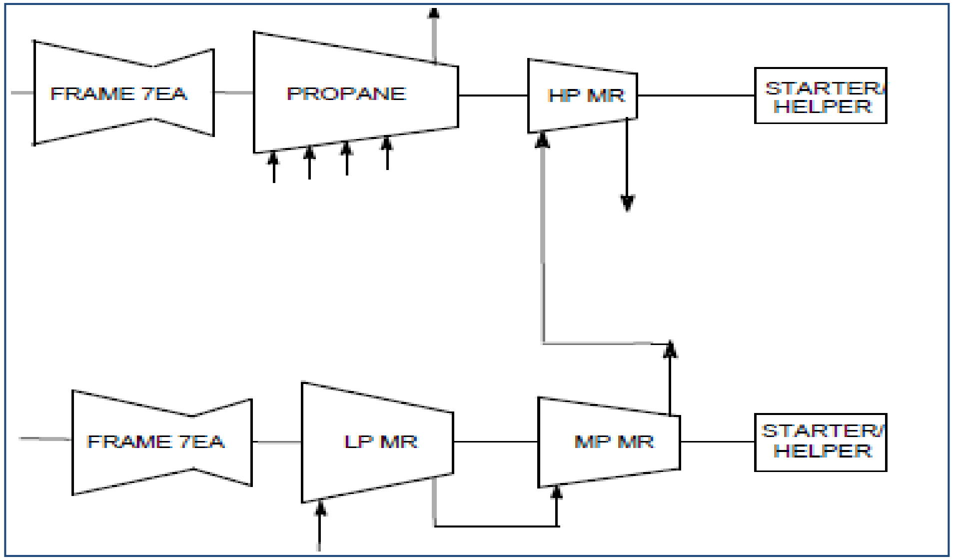
Optimization of Compressors and Drivers
C_3MR/SplitMR ™

- C_3MR/SplitMR matches power demand of refrigeration compressor turbines
- First used at Ras Gas II in Qatar
- Two Frame 7EA GE turbines
  - Propane compression + High Pressure MR compression
  - Low Pressure MR and Medium Pressure MR compression
- Optimizes
  - Power balance between C3 and MR refrigeration
  - Utilizes power from starter/helper motors
  - LNG production
- Similar power split arrangement used in AP-X ™ LNG process with Frame 9 turbines



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Optimization of Compressor and Drivers
Aero-derivative Gas Turbines as Drivers

- Aero-derivative gas turbines (GT's) are finding *increased use in LNG plants*
  - Aero-derivative GT's were originally developed from aircraft turbine designs
  - **Direct drivers**: LM2500 used at Darwin LNG in Australia
  - **Power generation** for electric drives: LM6000 used for power generation at Snohvit LNG in Norway for electric compressor drivers
- LM6000 selected for 2 trains at Wheatstone LNG in Australia
  - First use of LM6000's as direct drivers in an LNG plant
  - 12 LM6000's for compressor drivers
  - 4 LM6000's for power generation

GE LM6000 turbine

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Optimization of Compressor and Drivers
Aero-derivative Gas Turbines as Drivers

- Aero-derivative GT's offer advantages
  - Higher efficiency than industrial ("Frame") GT's
  - Variable speed drivers
  - No starter motor required, leading to reduced plant power generation requirement
  - High starting torque capacity. Able to start under settle out pressures
  - Dry-Low-emissions (DLE) technology proven on several engines
  - More rapid swap of engines with lower engine weight – improving maintenance flexibility, reducing maintenance downtime, and increasing overall plant production efficiency

Representative Gas Turbine Performance

Gas Turbine	Shaft	ISO rated Power (kW)	Efficiency
Frame 5D	Dual	32,600	29%
LM 2500	Dual	31,400	41%
LM 6000	Dual	44,700	43%
Frame 7E	Single	86,200	33%
Frame 9E	Single	130,100	34%

