# Selecting a Liquefaction Process for the Arctic Environment

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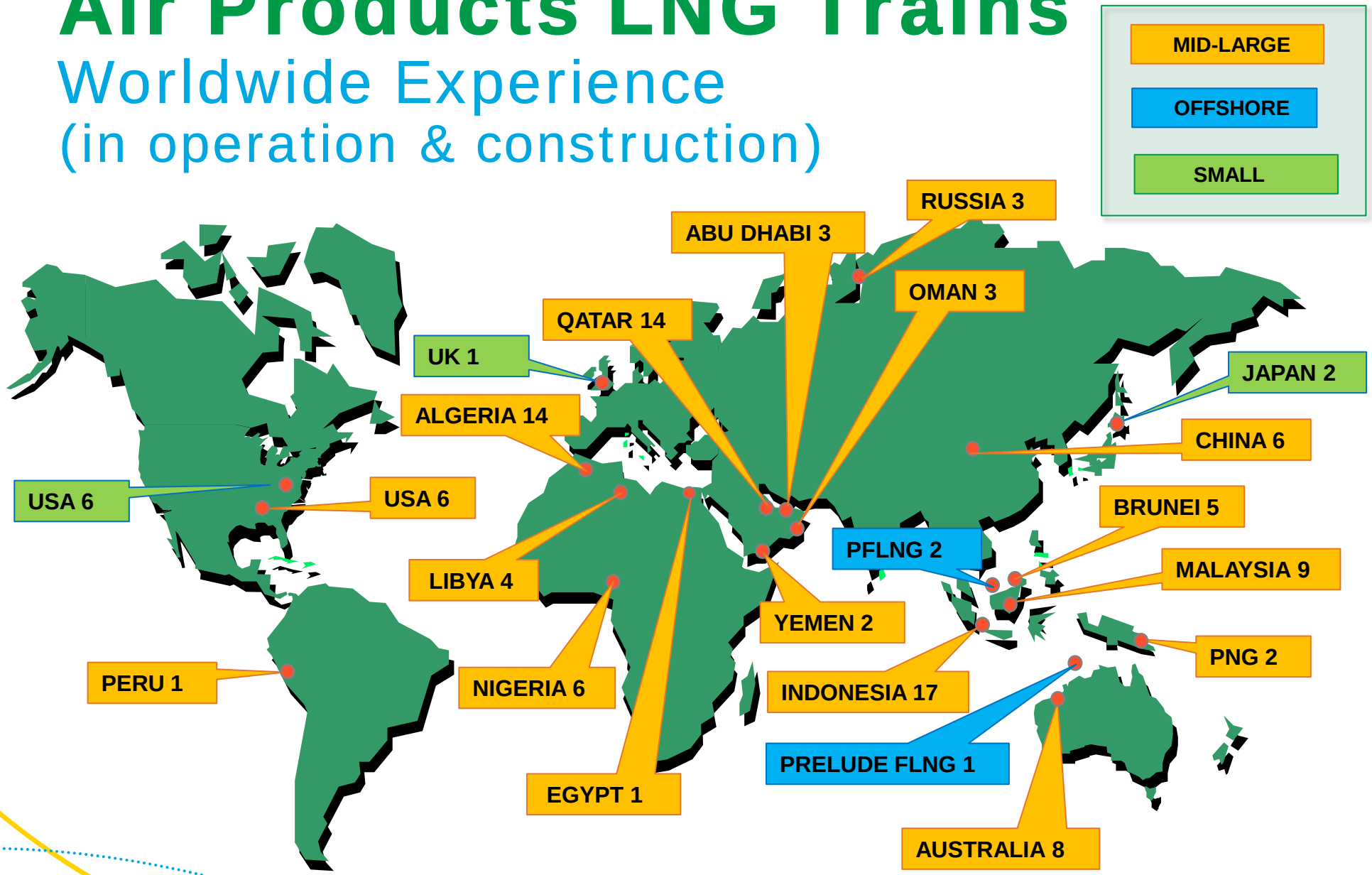
AIR PRODUCTS

# Air Products LNG Trains

## Worldwide Experience
## (in operation & construction)



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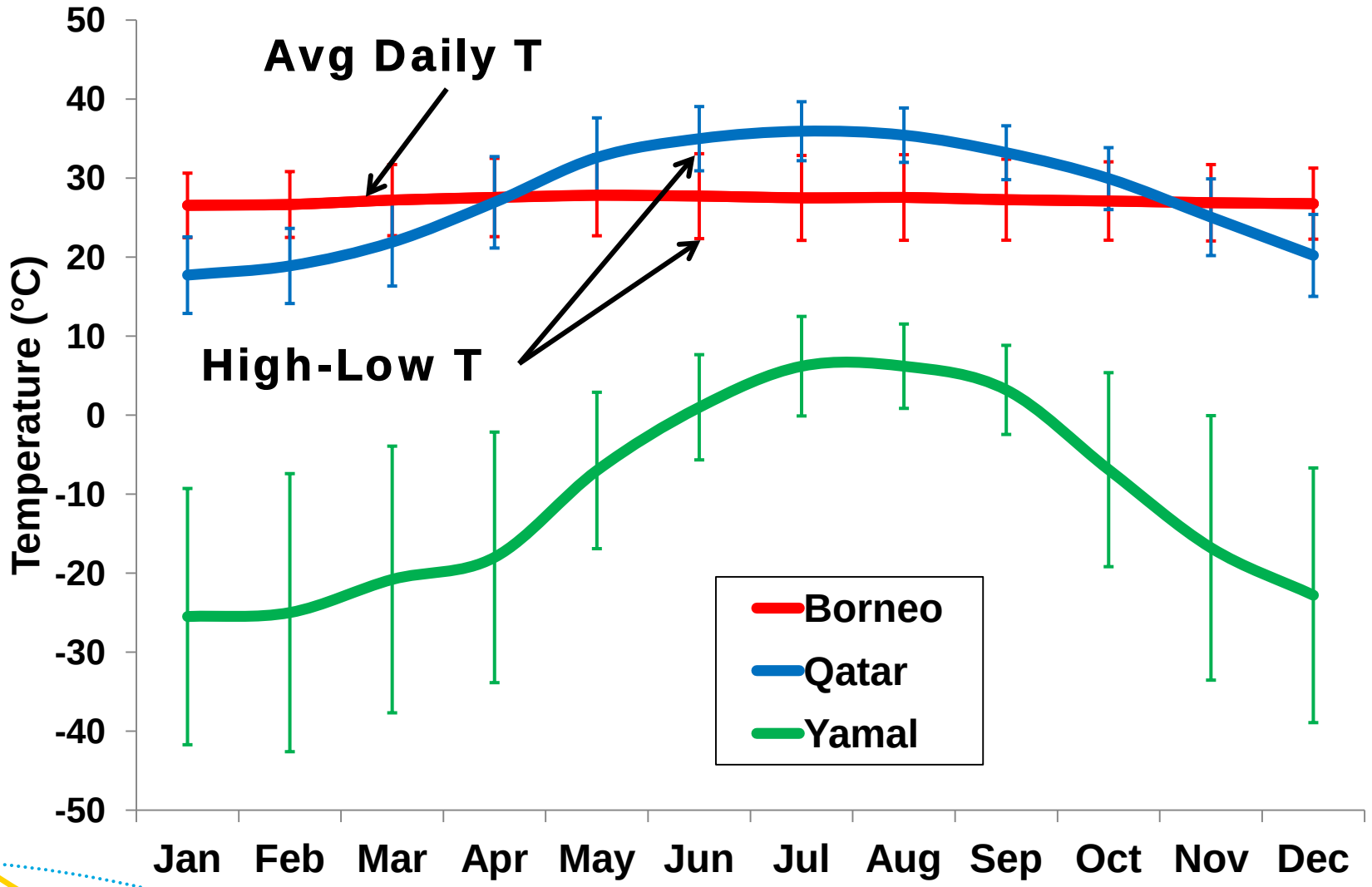
# Air Products Baseload LNG Trains

# Industry Arctic Plants

# What Makes an Arctic Location Different?

- Periods with very short and very long daylight
- Extreme winds
- Winter precipitation does not melt until summer
- Ice accumulation from sea spray and fog
- Sea contains ice and may even freeze over
- It's cold!
  - ✓**Cold cooling medium for process heat rejection**
  - ✓**Cold air to gas turbine drive**

