ARCTIC LNG PLANT DESIGN: TAKING ADVANTAGE OF THE COLD CLIMATE

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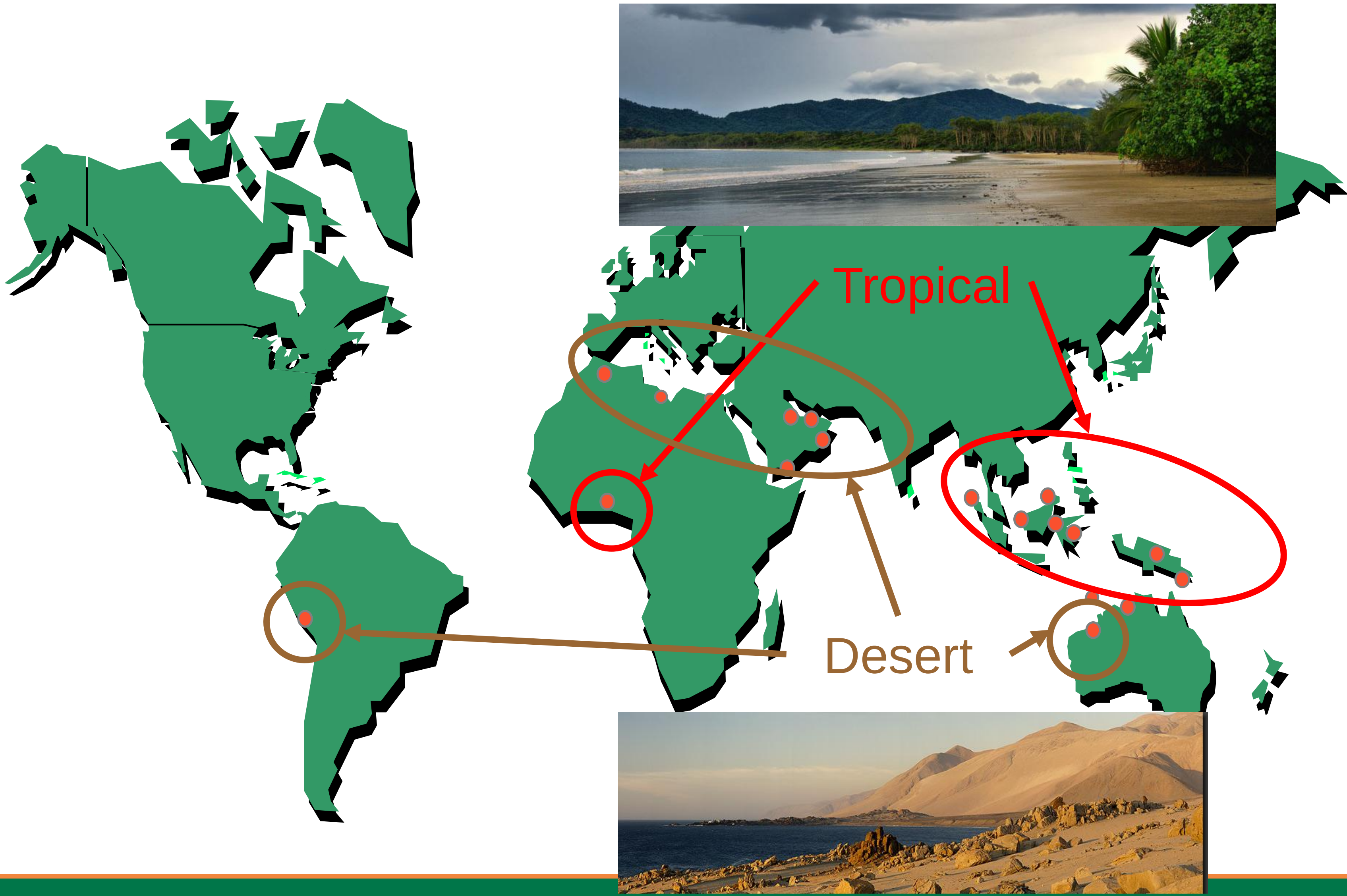
"Are Today's Proven Baseload LNG Liquefaction Processes Acceptable for Cold Climates?"

To Answer:

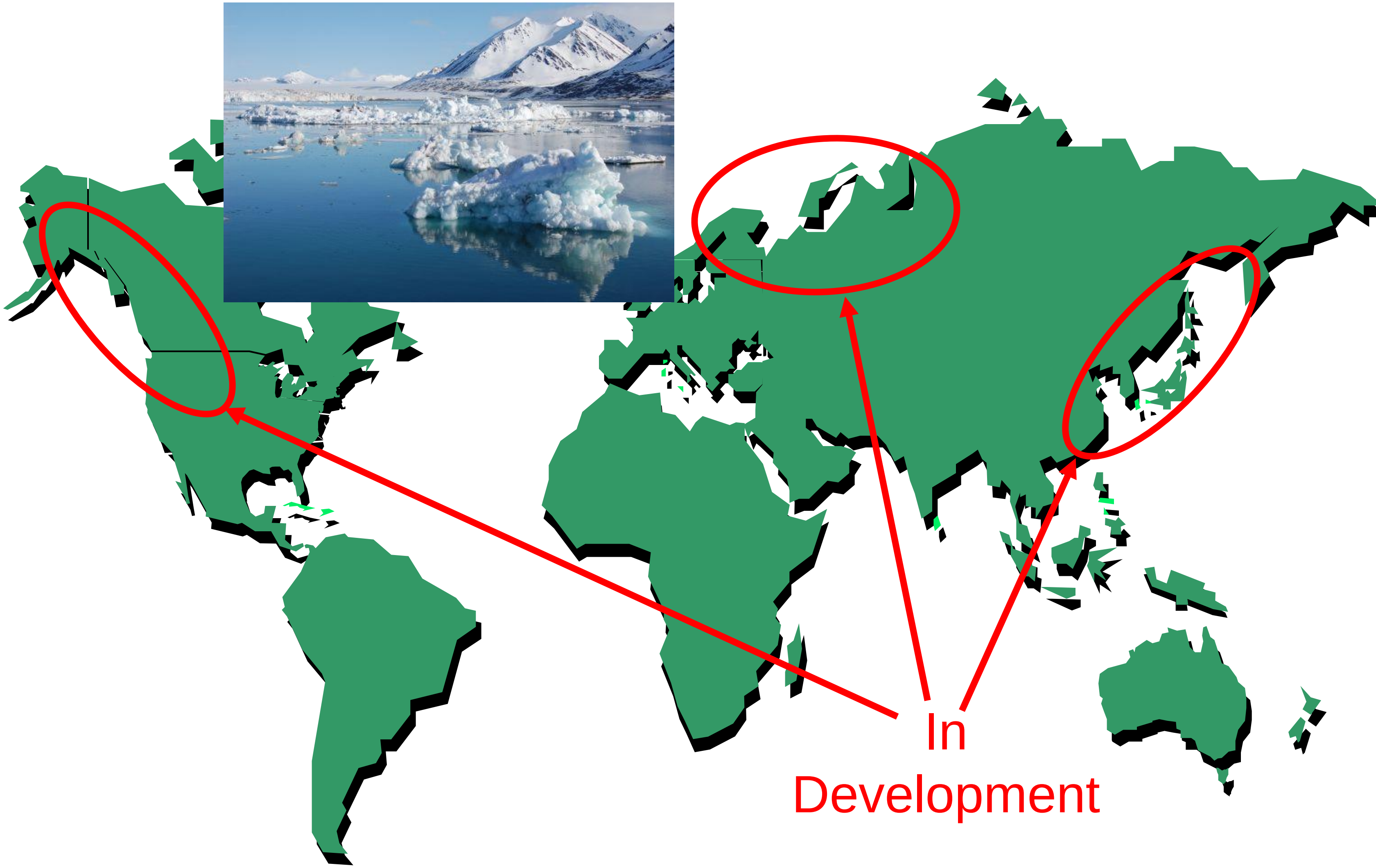
- **Current & future baseload LNG locations**
- **LNG liquefaction processes**
- **Characteristics of arctic climates**
- **How each process performs in arctic climates**
- **Summary**