Optimization of Compressor and Drivers
Aero-derivative Gas Turbines as Drivers

Design Considerations and Opportunities

- Generally smaller power output
  - May require parallel refrigeration compressor/driver trains for specified LNG production capacity
  - Larger power output aero-derivative GT's (e.g. LMS 100) could see wider use in LNG industry as operating experience is gained
- Power curves have steeper decline with high ambient temperatures
  - Power augmentation may be needed for locations with wide range of ambient conditions
    - Pre-cooling inlet air via evaporative cooling or mechanical chillers
  - Extensive operating experience with GT power augmentation in power generation applications

“Waste Heat” Recovery

Gas turbine exhaust heat recovery

- Heat facility heating media – e.g. hot oil, steam, hot water
- Heat dehydration unit’s regeneration gas
- Benefit:
  - Reduced number or size of boilers and fired heaters; reduced GHG emissions
  - Increased energy efficiency and reduced fuel gas consumption
- Becoming more widely used in LNG industry

"Waste Heat" Recovery
Combined Cycle Gas Turbine

- Combined Cycle Gas Turbines (CCGT) offer increased efficiency through greater integration
- Example: Tangguh LNG – waste heat recovered from Frame 7EA gas turbines utilized in several areas
  - Acid Gas Removal Unit (AGRU)
  - Helper Steam Turbines
  - Power Generation
- Design considerations
  - Integration and complexity
    - E.g. Boiler feedwater supply and steam condensers
  - Increased installed cost
  - Operational complexity and reliability need to be managed
    - E.g. Integration with plant electrical power

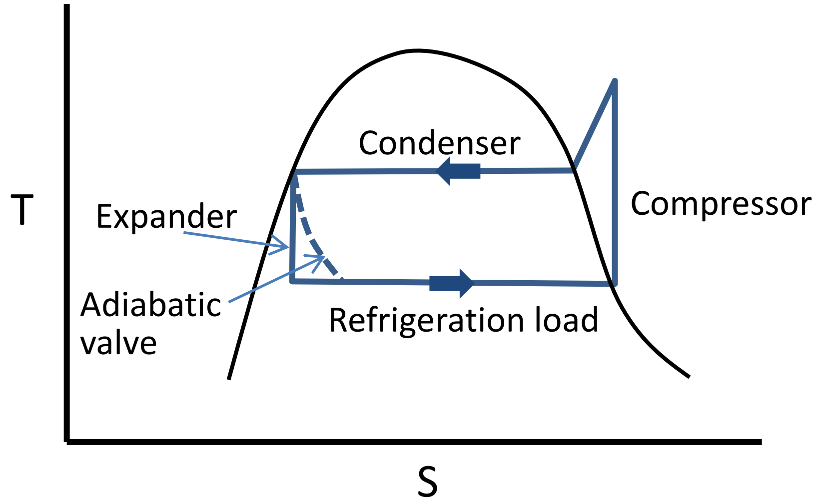
Tangguh LNG Plant
Combined Cycle Application

Item	Recovered Energy (MW)
AGRU reboilers & heaters	259.1
Frame 7EA helper steam turbines	50.3
Power generation	11.0
Total	**320.4**

Phillips, Solis, Konishi, 2005

Cryogenic Liquid Expanders

- Background
  - Transform high pressure liquid to low pressure liquid and vapor
  - Nominally isentropic (constant entropy) "expansion"
  - Reduces enthalpy of fluid, producing work
    - Can be converted to electrical energy



