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Business Case for Natural Refrigerants

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Transcritical CO_2 Refrigeration Systems For Industrial Refrigeration Applications

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ENGINEERING TOMORROW

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A Quick Historical Perspective

- Industrial Refrigeration markets are comprised primarily of:
  - Food Production
  - Cold Storage
- The preferred refrigerant has overwhelmingly been ammonia, a natural refrigerant with:
  - No Ozone Depletion Potential (ODP) ✓
  - No Global Warming Potential (GWP) ✓
- However, over the past decade, a lot of emphasis has been devoted to finding alternative approaches to:
  - The type of refrigeration system and/or,
  - The refrigerant

WHAT HAPPENED?

The World of Industrial Refrigeration Got Complicated

- PSM and RMP requirements continue to vex end users of large ammonia systems
- For those with smaller ammonia charges, the General Duty Clause took precedence
- RAGAGEP was intended to provide a roadmap but proved to be vague and inconsistent
  - A memo of clarification issued in 2016 was intended to provide clarity on how RAGAGEP was supposed to be used
  - With over a dozen standards and codes which could apply, end users, consultants, design/build contractors and regulators appear to be at odds as to what constitutes and what dictates the application of RAGAGEP
- At the same time, SNAP has an uncertain future
- Safety, product integrity, human talent present challenges up and down the entire food chain

There is no evidence to suggest that this is going to get easier!

Industrial Refrigeration
What are the options going forward?

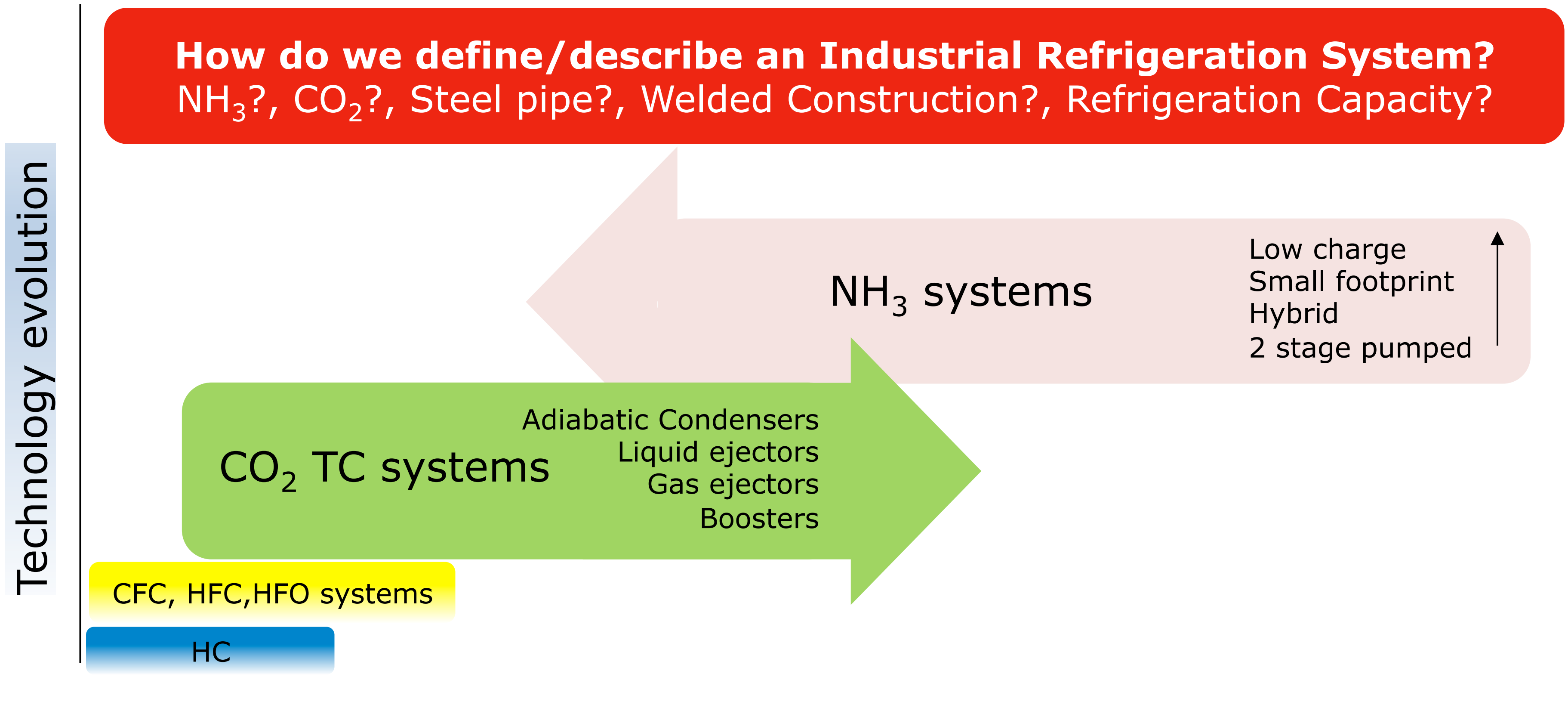
- Stay the course
- Switch to low ammonia charge systems (including CO_2/NH_3 cascade systems)
- Switch to synthetic refrigerants
- Move to Transcritical CO_2 Systems