# Average Monthly Air Temperatures



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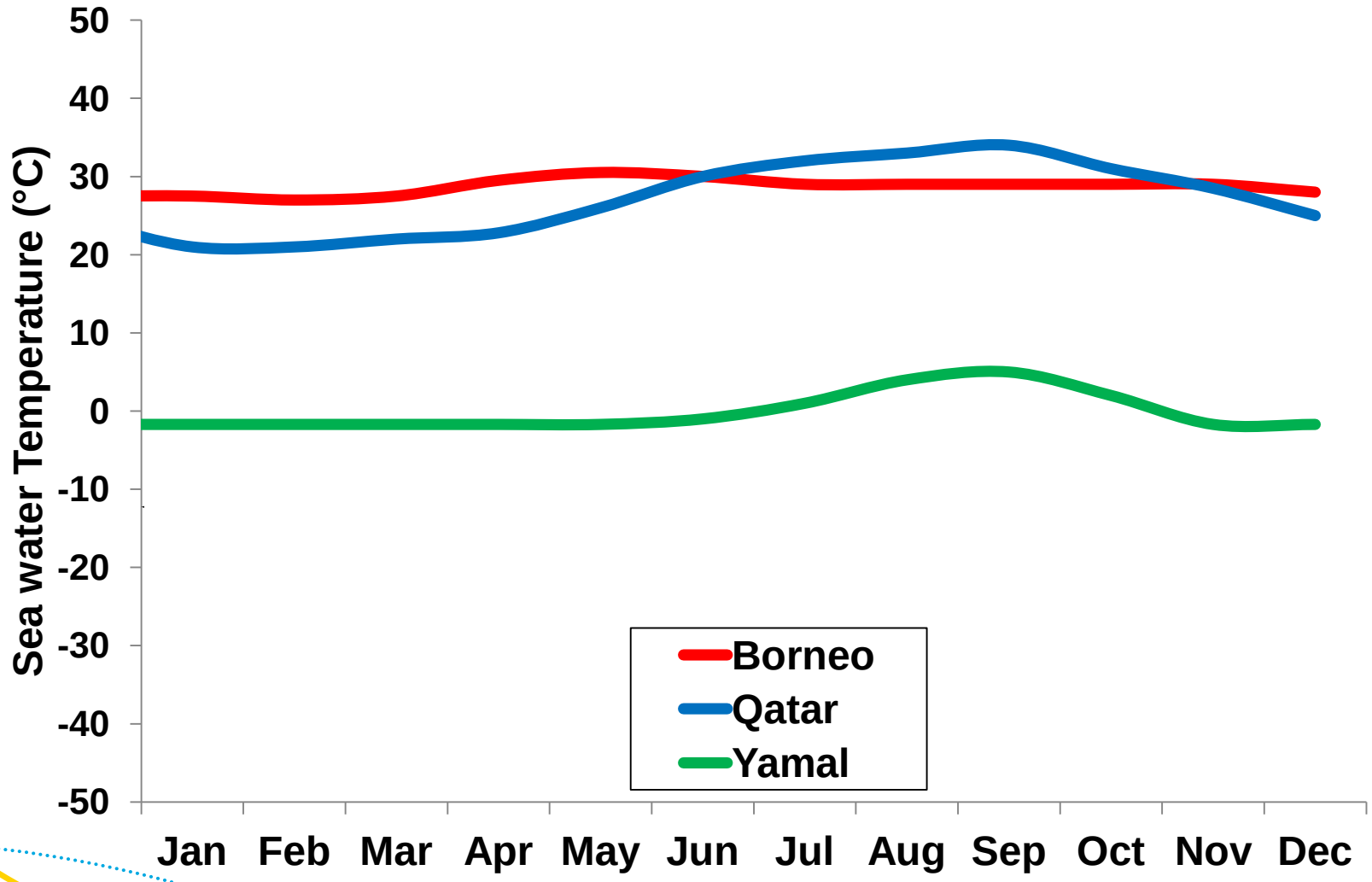
# Yearly Seawater Temperature Trend



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# Effect of Cold Ambient on Production

- **Production depends on available power**
  - Available power increases as air temperature decreases
- **Production depends on liquefaction efficiency**
  - Efficiency of liquefaction processes improves as cooling medium temperature decreases

LNG Production ↑ = $\text{Power}_{GT}$ ↑ * Efficiency ↑



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# Outline for Remainder of Talk

Review Two Liquefaction Processes

- ✓ AP-C3MR™ – extensively used in industry
- ✓ AP-DMR™ - can be of interest for arctic climates
- ✓ Efficiency definition

Three case studies for arctic conditions



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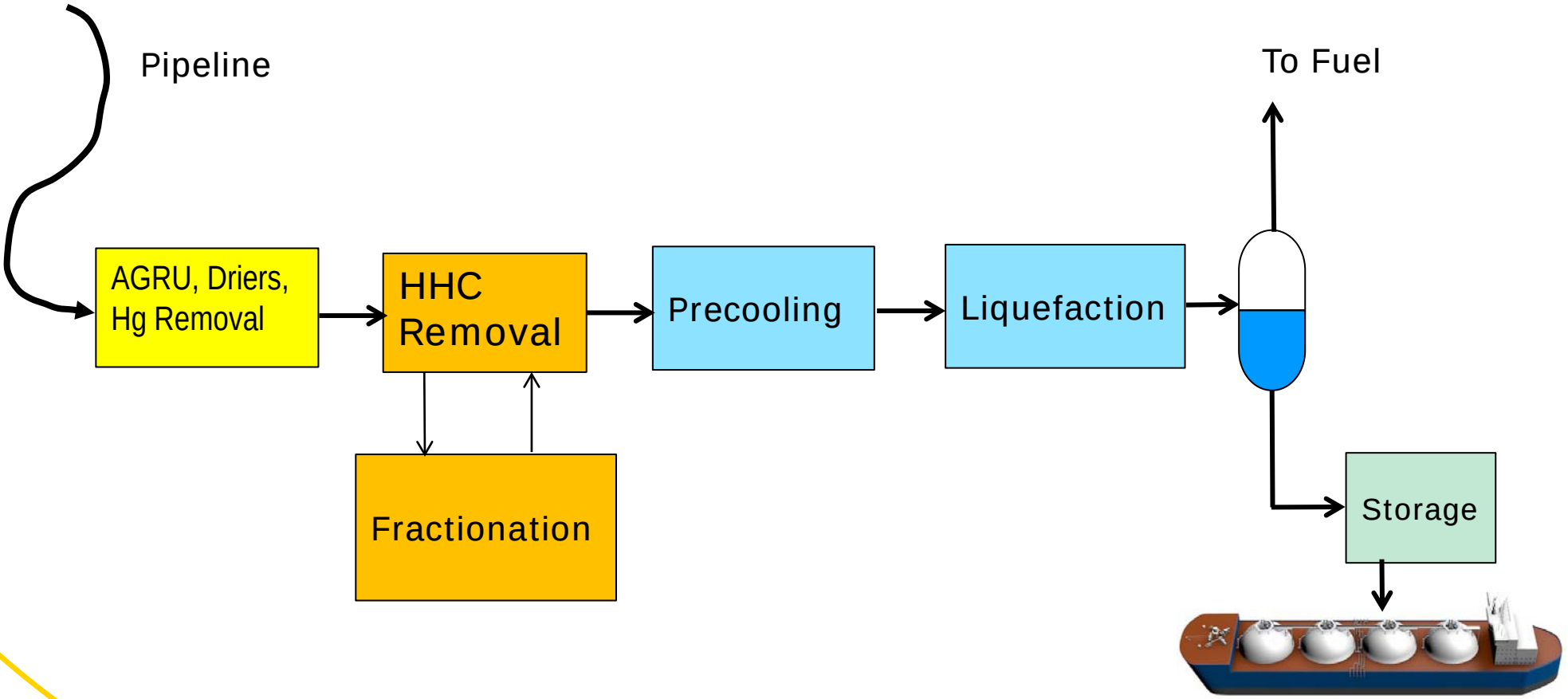
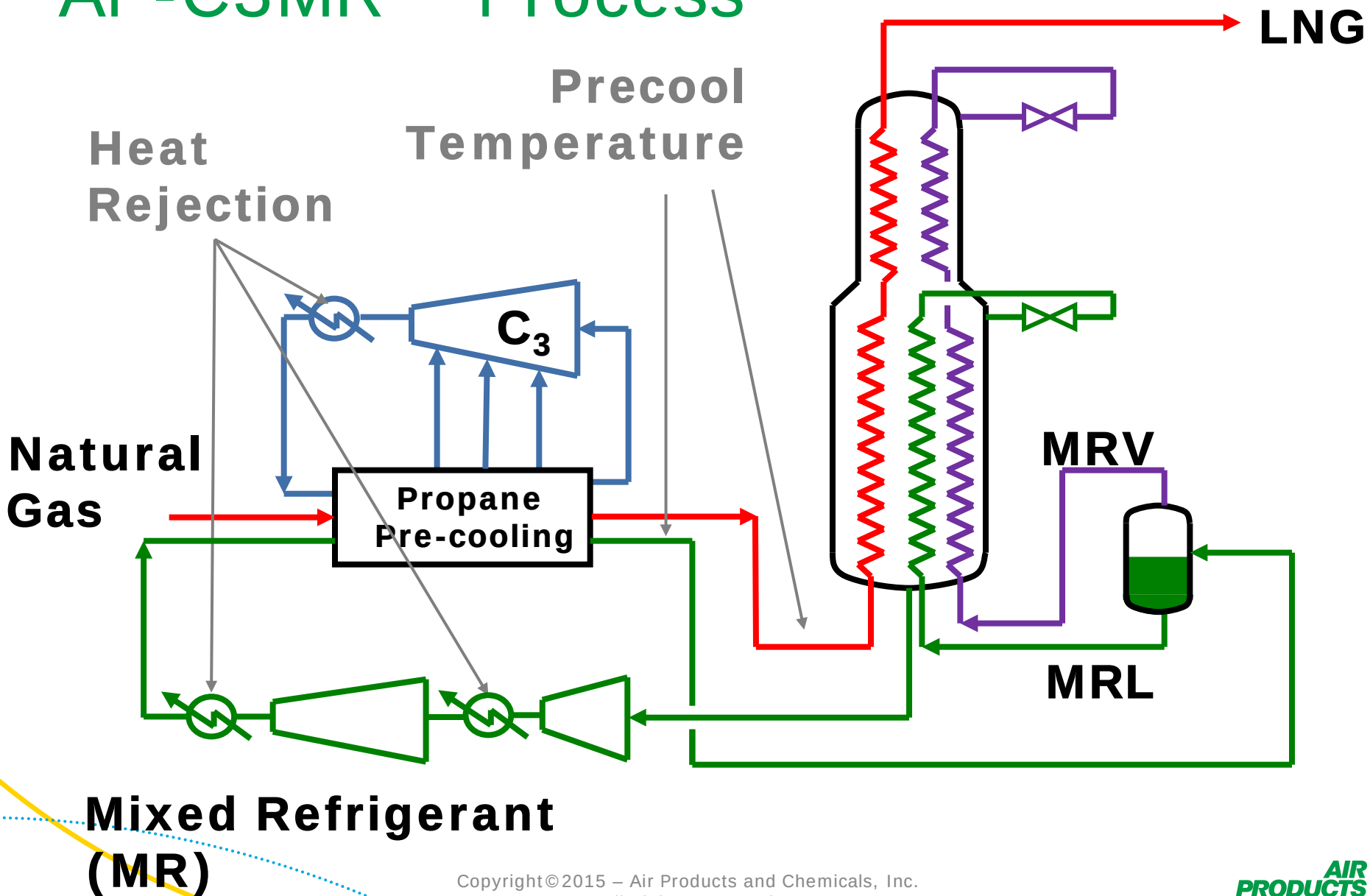
# Overview of the LNG Process