Air Products Baseload LNG Trains

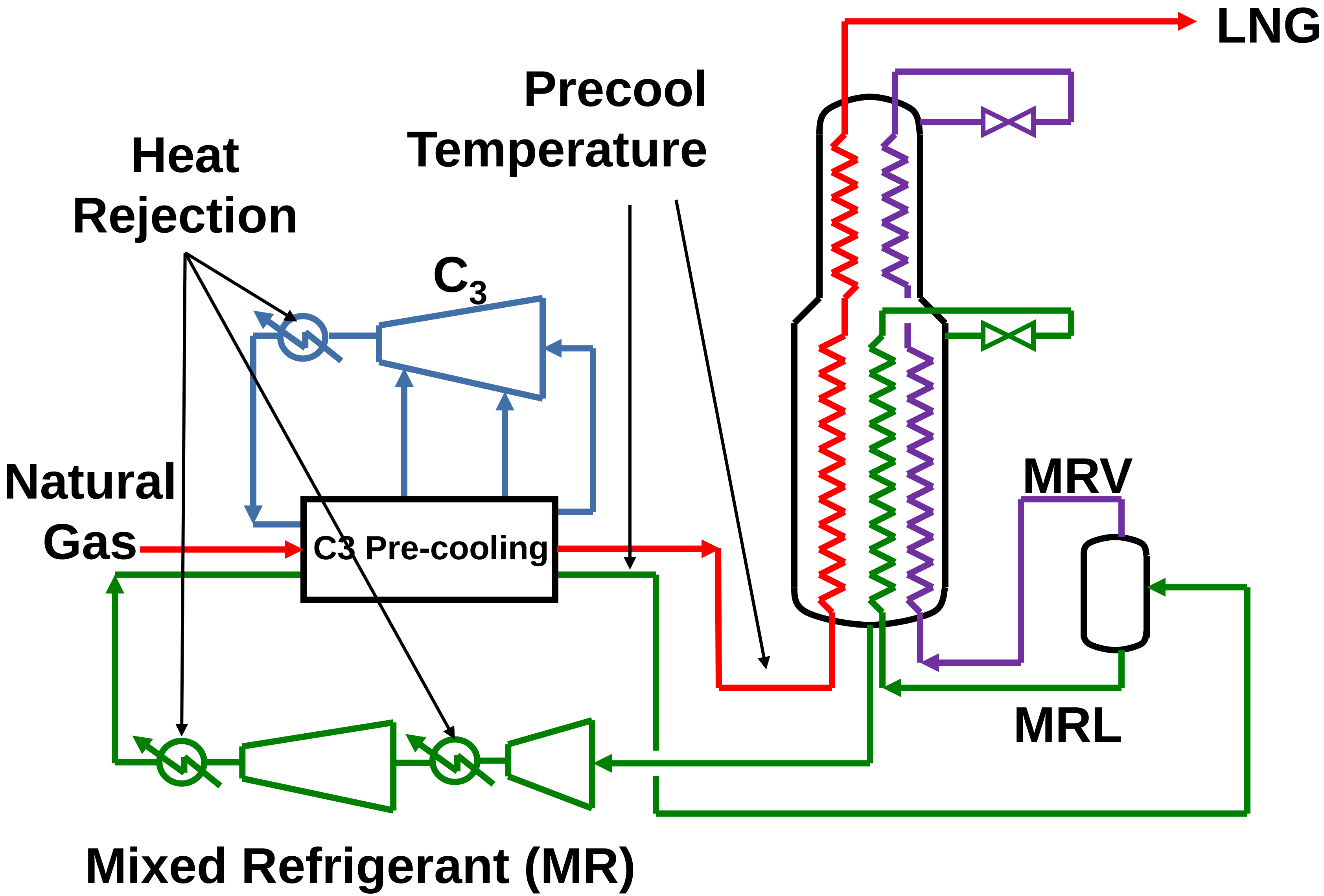


Industry Arctic Plants

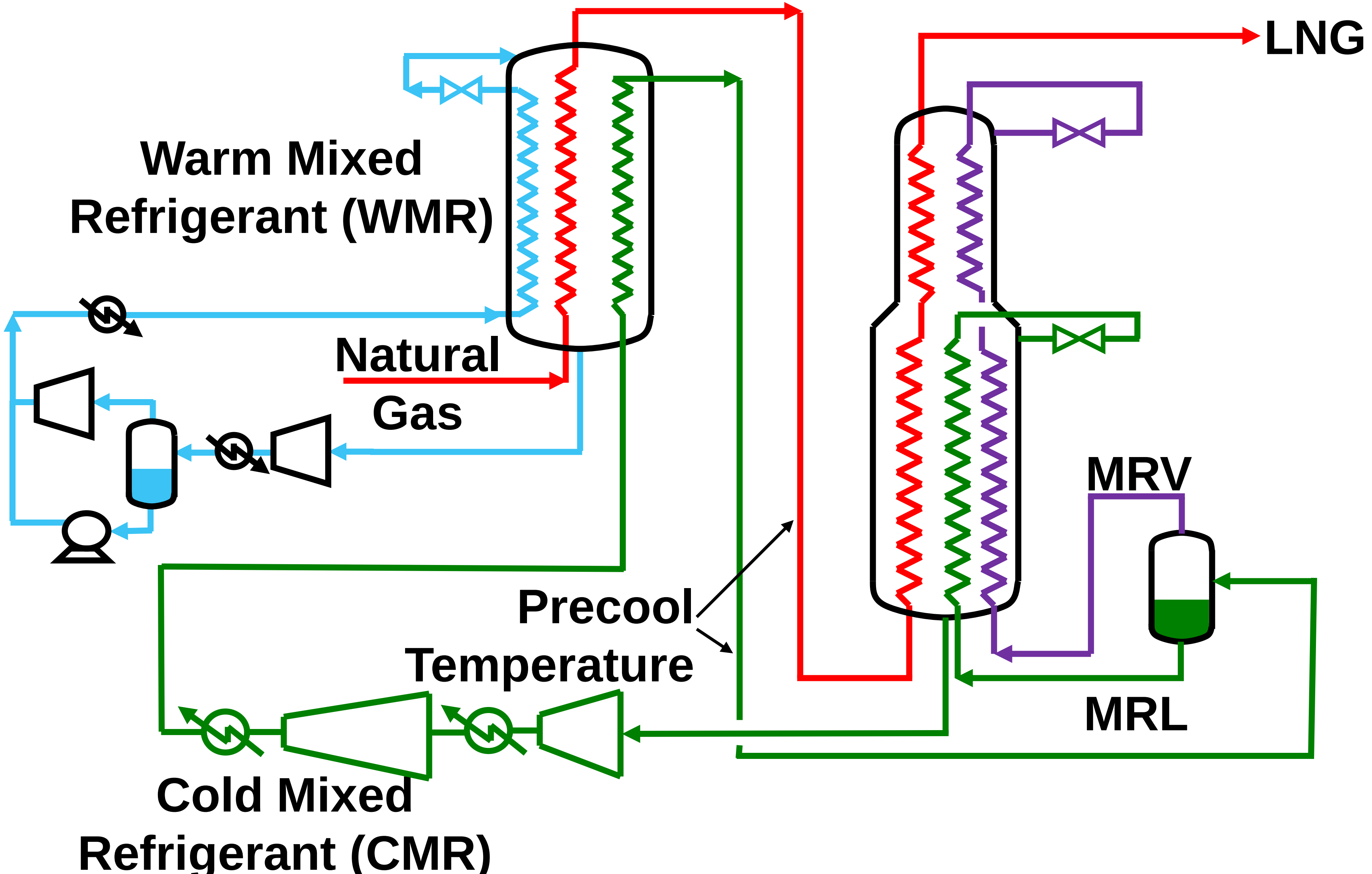
Industry Arctic Plants