Move to Transcritical CO_2 for Industrial Refrigeration Systems?

Seriously?

Uniting Technologies and Market Requirements

How do we define/describe an Industrial Refrigeration System?
NH_3?, CO_2?, Steel pipe?, Welded Construction?, Refrigeration Capacity?



Capacity range

Up to 50 TR	50 – 150 TR	150-300 TR	300-2500 TR	> 2500 TR

Skepticism Runs Rampant

The Cliches

1. Transcritical CO_2 systems are only applicable in cold climates
2. Transcritical CO_2 systems are only applicable to smaller commercial size systems
3. Pressures are too high
4. Transcritical CO_2 systems require far too many compressors for industrial applications
5. Maintenance will be a nightmare
6. Transcritical CO_2 systems are too complicated

There are some interesting considerations, however:

- Water – Evaporative Condensers vs. Adiabatic Coolers
  - Water Usage – Lower with Adiabatic Coolers
  - Water Disposal – None with Adiabatic Coolers
  - Water Treatment – None with Adiabatic Coolers
- Regulatory Compliance – NH_3 vs. CO_2
  - Ammonia is a Class B2 Refrigerant, CO_2 is a Class A1 Refrigerant
  - PSM – None with CO_2
  - General Duty Clause – Reduced requirements with CO_2
- Smaller Compressors – Advantage or Disadvantage?
- More Compressors – Advantage or Disadvantage?
- Head Pressure
  - Evap Condensers typically limited down to 65ºF
  - Adiabatic coolers down to 50ºF
- Maintenance ?
- First Cost ?

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So, what exactly does a Transcritical CO_2 Industrial Refrigeration System Look Like?

- Do we just take a food retail system and multiply by **x** times?
- Today, the answer clearly depends on who you talk to
- Some leading questions:
  - What kind of Design Life is expected – 10 years?, 20 years?, 30 years?
  - How many temperature levels does the facility require?
  - Are there convertible rooms?
  - What type of defrost methodology will we use and how often do we expect to defrost?
  - How do we feed liquid – Direct Expansion, or Pumped?
  - What kind of piping material and joining methods will we employ and why?
  - What do our load profiles look like?
  - Do we have a need for heat reclaim?
  - What kind of environment will the equipment be exposed to?

What are our Design Options?

- High Side Heat Rejection
  - Air Cooled
  - Adiabatic
  - Evaporative
- Parallel Compression
- Ejectors
  - Gas
  - Liquid
- Compressors
  - Large
  - Small
  - Reciprocating or Screw
- Controls and Control Strategy
- Defrost
  - Electric
  - Hot Gas
  - Other
- Liquid Feed
  - Direct Expansion
  - Flooded/Overfeed
- Methods of Construction
  - Copper Tubing
  - Steel Pipe
  - Stainless Steel Pipe
- Machinery Location
  - Rack
  - Engine Room?
- Heat Reclaim
  - Underfloor
  - Dock/ Dock dehumidification
  - Space Conditioning
  - Process Water

And, What About Efficiency?