# AP-C3MR™ Process



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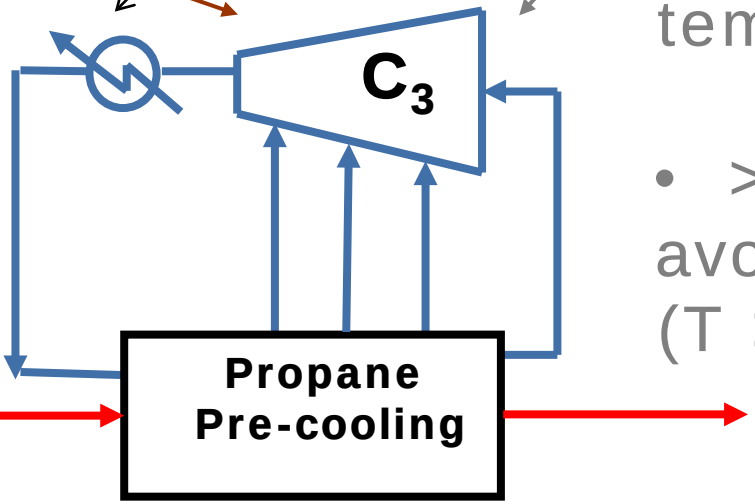
# AP-C3MR™ Process –Precooling Section

**Discharge Pressure**

- Set by C3 condensing P
- Is a function of cooling medium T
- Effects compressor power

Propane Condenser




**Suction Pressure**

- Sets precooling temperature
- > 1 bara to avoid vacuum (T > ~ -37°C)

**Natural Gas**



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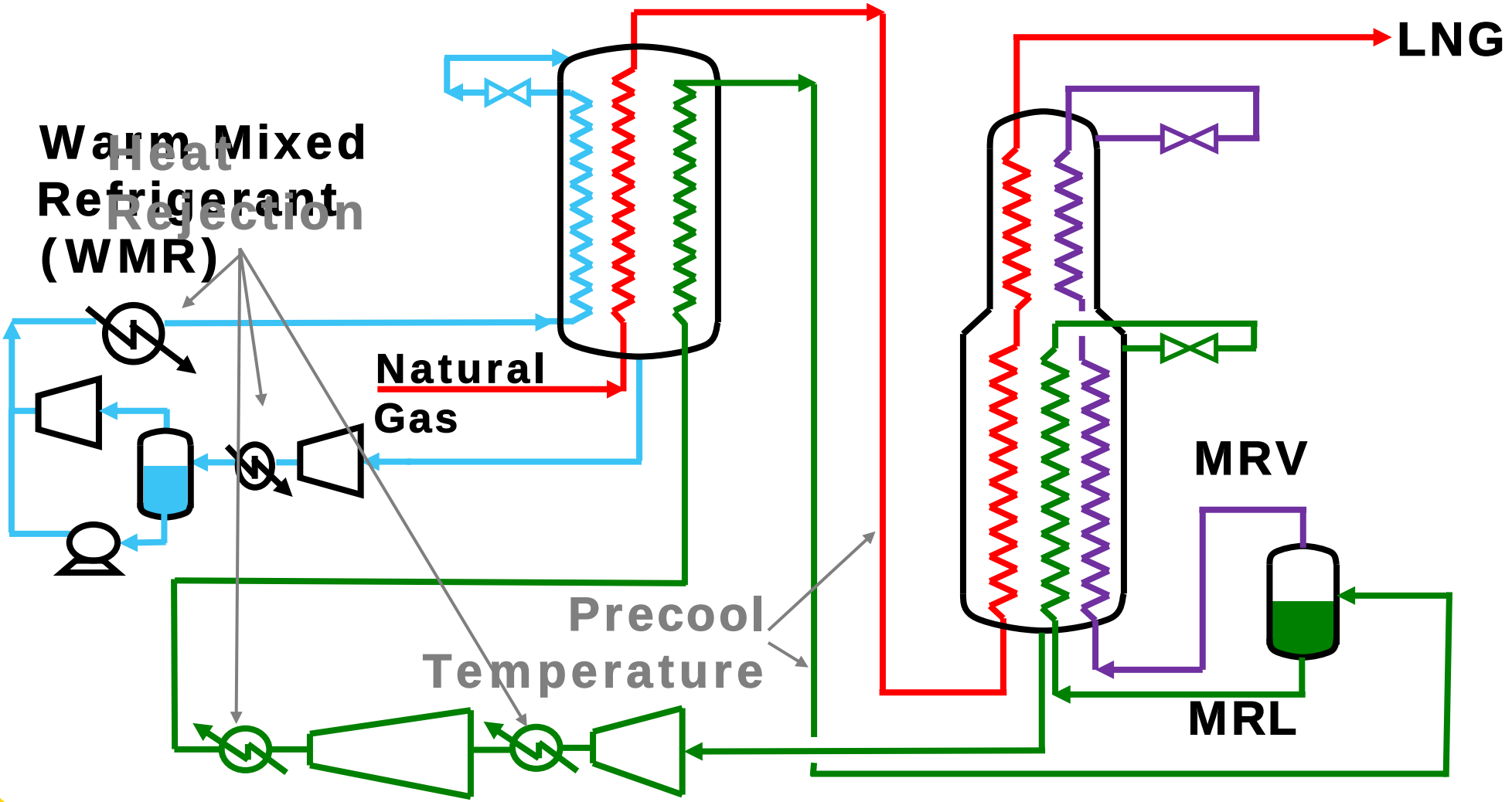
# AP-DMR™ Process