AP-C3MR^{TM} Process



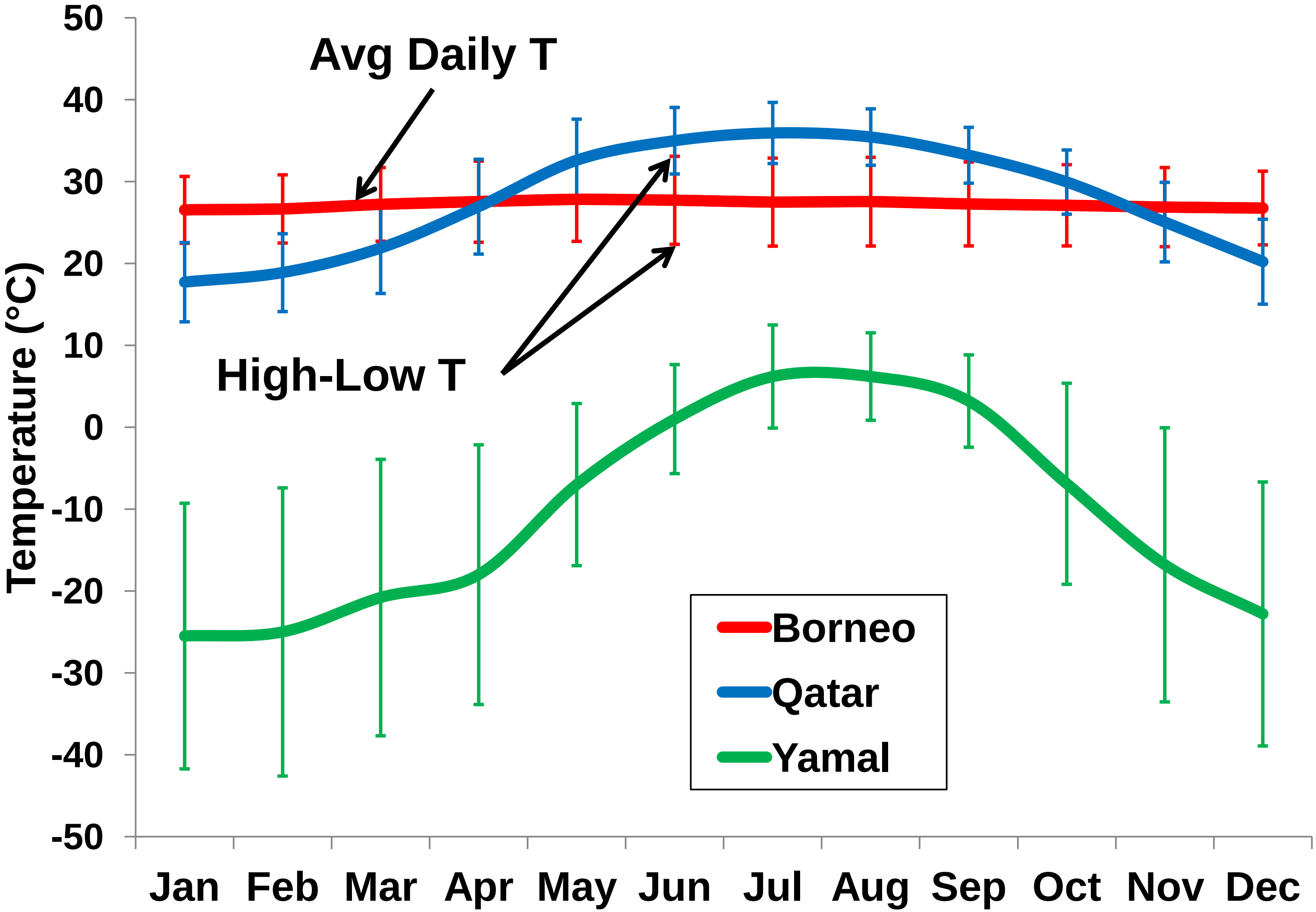
AP-DMR™ Process



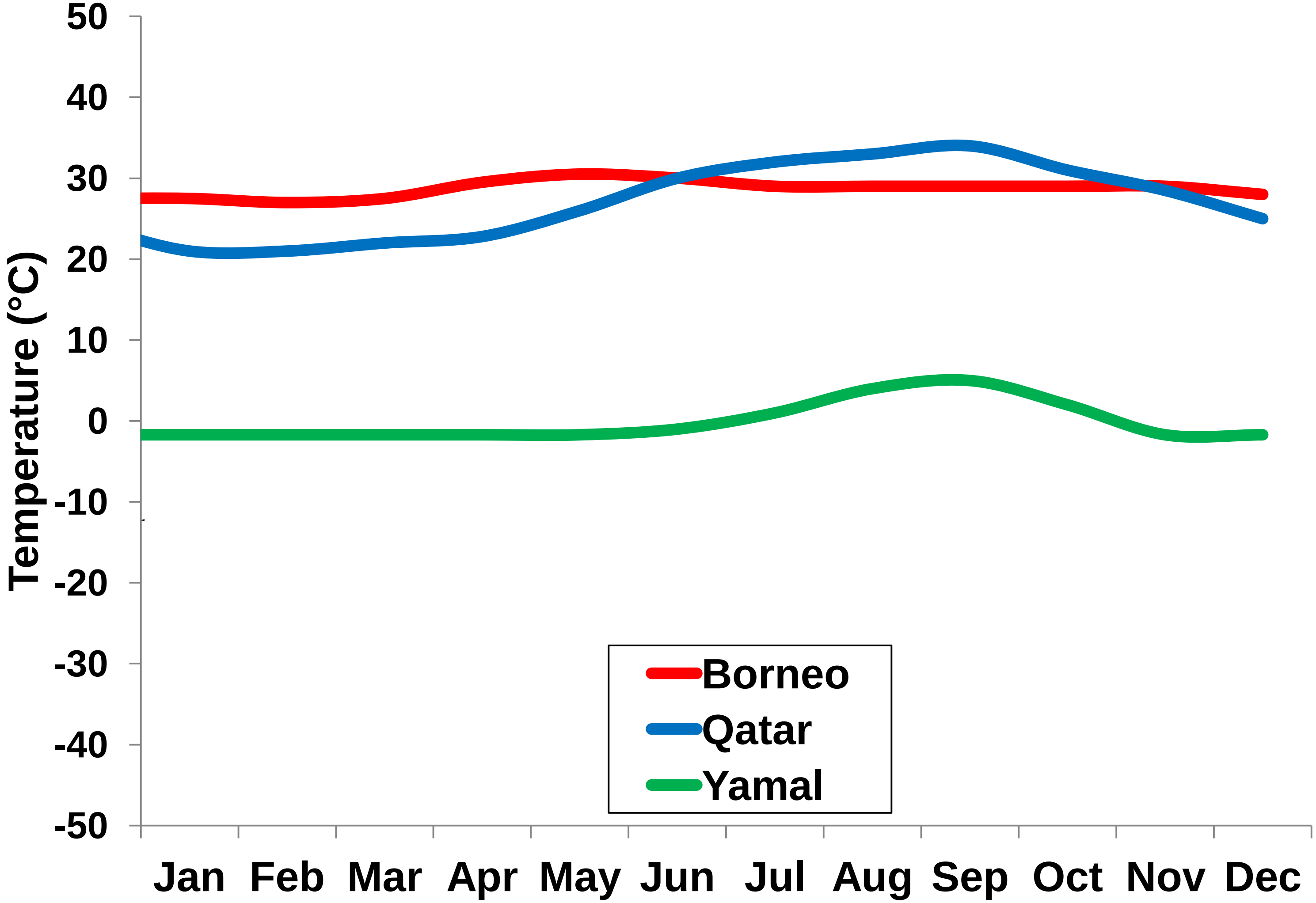
What Makes an Arctic Location Different?