Cryogenic Liquid Expander

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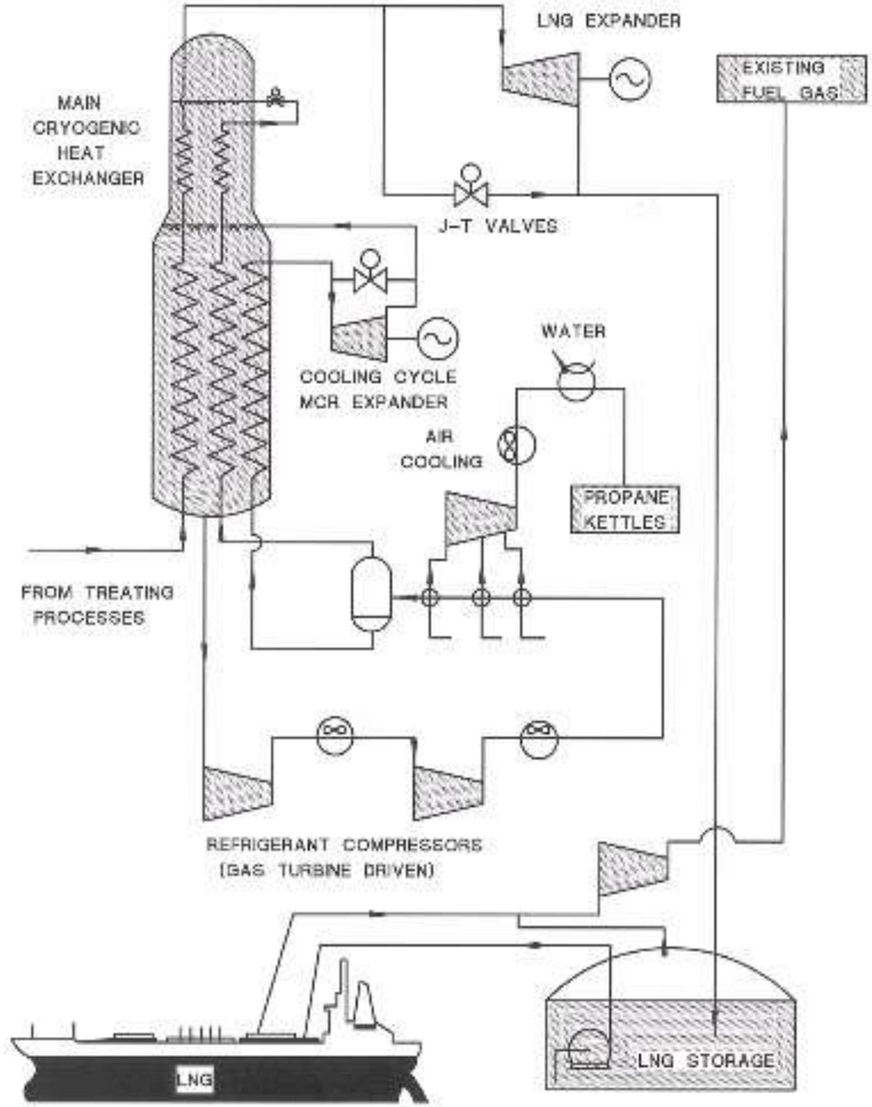
Cryogenic Liquid Expanders

- Applications in C_3MR or SplitMR ™ processes
  - Heavy Mixed Refrigerant (MR) Liquid
  - LNG Product
- Benefits
  - Increased efficiency
  - Increased LNG production, up to about 6%
- Technology advances
  - Variable speed design
    - Optimization of operation over range of LNG production
  - Two-phase expanders being developed
    - Further enhance efficiency
  - Opportunity for applications in other LNG processes