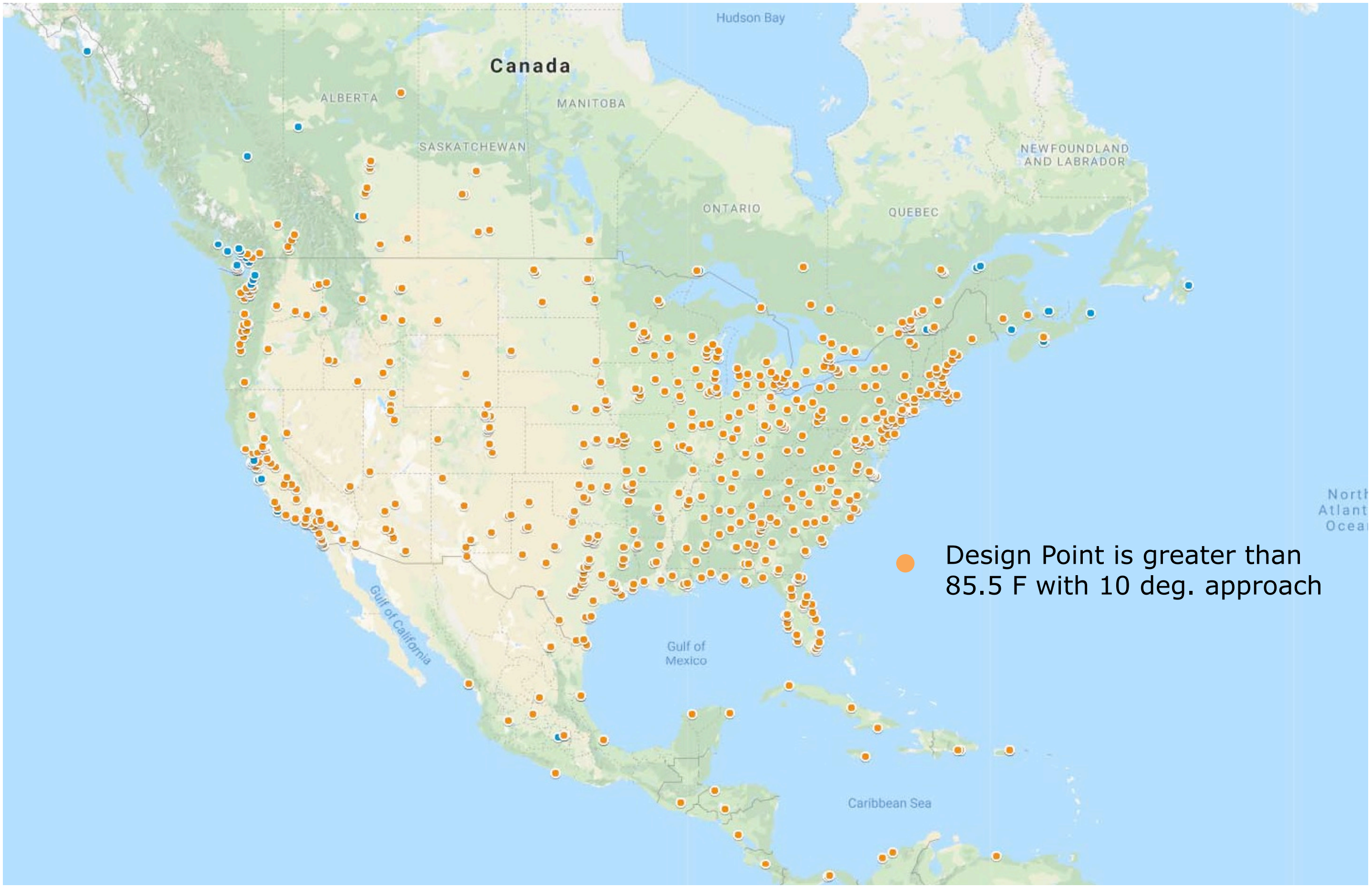
Game Changers

- Many responses to the "Clichés" are, to a large extent, subjective
- Geography, has appeared to be the determinant as to whether Transcritical CO_2 becomes a niche product or will have wide-spread appeal
- Two technologies, however, appear to have the potential to minimize this concern:
  - Adiabatic Condensers **Focus**
  - Ejectors: liquid and vapor **The Future?**