- 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 freeze over
  - Problem for shipping
- It's Cold!
  - Cold cooling medium for process heat sink
  - Cold air to gas turbine drive

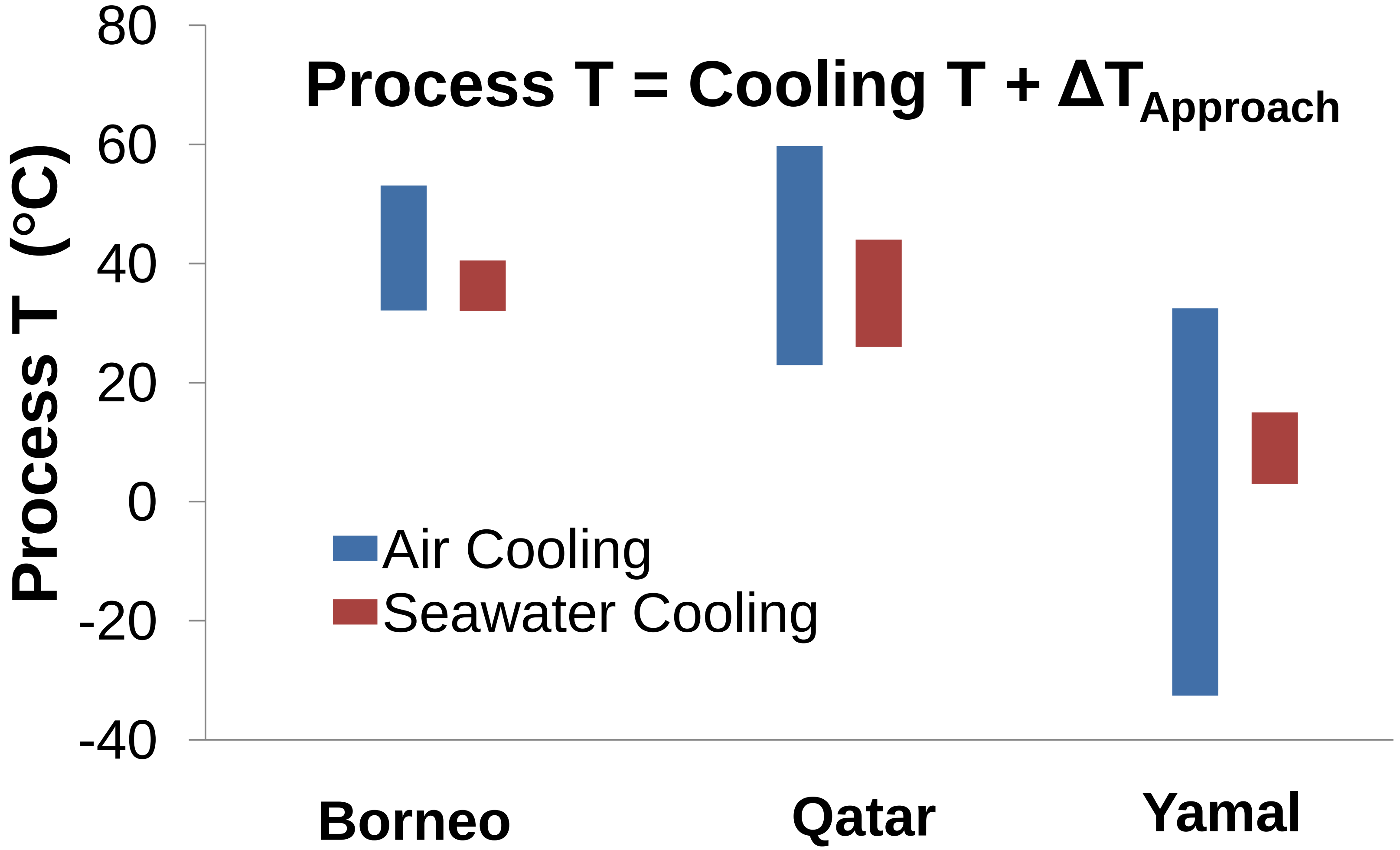
Yearly Air Temperature Trend



Yearly Seawater Temperature Trend



Process Temperatures Yearly Range



Case Study
Arctic Climate

- Compare two LNG Liquefaction Processes
  - AP-C3MR™ and AP-DMR™
- Generic Arctic Location, Ambient -20°C to +22°C
- Compressors
  - 2 x Frame 7 Mechanical Drive Gas Turbine
  - Each GT drives 50% compression string
  - Design compressors at average T
    - Rate for other conditions
- Air Cooling

Case Study
Arctic Climate (cont)

- **Unlimited Feed Rate**
  - **Maximize LNG using all available gas turbine power**

What is Effect of Cold Ambient?

- **LNG Production depends on**
  - **How much power is available**
  - **How effectively the power is used**

What is Effect of Cold Ambient?