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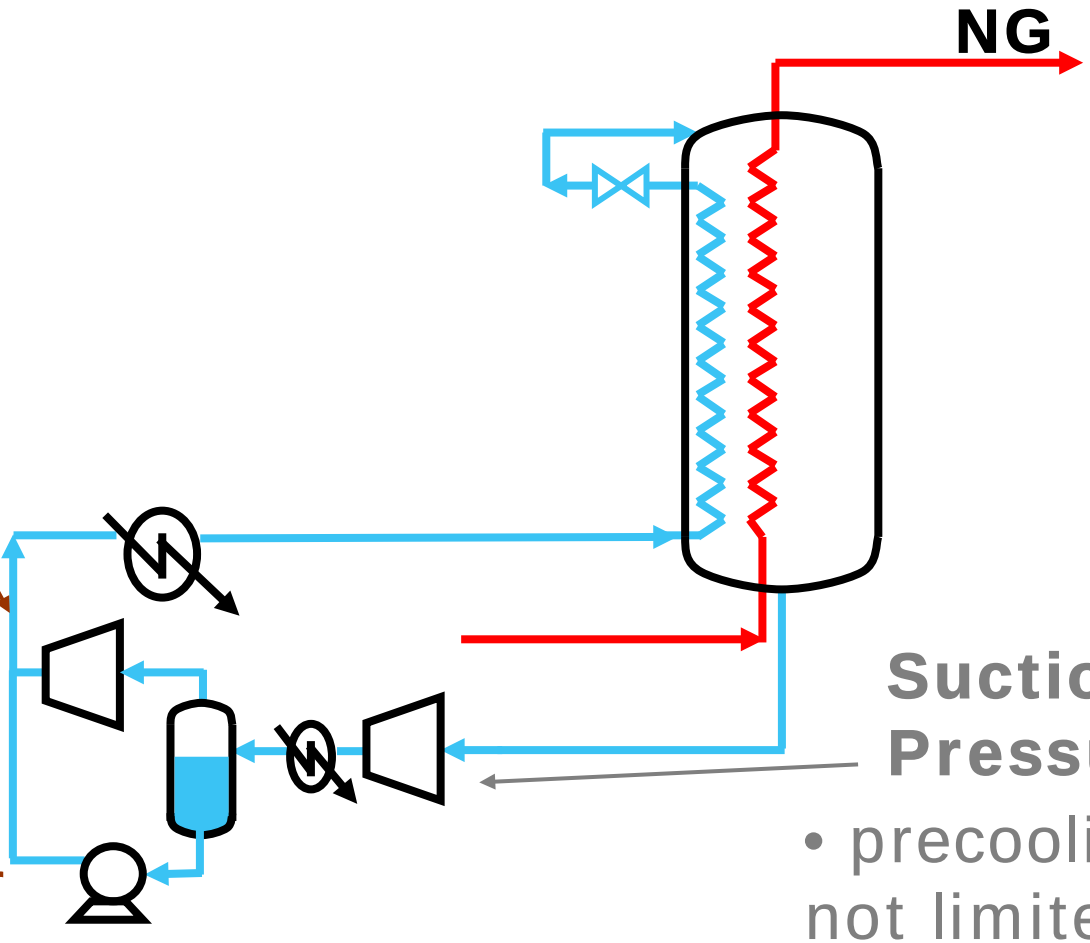
# AP-DMR™ Process




- Set by WMR condensing P
- Is a function of cooling medium T
- Effects compressor power

- precooling T not limited by min suction P

# Definition of Efficiency for Liquefaction Cycles

- Measures thermodynamic efficiency of a cycle
  - Includes compressor efficiency
  - Does not include driver efficiency

$$\eta = \frac{\text{LNG (t/h)}}{\text{Compressor Power (kw)}}$$

Compressor Power = precooling compressor power + main refrigerant compressor power



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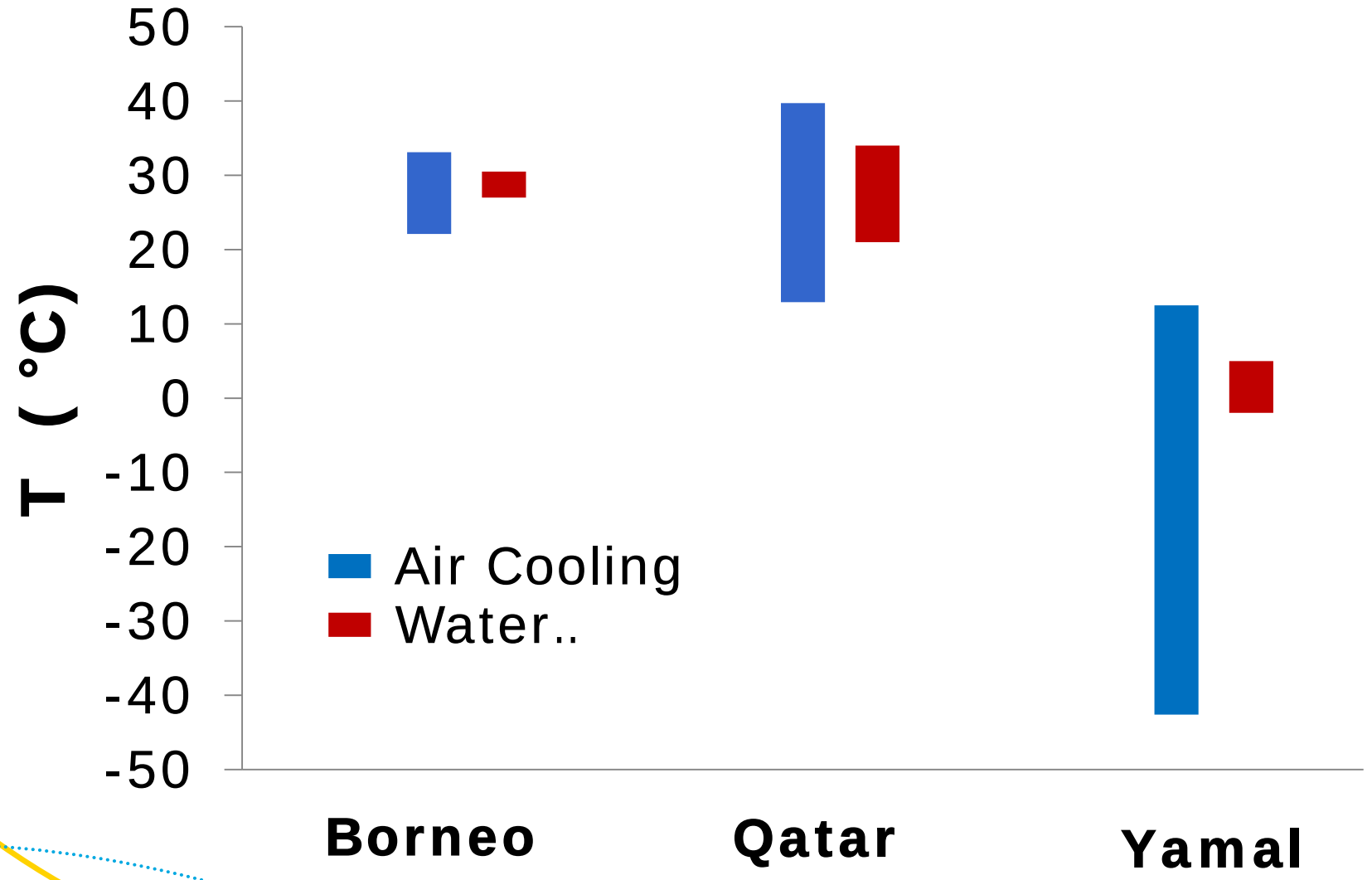
# Range in Cooling Medium Temperature



# What have we learned?

- **Arctic differs from desert and tropical climates by:**
  - Larger yearly and monthly air temperature range
  - Range in seawater temperatures is narrower than range in air temperatures

- **Production depends on available power and how effectively that power is used**
  - Available power from gas turbine increases with decreasing air temperature
  - Liquefaction process efficiency improves with colder heat sink



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# Case Studies for Arctic Climate

- Compare Two LNG Liquefaction Processes
  - AP-C3MR™ and AP-DMR™
- Generic Arctic Location
  - Ambient -20 °C to + 22 °C
- Machinery
  - 2 x Frame 7 Mechanical Drive Gas Turbine
  - Drives in parallel arrangement
  - Compressors designed for average T
  - Compressors rated for other temperatures