Adiabatic Condensers

- Similar to an air cooled condenser but with some characteristics of an evaporative condenser.
- As ambient temperatures force the refrigerant discharge temperature to rise and approach the critical point, a small amount of water is used to lower the dry bulb temperature of the incoming air to a point low enough to maintain condensing/gas cooling in the sub-critical realm.
- Each city studied has its own "typical" temperature profiles over the course of the year.
- The primary objective here is to minimize the number of hours that a system operates in the supercritical realm.
- Using historical ASHRAE "bin" data, system simulations can be conducted which will allow the designer to predict the overall efficiency of the system.
- DISCLAIMER: as with any simulation, many assumptions need to be made which can negatively or positively impact the predicted performance. It is essential that the user understand the nature of the assumptions and their relationship to reality.

Regions of North America for DRY CO_2 condensers.
Design point is subcritical at 10°F approach to ASHRAE 2% occurrence dry bulb & mean coincident wet bulb



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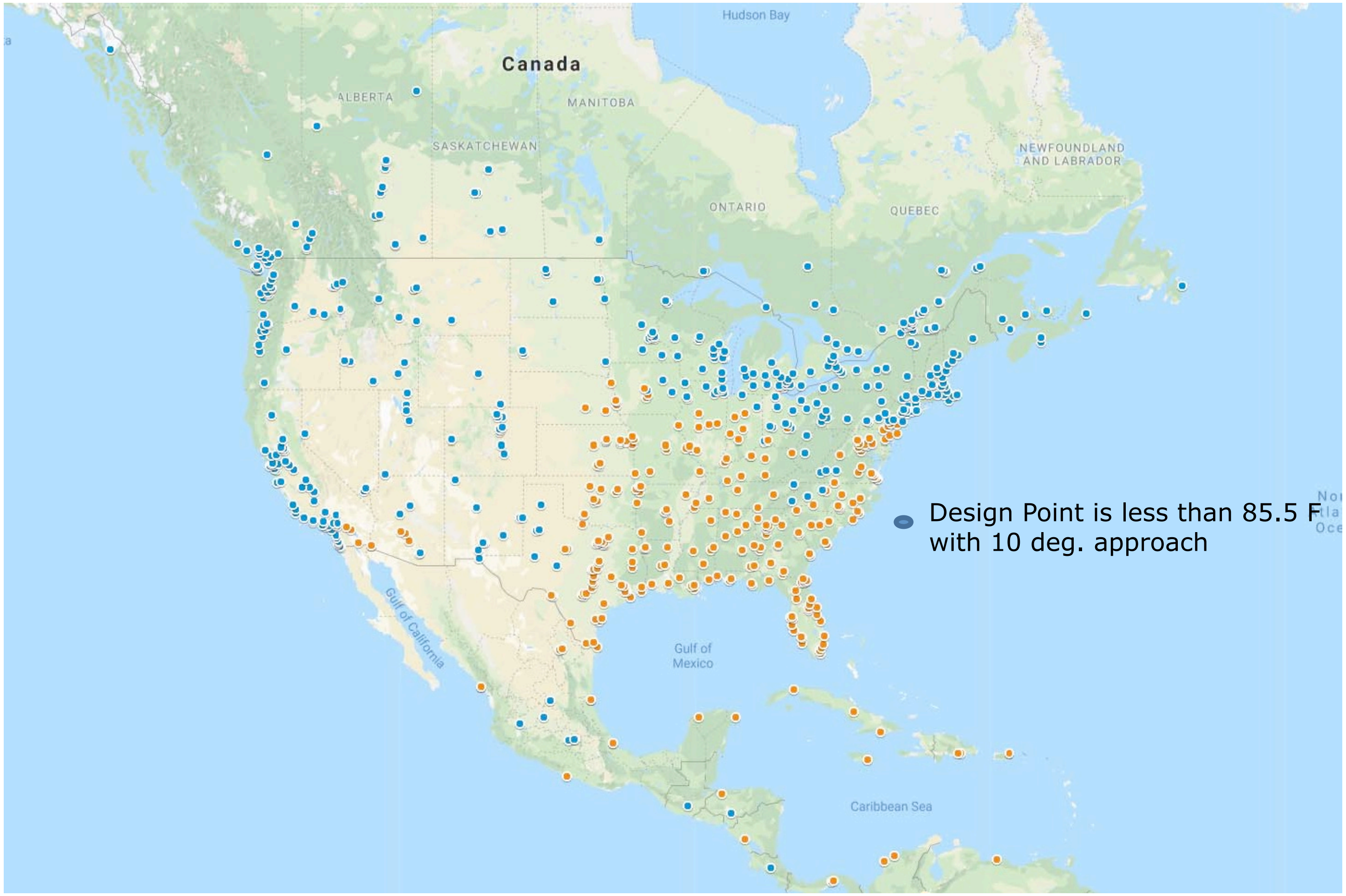
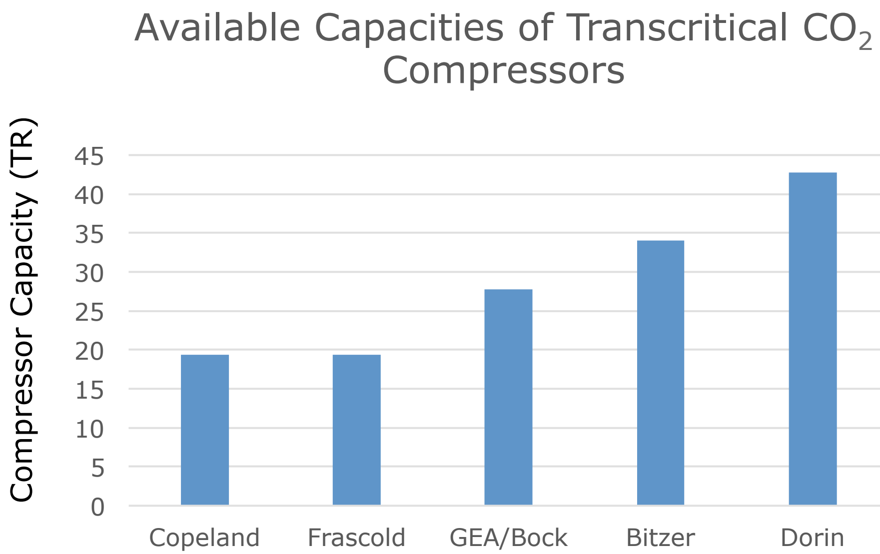
Regions of North America for ADIABATIC CO_2 condensers. Design point is subcritical at 10°F approach to ASHRAE 2% occurrence dry bulb & mean coincident wet bulb