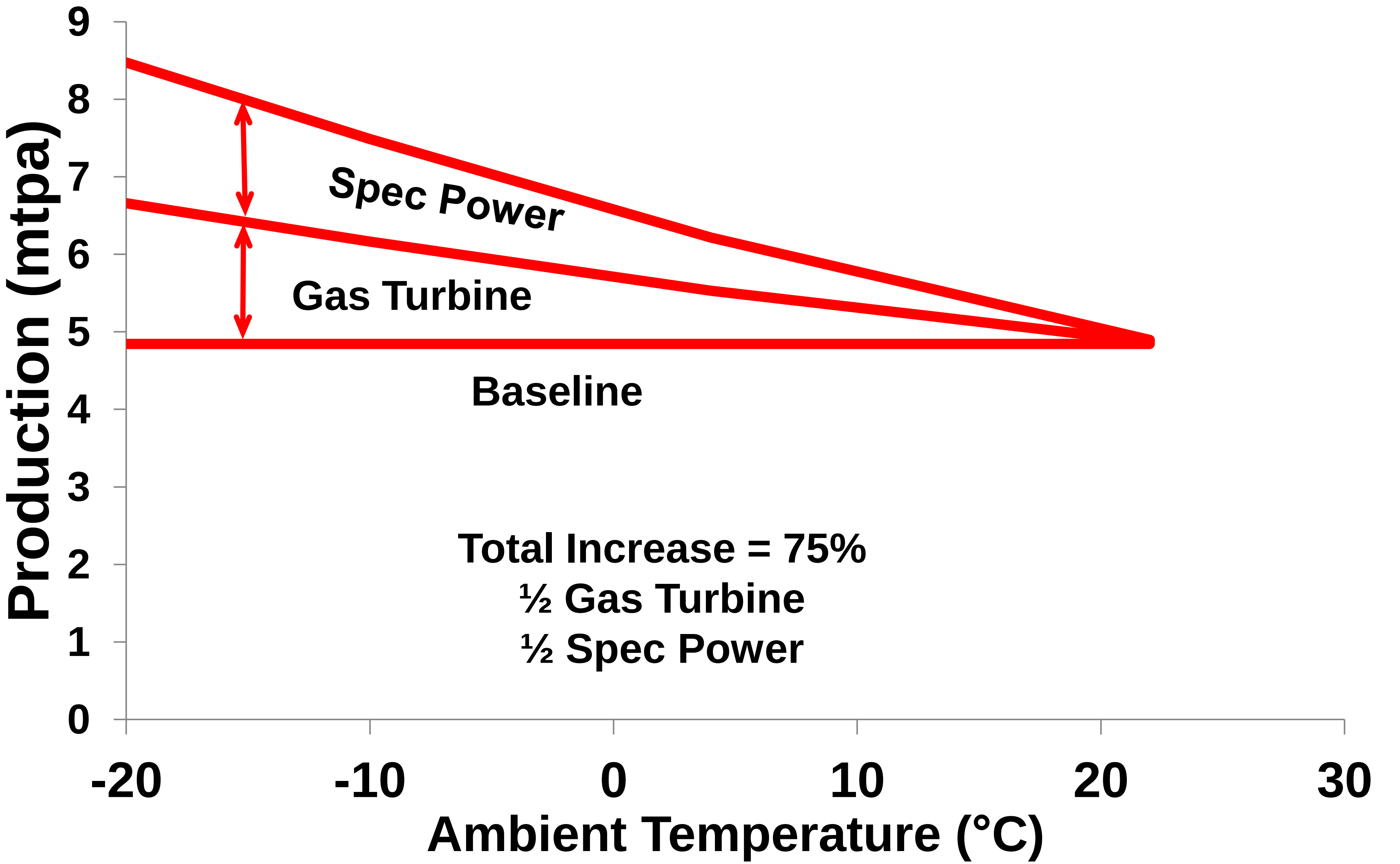
- $$LNG = \frac{P_{Avail}}{P_{Spec}}$$

  LNG = production (t/hr)
  P_{Avail} =Available power (kW)
  P_{Spec} = Liquefier spec power (kWh/tonne)

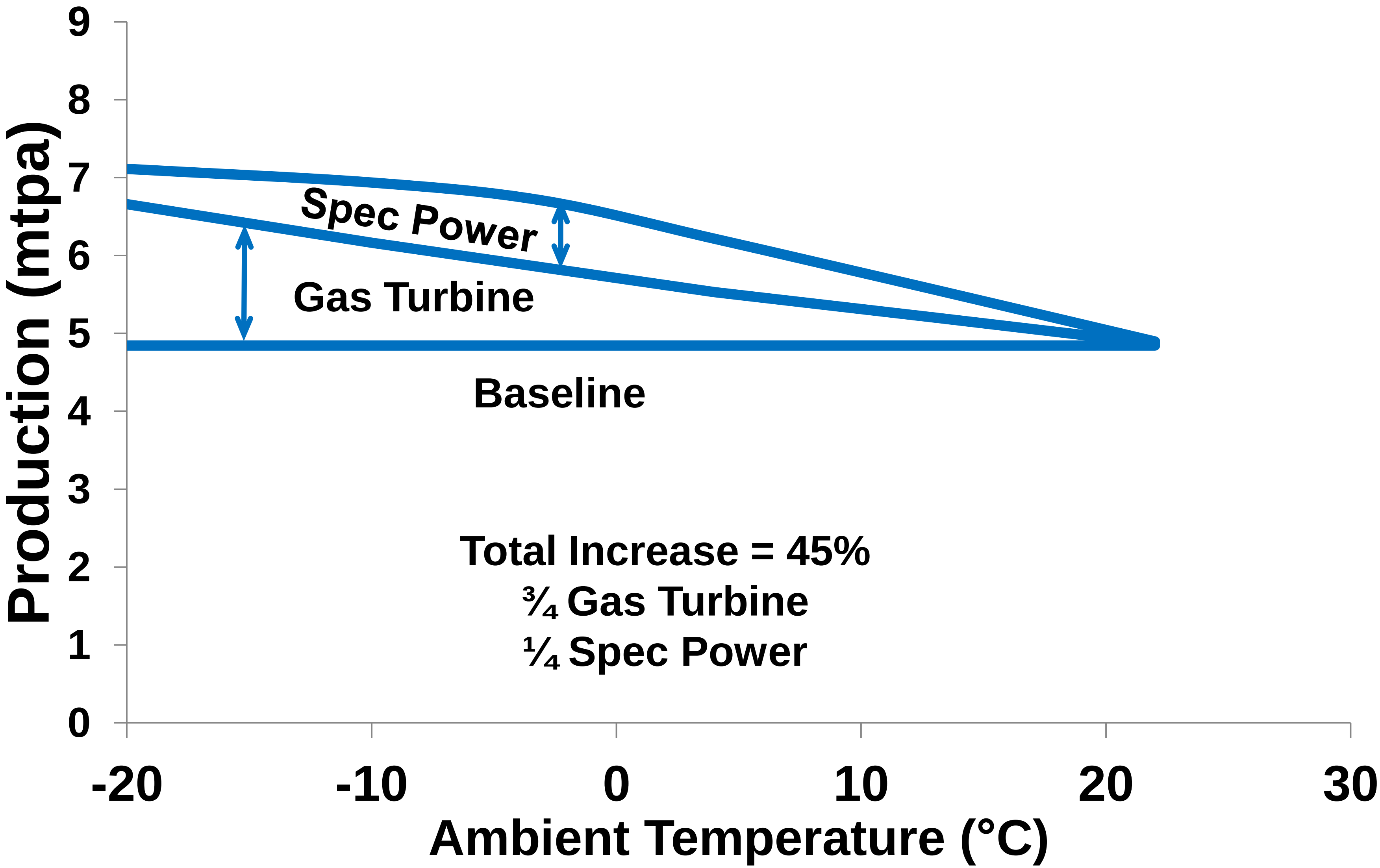
- Colder air T raises LNG production by
  - Increasing P_{Avail}
  - Improving (lowering) P_{Spec}