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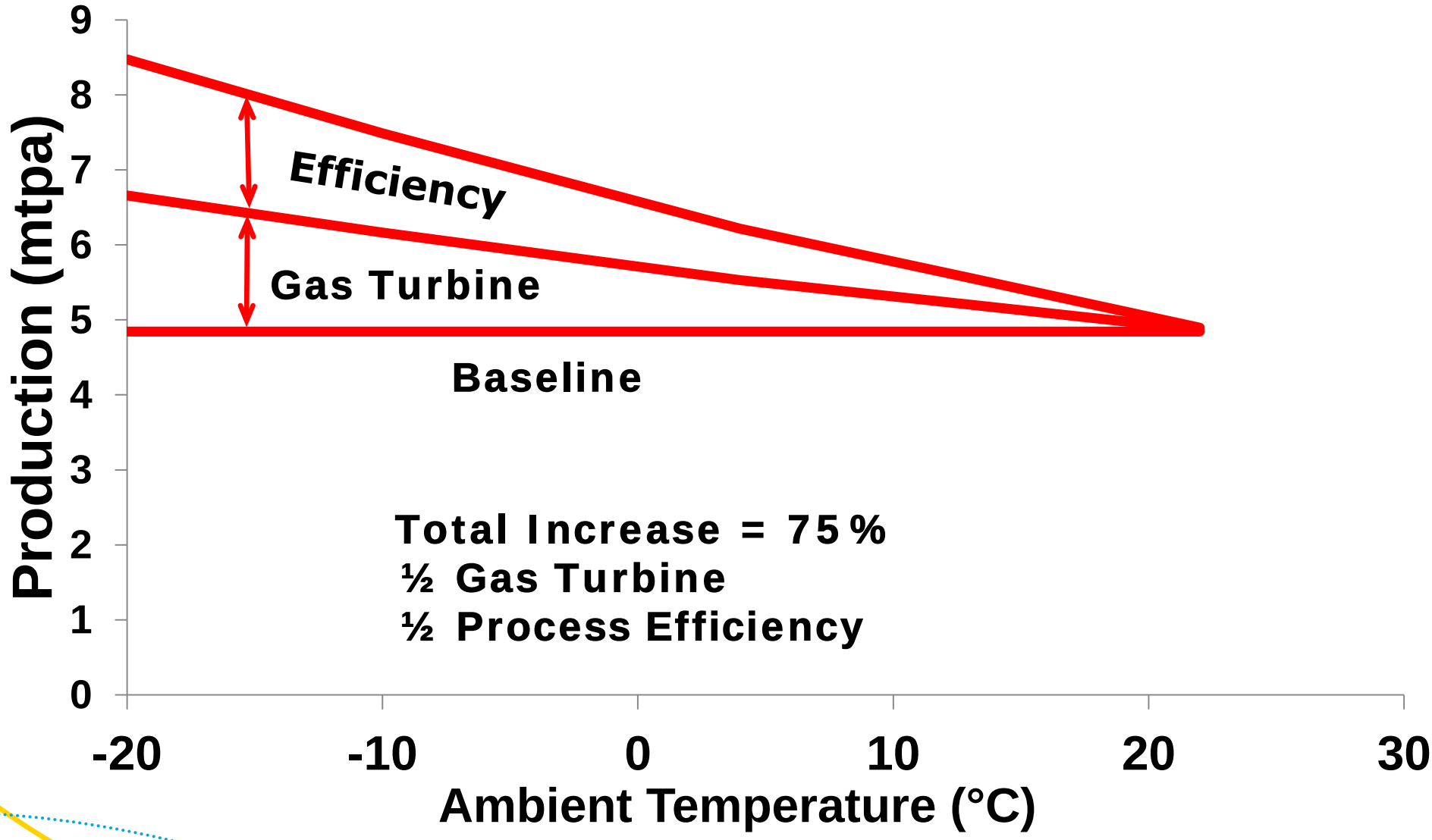
# Case 1:

1. Air Cooled
2. Unlimited Feed Gas Supply
3. Maximize Production throughout Year

# DMR Production



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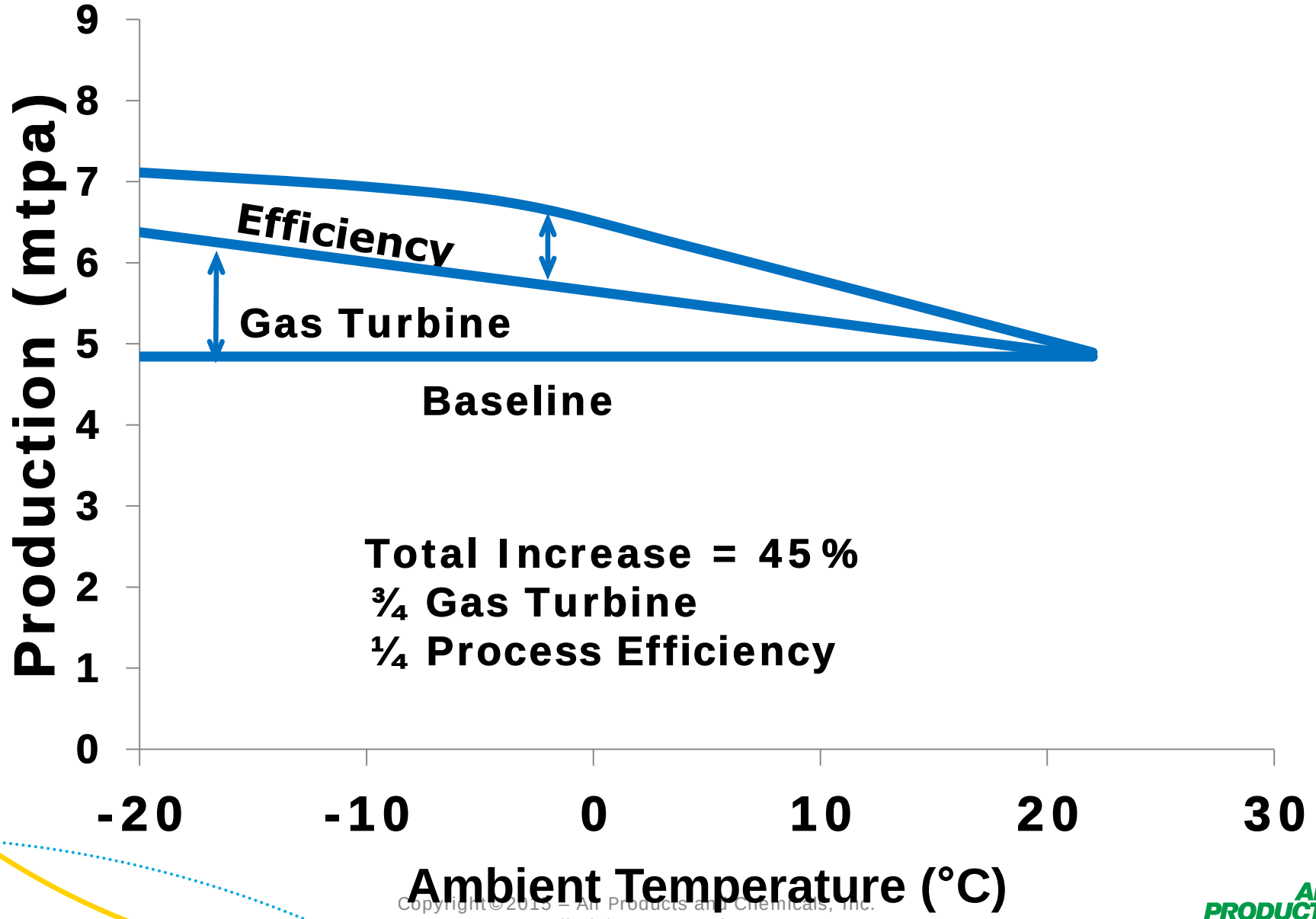
# C3MR Production



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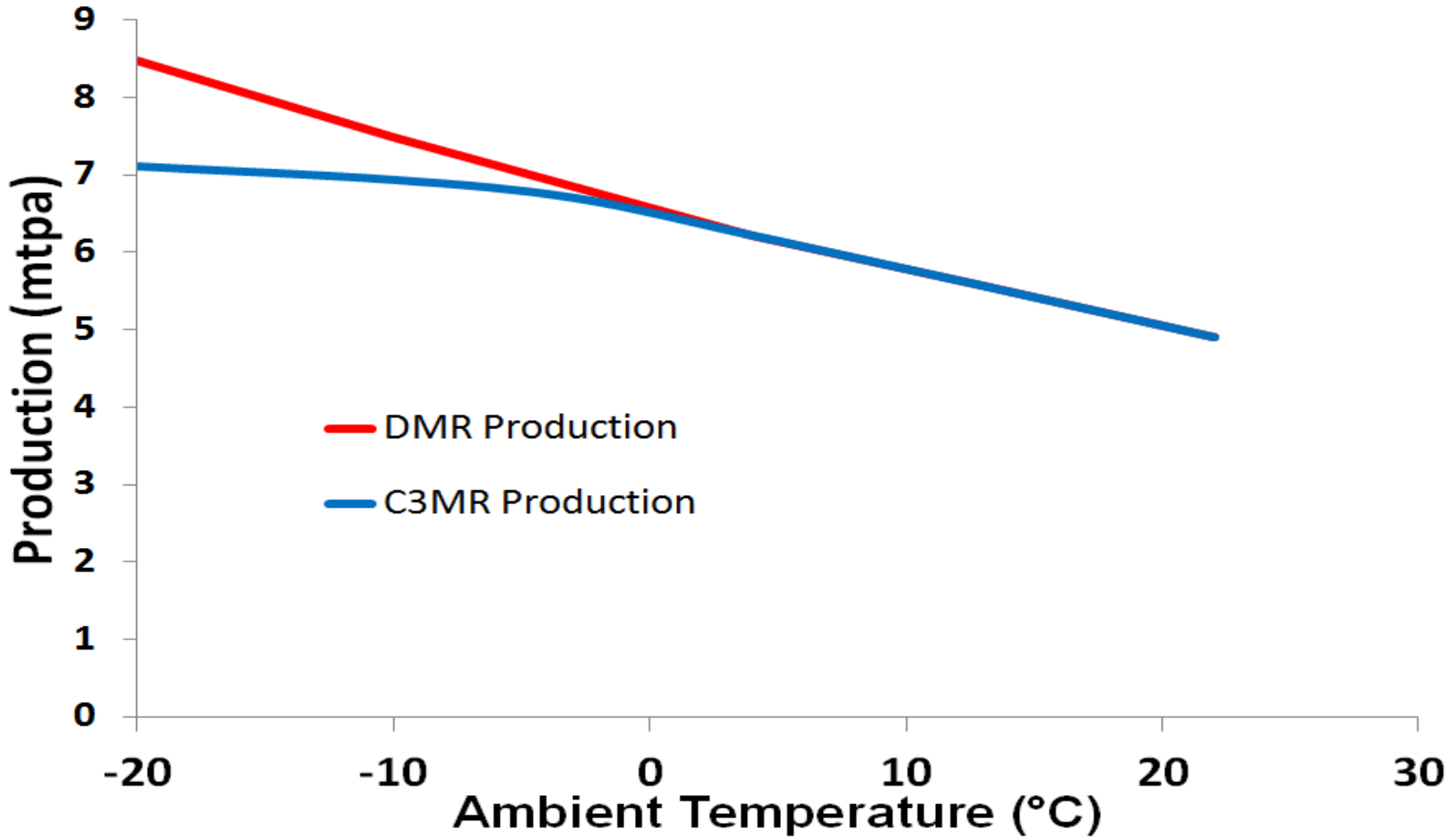
# C3MR vs. DMR
# Air Cooled Arctic Case Study