And, What About Compressors?



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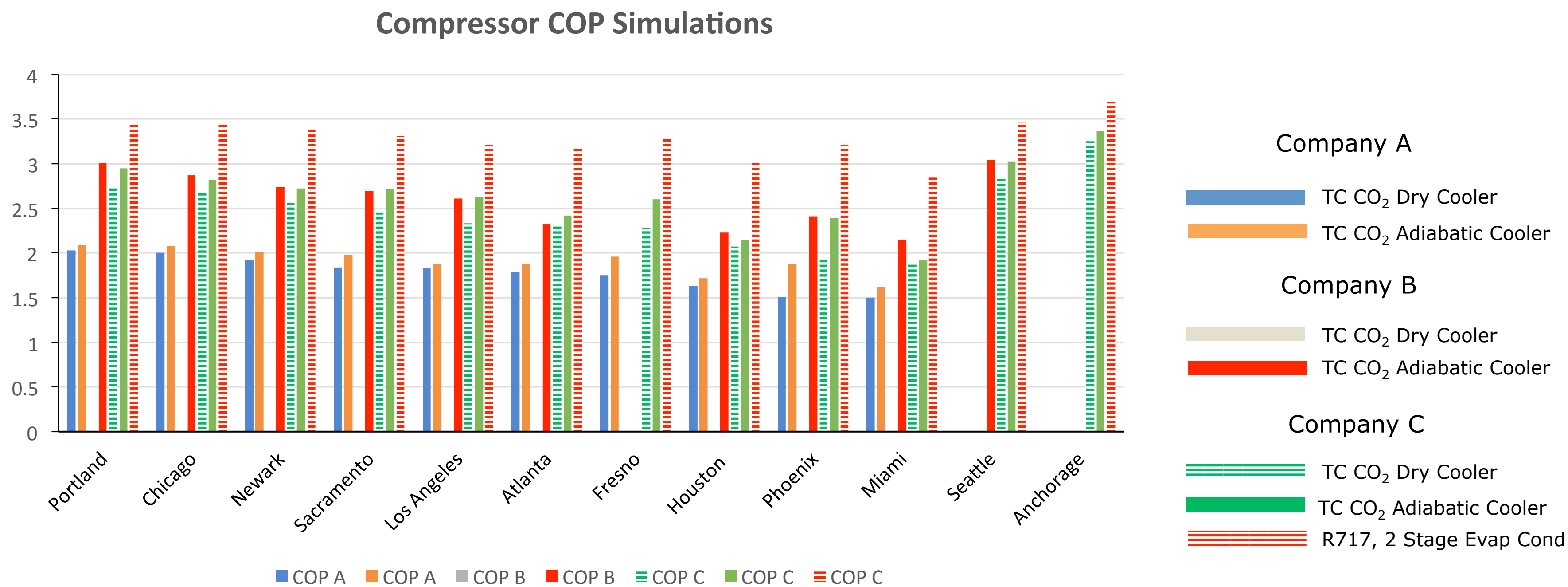
Judging the Efficiency of a Refrigeration System