$$LNG \uparrow = \frac{kW \uparrow}{SP \downarrow}$$

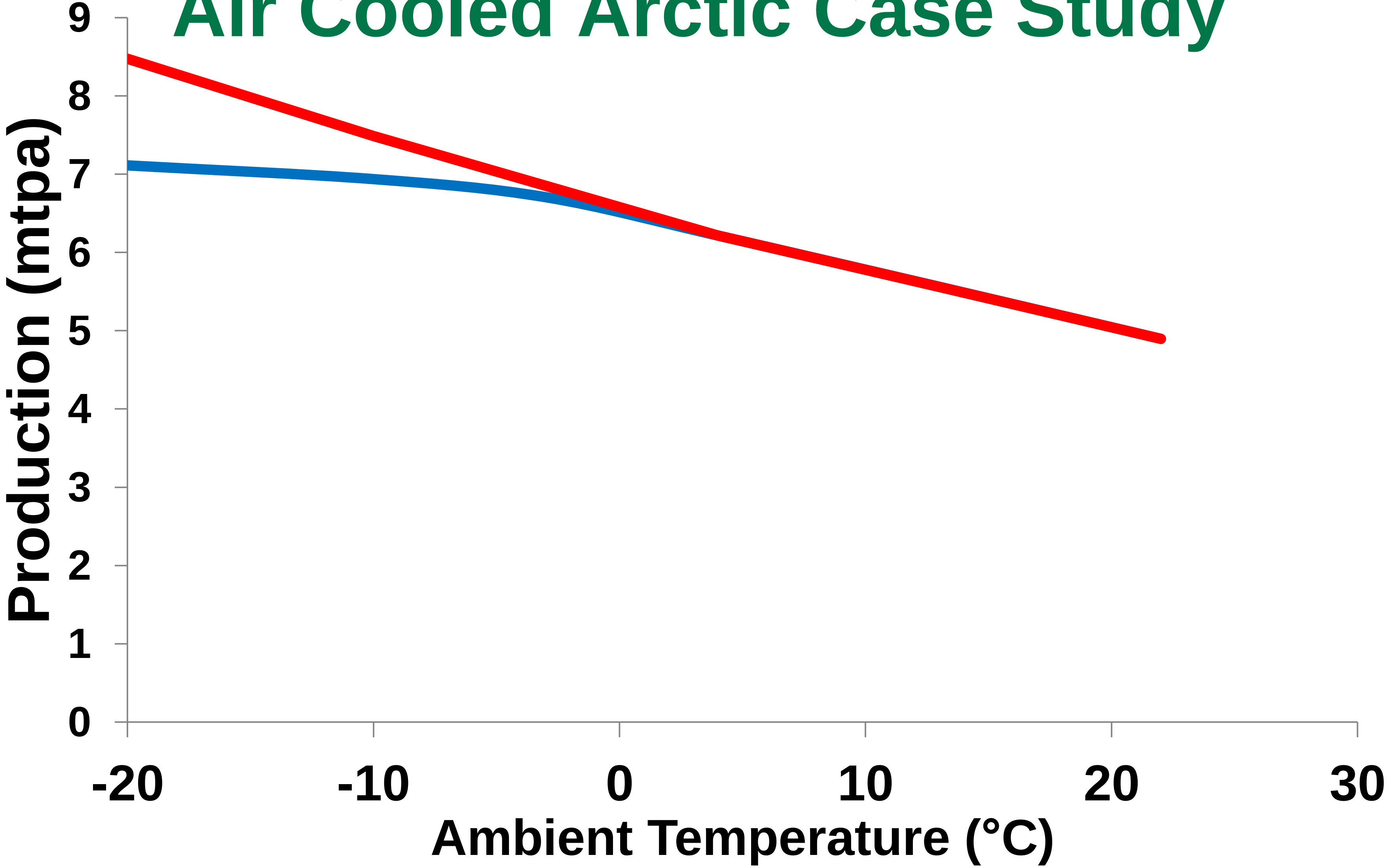
DMR Production



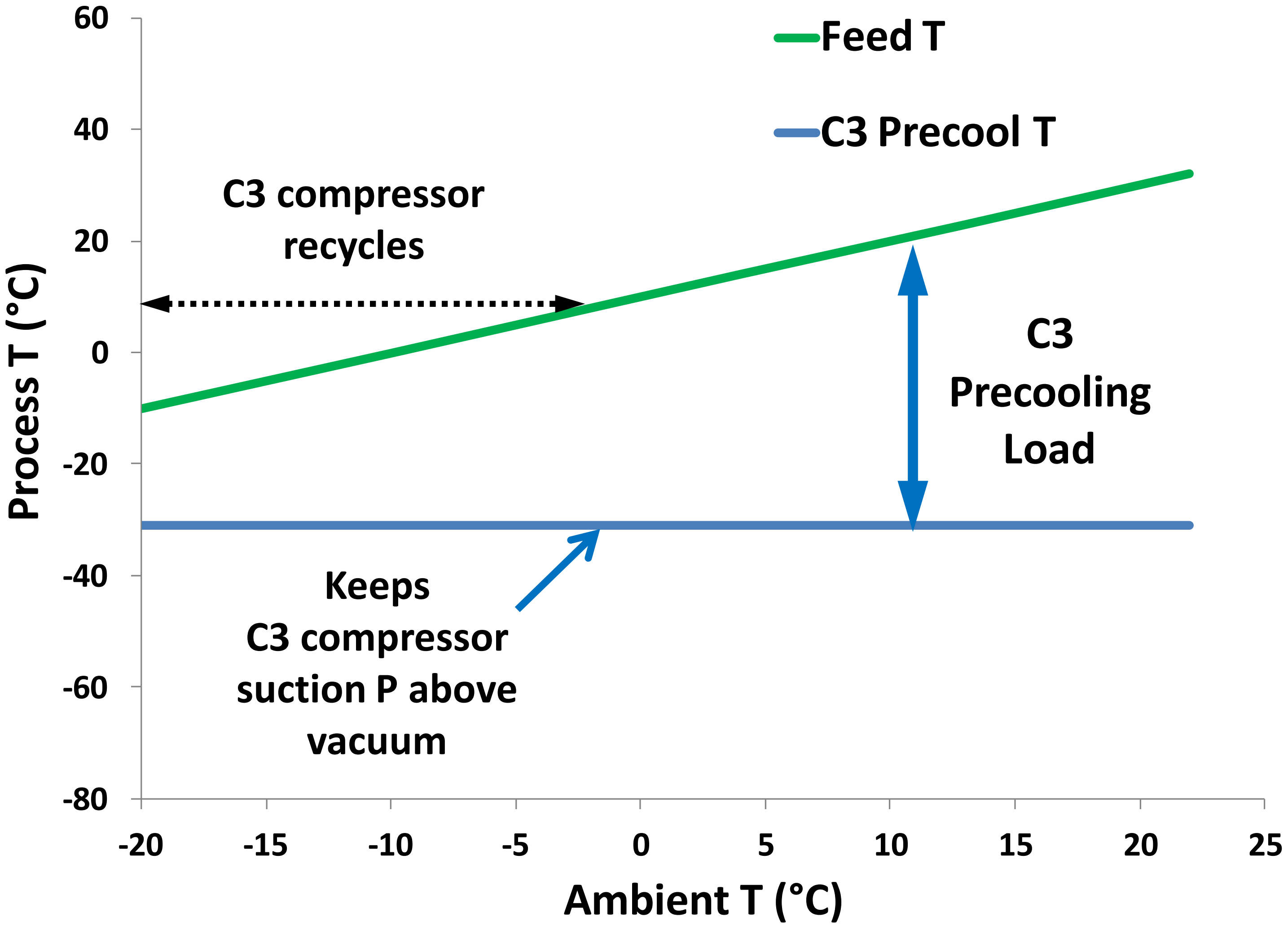
C3MR Production



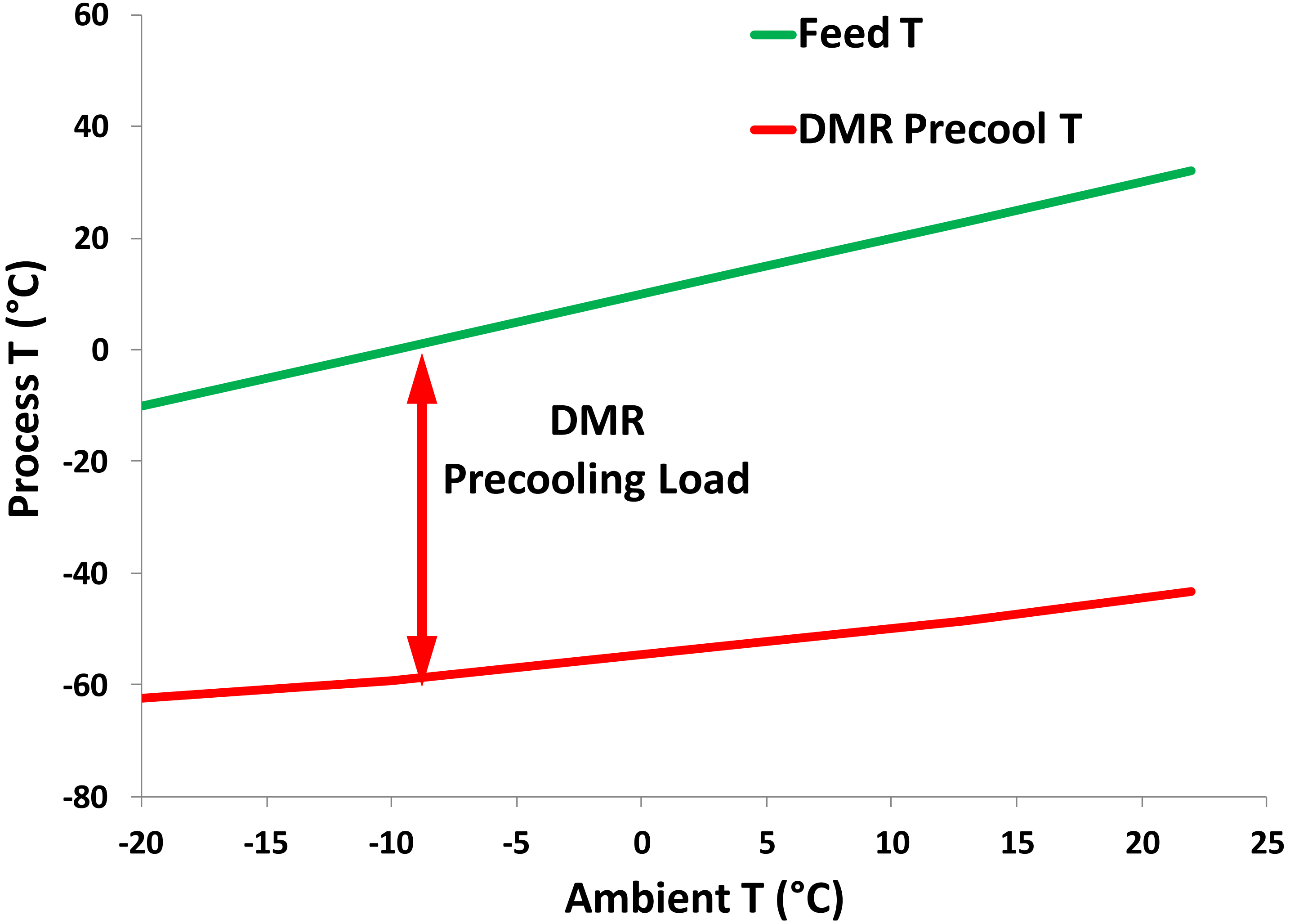
C3MR vs. DMR
Air Cooled Arctic Case Study