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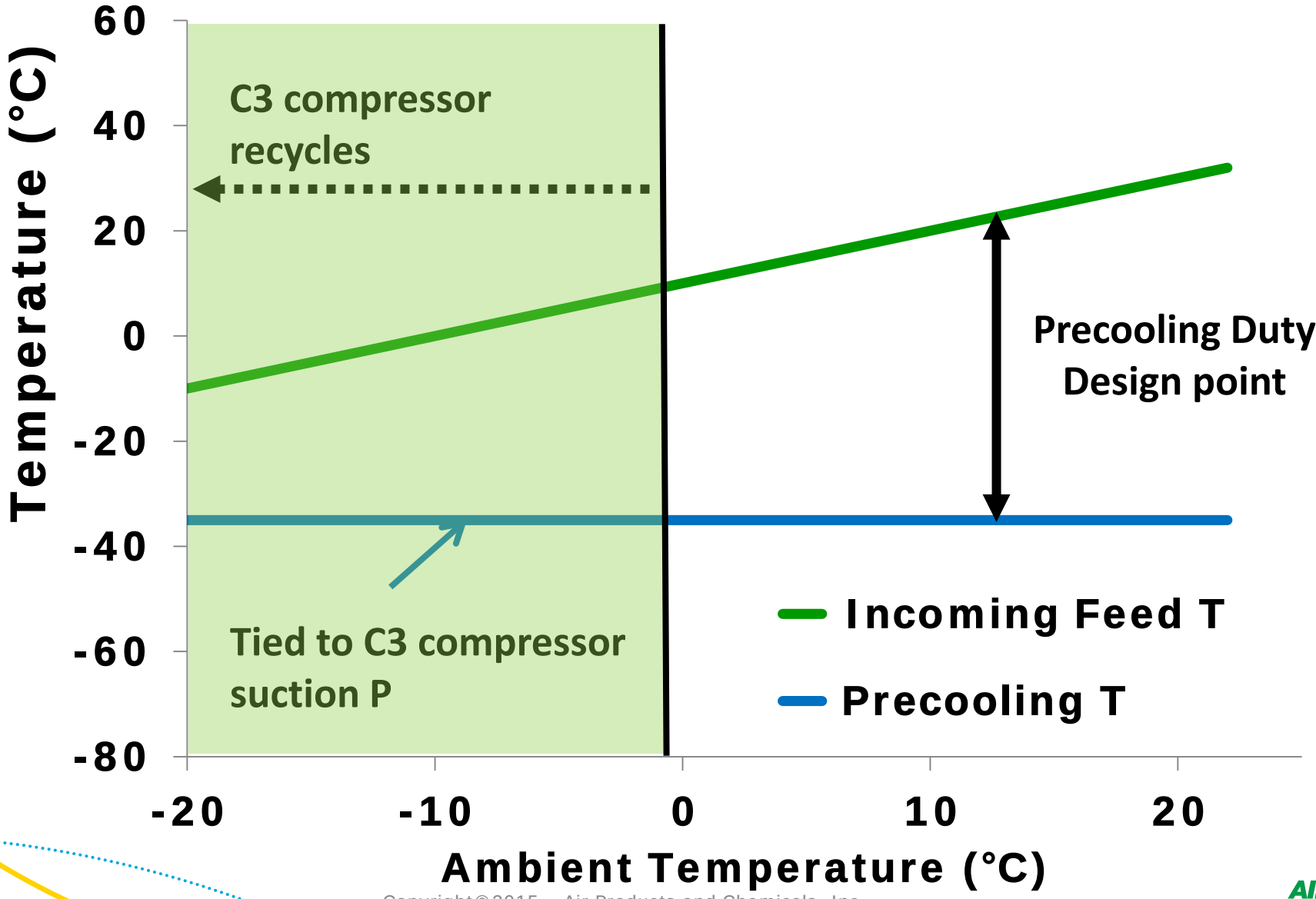
# What Causes C3MR efficiency to level off?

# Propane Precooling Duty for C3MR



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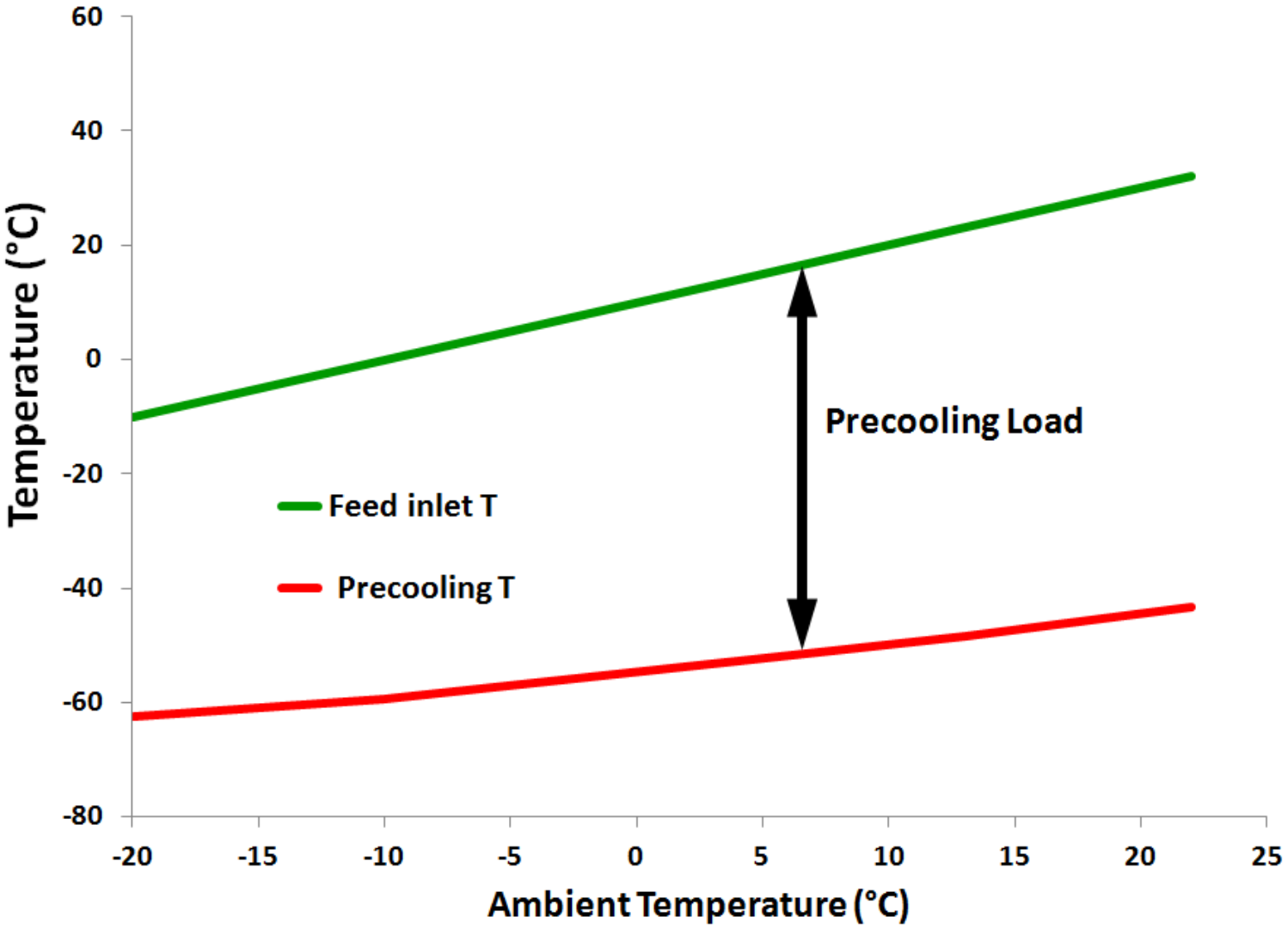
# DMR for Colder Ambient T