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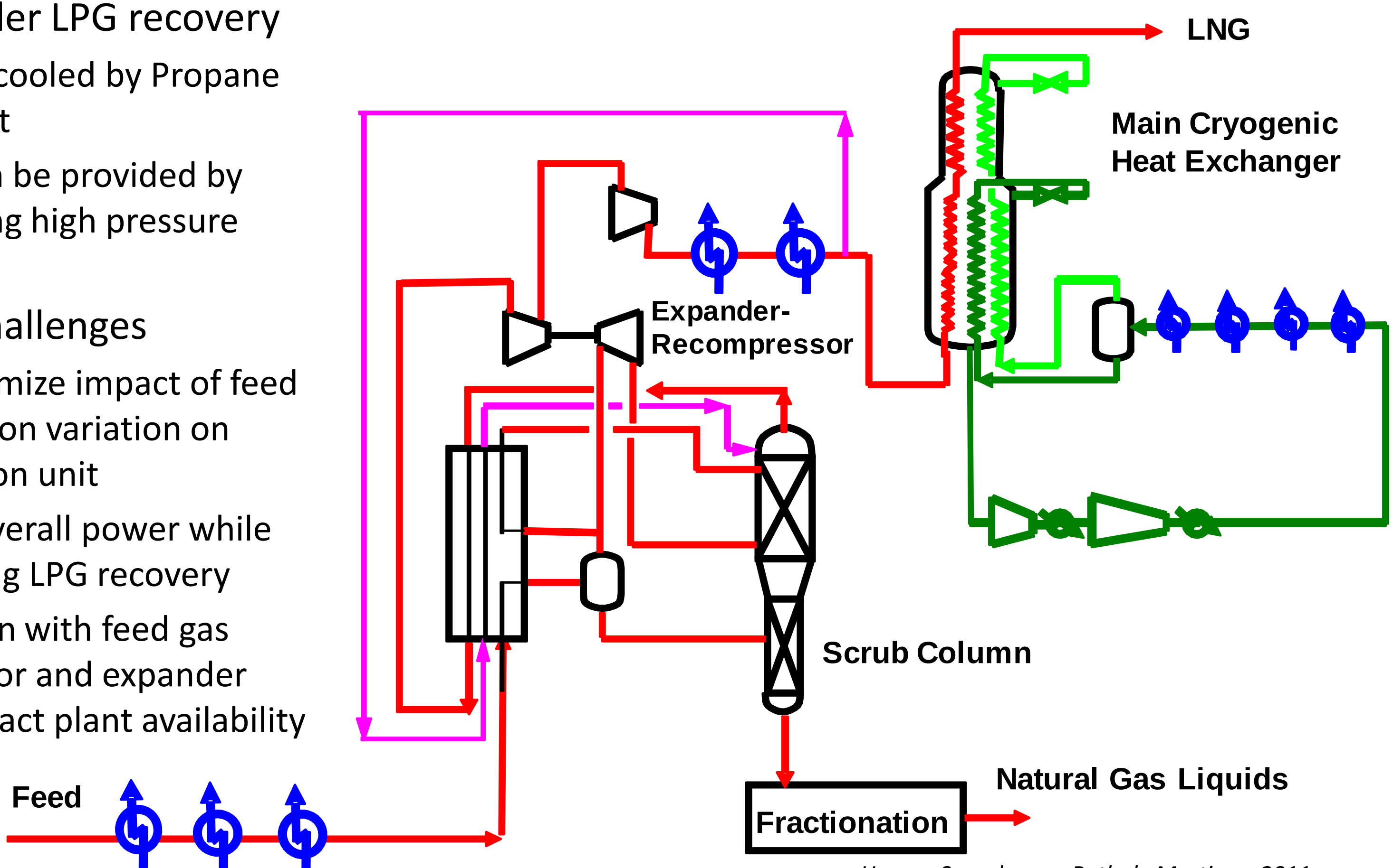
Integration of LNG Production and NGL Recovery

- Various levels of integration possible
- Example: Integration with turbo-expander LPG recovery
  - Feed pre-cooled by Propane refrigerant
  - Reflux can be provided by condensing high pressure lean gas
- Benefits & Challenges
  - Help minimize impact of feed composition variation on liquefaction unit
  - Reduce overall power while maximizing LPG recovery
  - Integration with feed gas compressor and expander could impact plant availability



Huang, Saunderson, Pathak, Martinez, 2011

Conclusions

- Baseload LNG production, with its large scale, is energy intensive
- Many options available to increase efficiency, including
  - Refrigerant compressor drivers
  - “Waste heat” recovery
  - Cryogenic liquid expansion
  - Integration of LNG production and NGL recovery
- What would you choose?
  - Improve efficiency by 1 % or produce 1 extra cargo every 8 months?
- Answer: It depends
  - These can be equivalent for a given scenario (10 MMtpa LNG plant capacity and 160,000 cu.m. cargo), but …
- Must consider the facility and project holistically. Some factors:
  - Facility location, conditions, and gas supply
  - Capital Cost and Operating Expense
  - Reliability, Availability, Maintainability
  - Safety and Environmental
  - Risk and Technology Development Stage
  - Procurement, Supply Chain, Intellectual Property
  - Stakeholder (government and industrial) preferences and requirements

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