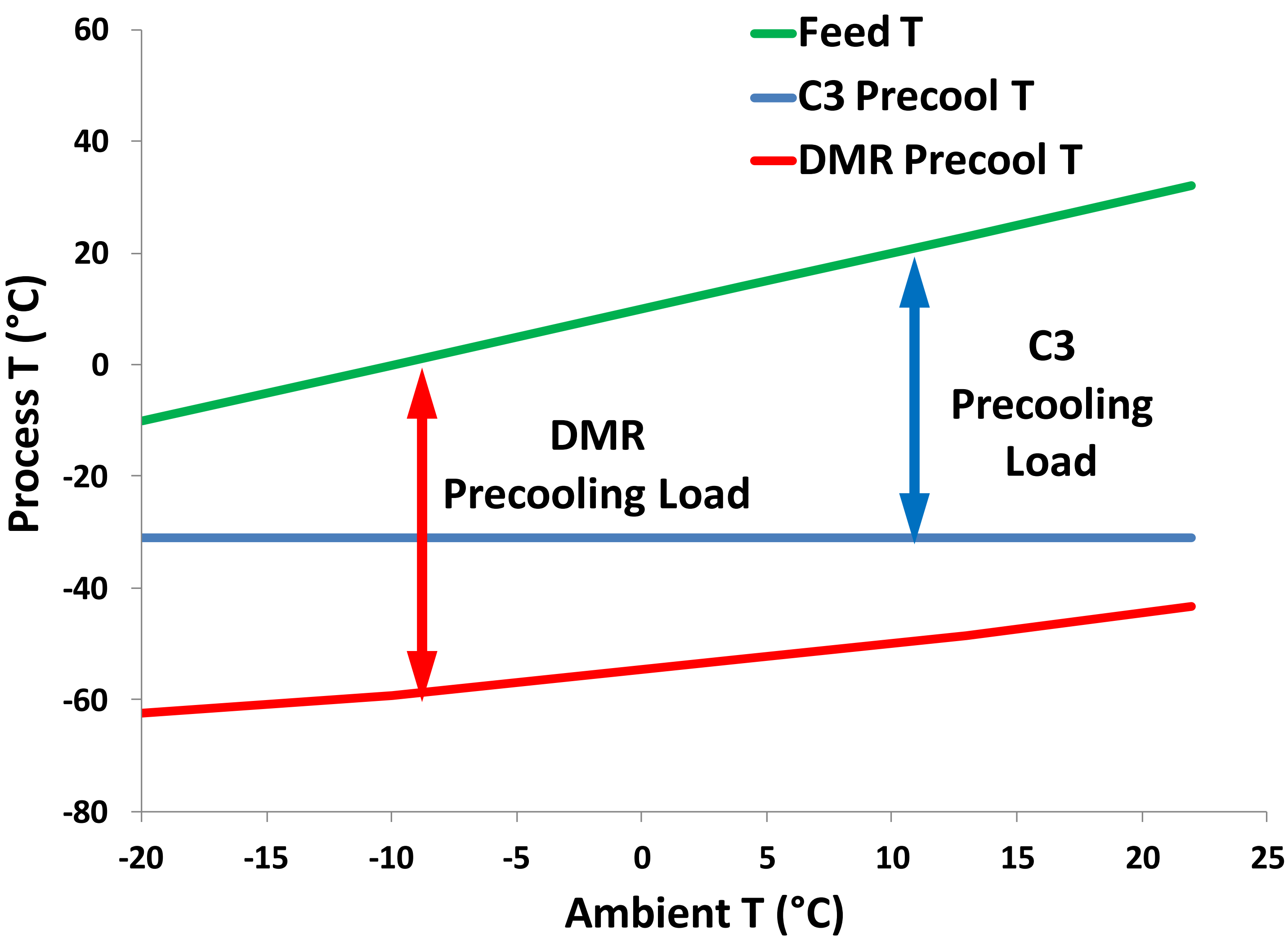
C3MR for Colder Ambient T



DMR for Colder Ambient T



C3MR and DMR for Colder Ambient T



So what have we learned?

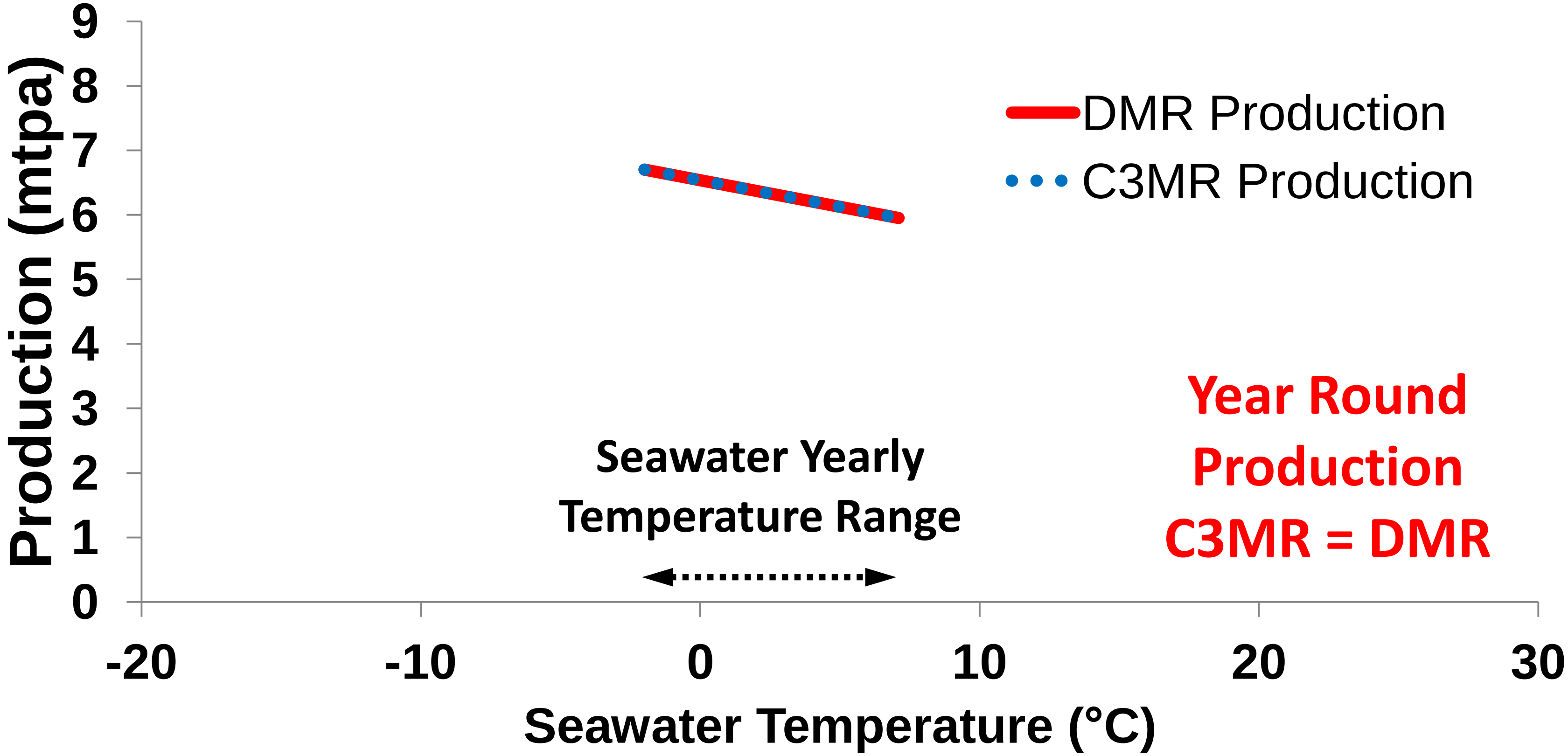
- For winter-to-summer temperature range, compare arctic to tropical/desert climate
  - Ambient air: very wide for arctic
  - Seawater: similar or smaller
- Air cooled
  - For moderate air T range,
    C3MR and DMR produce equal LNG
    - Approx 30°C for this case study
  - With large air T range,
    DMR produces more LNG than C3MR
    - Based on 3 key assumptions