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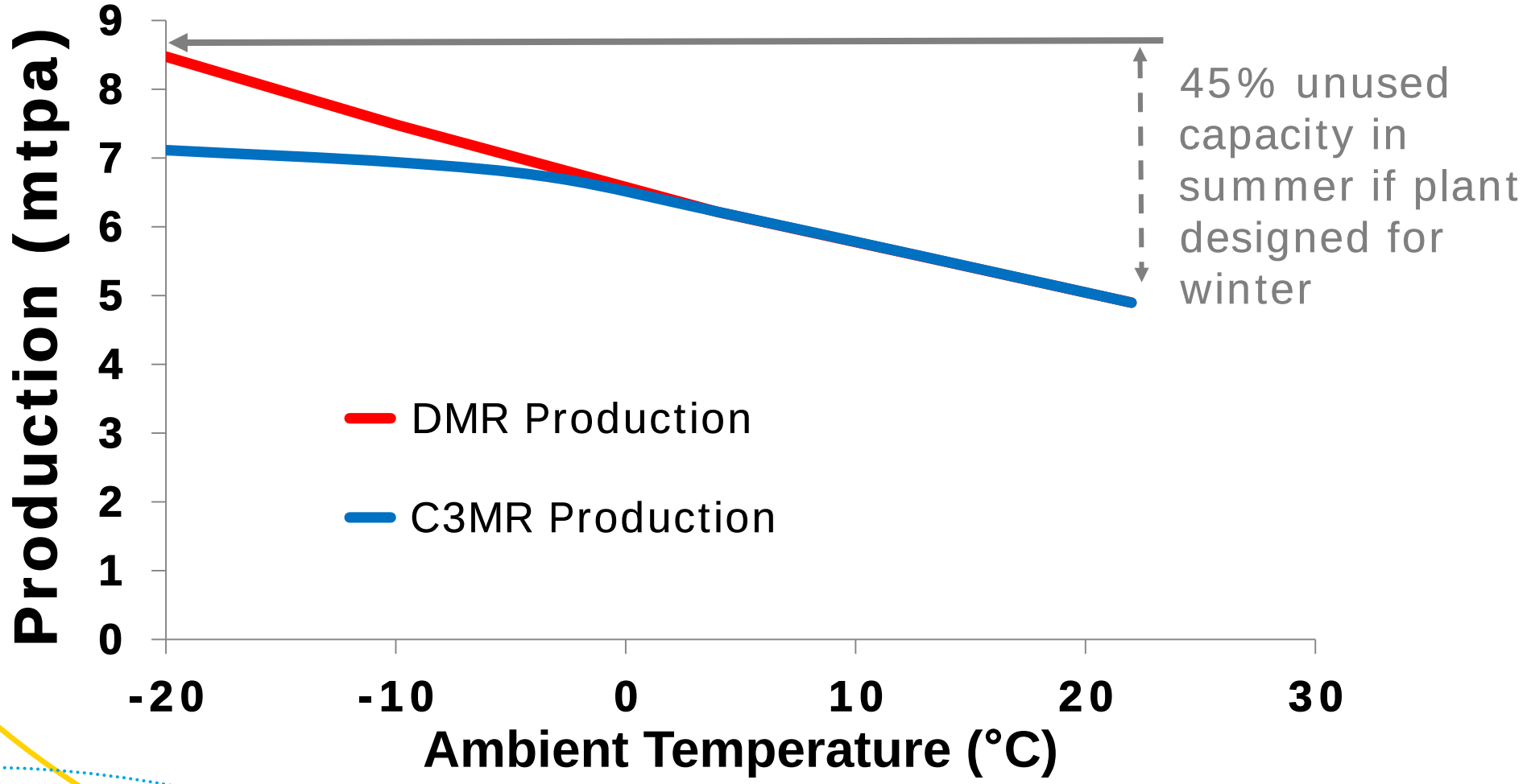
# What is cost of extra production at lower temperatures?

# DMR Production
# Air Cooled Arctic Case Study



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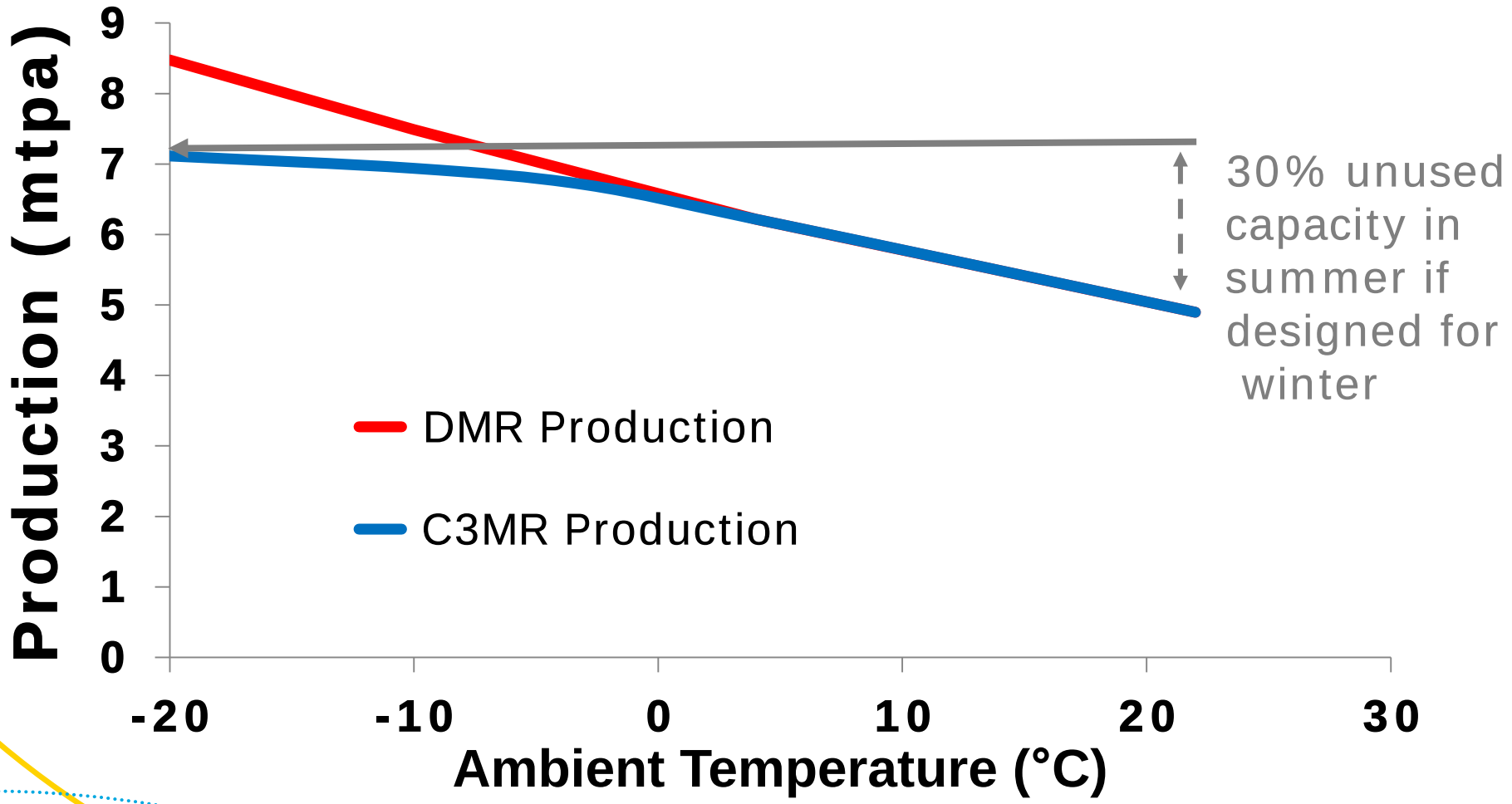
# C3MR Production
# Air Cooled Arctic Case Study



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# Case 1 Summary

- Base Assumptions
  - Air cooled
  - Unlimited feed/ maximize production year long
- Inherent assumptions:
  - Rest of plant is upsized for winter capacity (AGRU, dehydration, HHC removal, storage, shipping …)
  - Variable monthly production is economical

➔ With all these assumptions: DMR process will produce more LNG than C3MR process annually but at a cost