3 Key Assumptions

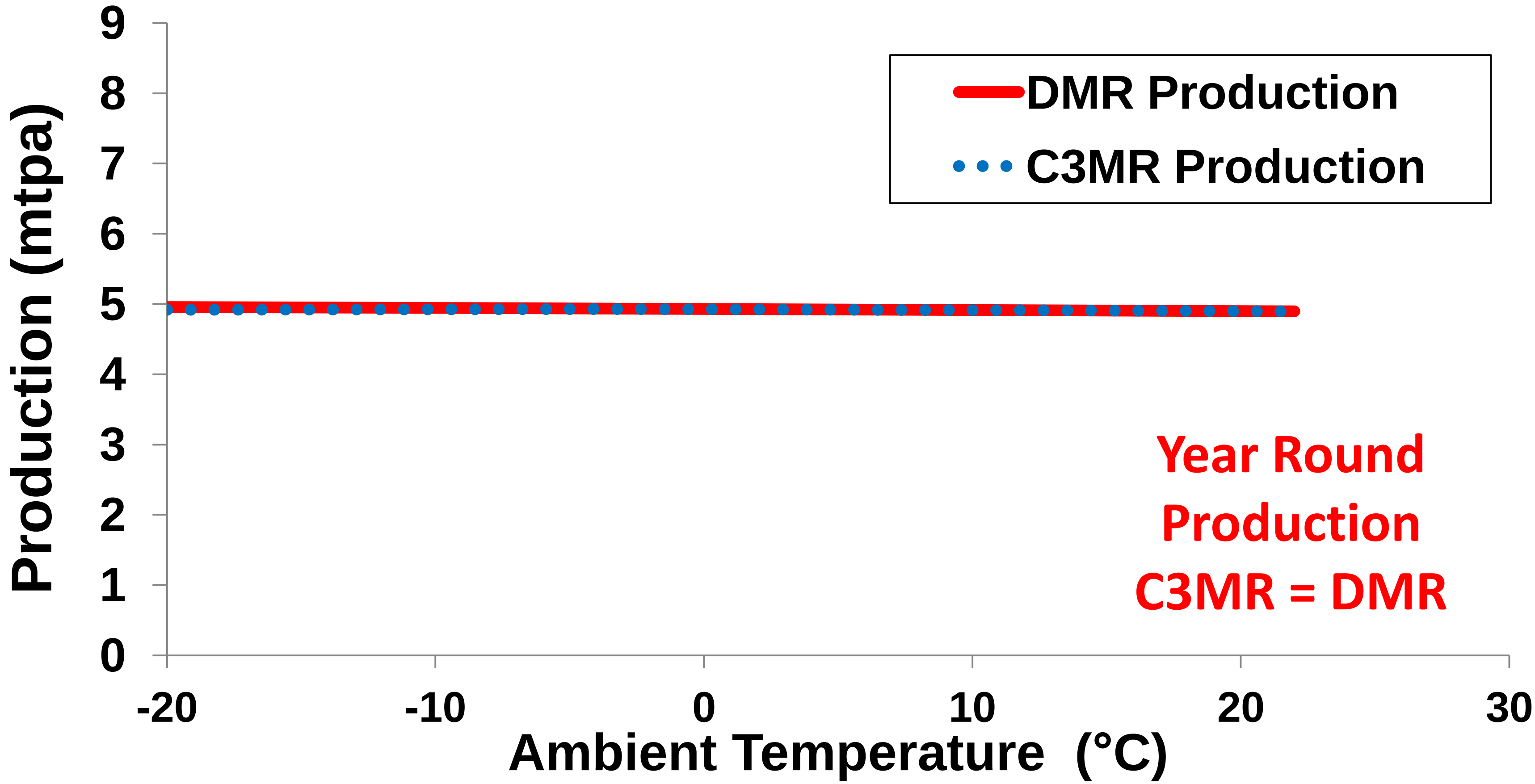
1. Plant is air cooled
2. Available refrigeration power limits production
   – Entire value chain can process extra feed
   – Gas fields, pipeline, slug catcher, AGRU, dehydration, storage, carriers . . .
   – Additional CAPEX used only part of year
3. Customers' needs match plant production
   – Vary seasonally
   – Supply and demand are synchronized

- If all three are true, then DMR liquefaction will produce more yearly LNG

C3MR vs. DMR
Yearly Production Range
Seawater Cooled Arctic Case Study



C3MR vs. DMR - Fixed Feed Yearly Production Range Air Cooled Arctic Case Study



Where does each process produce most annual LNG?

Climate	Cooling Media			
	Air		Seawater	
	Constant Feed	Variable Feed (Inc >~30%)	Constant Feed	Variable Feed (Inc >~30%)
Tropical				
Desert				
Arctic		AP-DMR™ > AP-C3MR™		

Where does each process produce most annual LNG?

<table>
<tr><th rowspan="3">Climate</th><th colspan="4">Cooling Media</th></tr>
<tr><th colspan="2">Air</th><th colspan="2">Seawater</th></tr>
<tr><th>Constant Feed</th><th>Variable Feed (Inc >~30%)</th><th>Constant Feed</th><th>Variable Feed (Inc >~30%)</th></tr>
<tr><td>Tropical</td><td colspan="4" rowspan="2">AP-DMR™ = AP-C3MR™</td></tr>
<tr><td>Desert</td></tr>
<tr><td>Arctic</td><td></td><td>AP-DMR™ > AP-C3MR™</td><td></td><td></td></tr>
</table>

DMR and C3MR – Other Factors

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

Summary

- **Arctic compared to desert and tropical climates**
  - **Colder - gives more production**
  - **Ambient air T range: wide summer-to-winter**
  - **Seawater T range: similar summer-to-winter**
- **When selecting liquefaction process for arctic, DMR produces same LNG as C3MR, unless:**
  - **Air Cooling with wide T variation, and**
  - **Excess value chain capacity installed, and**
  - **Extra production can be sold seasonally**

Conclusion

Both AP-C3MR^{TM} and AP-DMR^{TM}

are viable liquefaction processes

for arctic climates

Thank you

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