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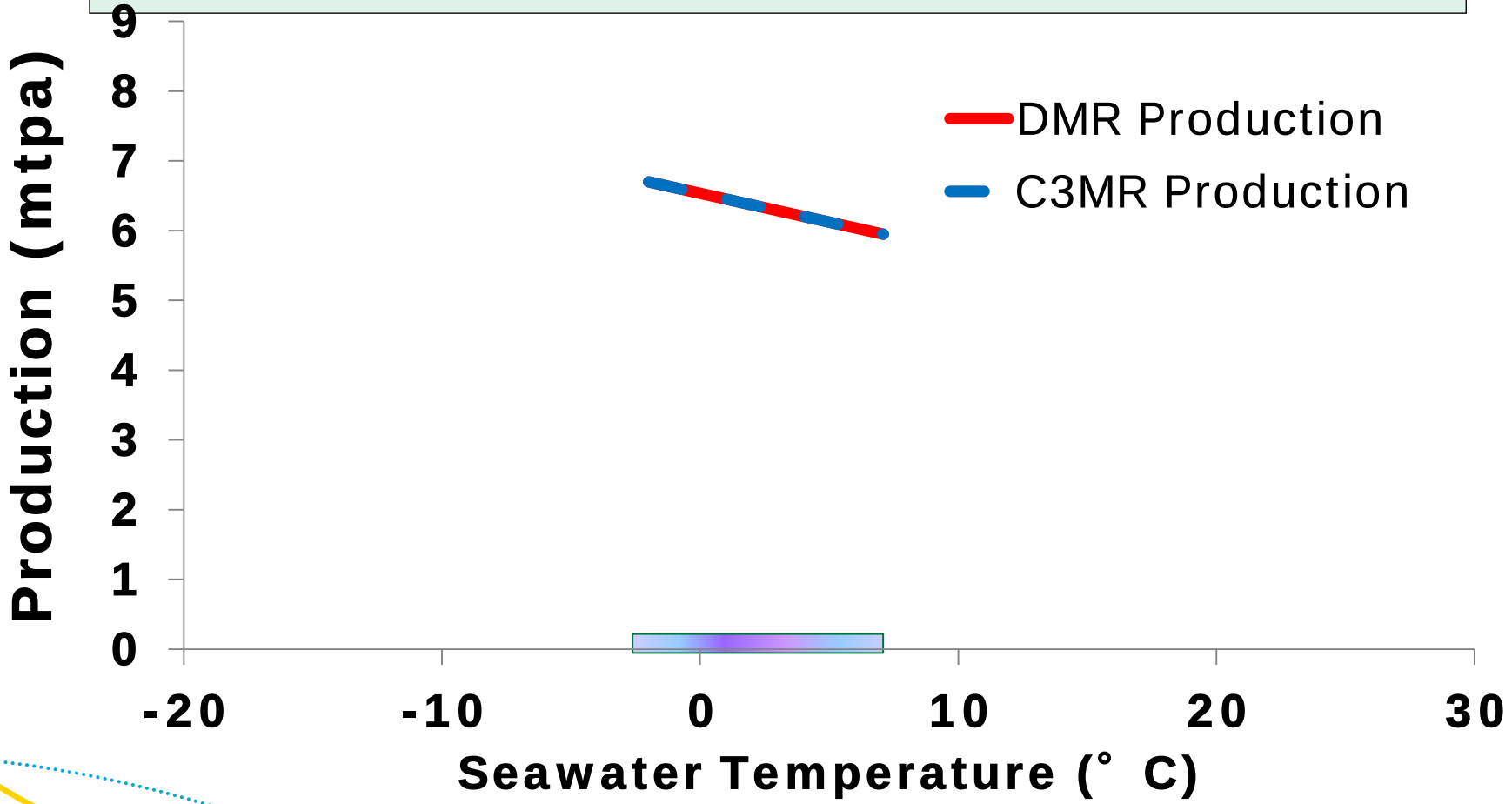
# Case 2:

1. ~~Air~~ Water Cooled
2. Unlimited Feed Gas Supply
3. Maximize Production throughout Year

# Case 2: Water Cooled, Maximize Yearly Production

**For Year Round Production C3MR = DMR**



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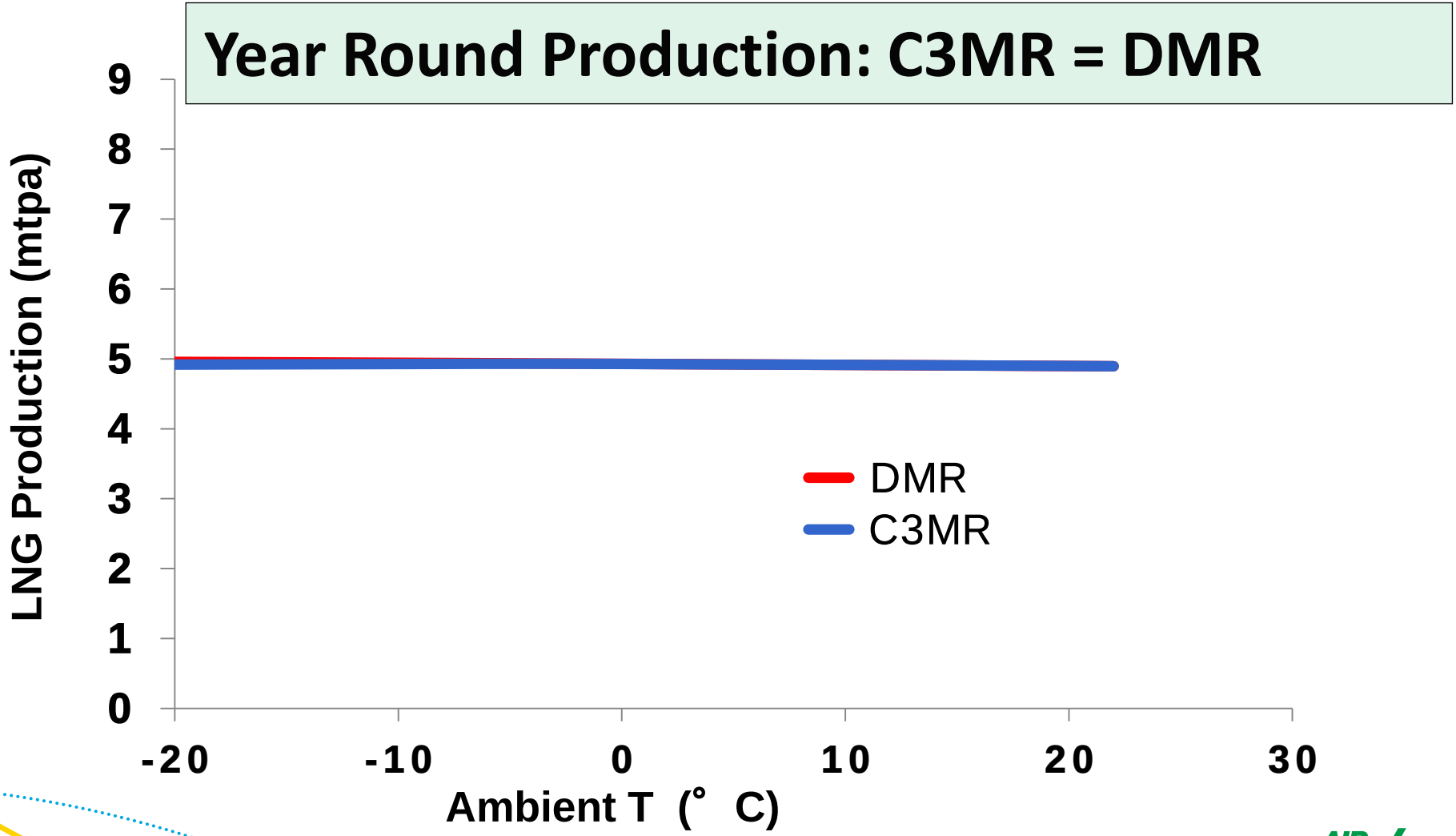
# Case 3:

1. Air Cooled
2. Fixed Feed Gas Supply
3. Maximize Production throughout Year

# Case 3: Fixed Feed, Air Cooled



# Production in Arctic Climates:

| | Air Cooled | Water Cooled |
|---|---|---|
| Unlimited feed rate | **AP-DMR™ > AP-C3MR™** *Case 1* | **AP-DMR™ = AP-C3MR™** *Case 2* |
| Fixed feed rate | **AP-DMR™ = AP-C3MR™** *Case 3* | **AP-DMR™ = AP-C3MR™** |



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# AP-DMR™ and AP-C3MR™ – Other Factors

- **Type of pre-cooling equipment**
  - Coil Wound Heat Exchanger (DMR) vs. Kettle evaporators (C3MR)
- **Equipment Count & Footprint**
- **Operating considerations**
- **Experience and reference list**
- **Capital expenditure**
- **These are very project specific, and must be evaluated for each individual project**



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# Summary

- **DMR and C3MR have same yearly production unless:**
  - Air Cooling in arctic regions
  - Project infrastructure is up-sized for more than 30% extra production in winter (pipeline, pretreatment, liquefaction, storage…)
  - LNG supply-demand are synchronized

- **Other factors affecting production**
  - Driver selection and compressor /driver configuration
  - Compressor design point
  - Precooling refrigerant condenser design
  - And many others ….

- **These critical technical choices are made early**
  - And strongly affect the project success
  - Choose them wisely!



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# Conclusion

*AP-C3MR™ and AP-DMR™ are viable liquefaction processes for arctic climates; the selection depends on project goals*



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