- Operating costs must be judged from a
  - Geographical,
  - Load Size and Type, and
  - Annualized perspective

  Rather than from a single design point.
- While important, system efficiency involves far more than just compressor efficiency.
  - Fans,
  - Pumps,
  - Heat Quality for Reclaim

Trans-critical CO_2 Refrigeration System Simulations* By City



*Non-optimized Systems

TC CO_2 Systems for Industrial Refrigeration

Extreme 1
Standard commercial built

Multiple standard commercial (supermarket) systems

- DX injection on all temp. levels
- Electric defrost
- Copper pipes at cooling levels
- K65 up to 120 bar, SS up to 1740 psi, Or?
- Soldered/brazed connections
- Pressure ratings 580/754/870/943 psi/?

Extreme 2
Industrial built

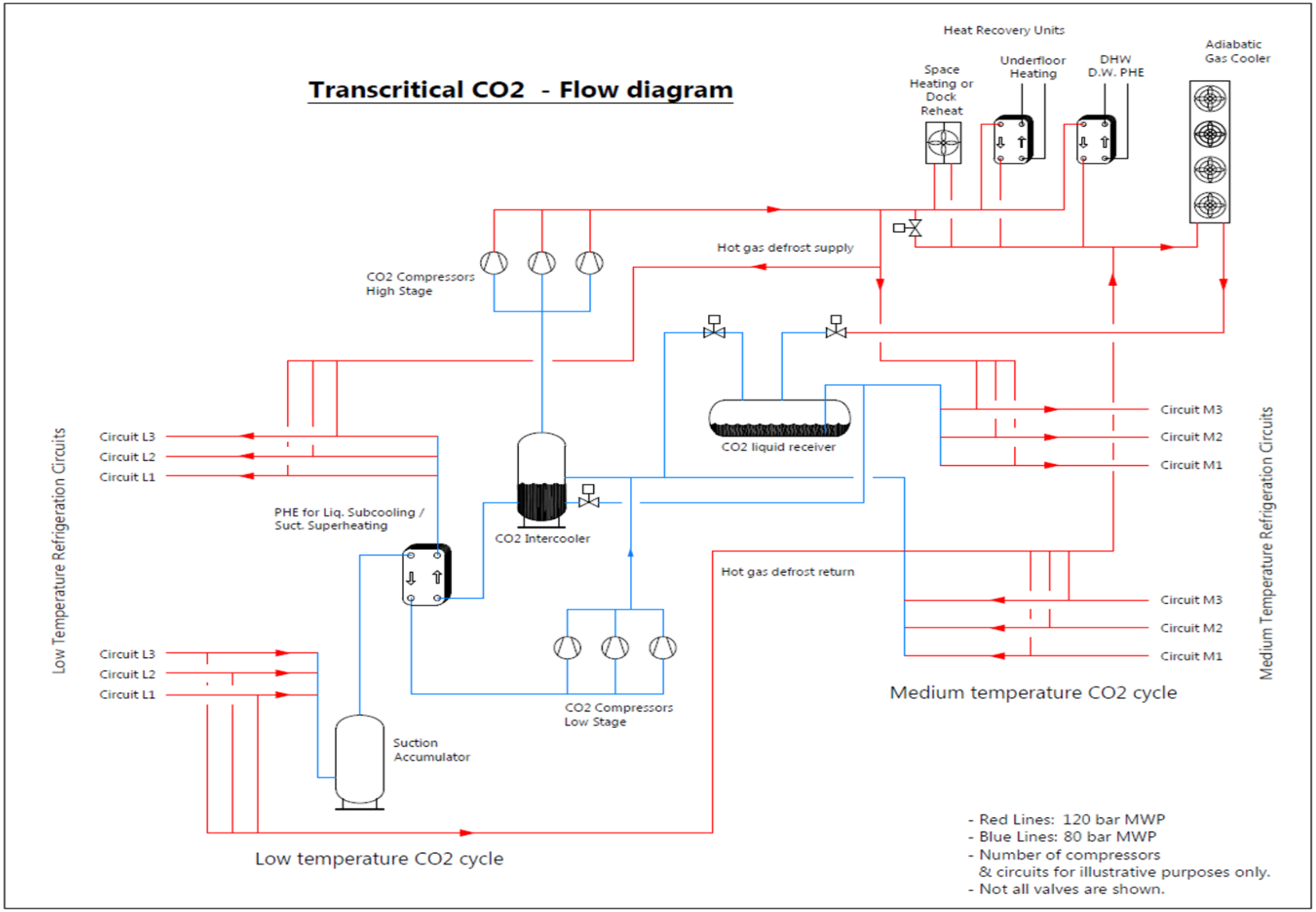
Fully dedicated IR system

- Pumped systems
- HGD
- Steel/stainless steel pipes
- Welded Construction
- Pressure ratings 754/943/1250/higher? psi

Considerations for both systems

- Compressor capacity is still relatively small
- Energy efficiency
- Heat recovery
- Defrost
- First cost
- Operating cost
- Maintenance cost
- Safety ("safe and future proof refrigerant"?)
- Pressure rating and stand still pressures

One Current Transcritical CO_2 System

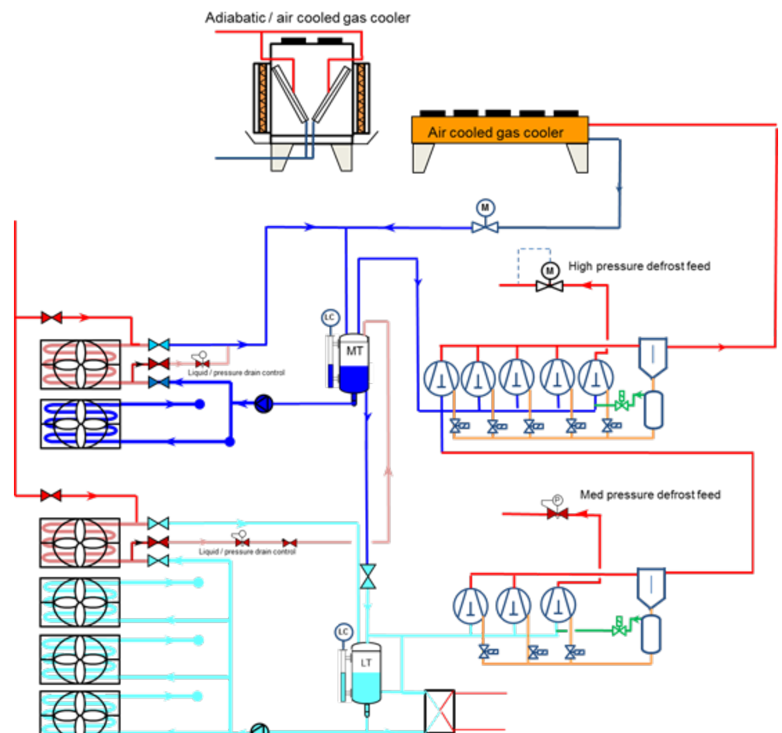


One concept for a TC CO_2 Industrial Refrigeration System

Pumped Circulated Liquid

Fully dedicated IR built

- Flooded system all levels (lower dT, better HTE, better cooler eff, easy to control)
- Dedicated compressors for MT temp. level (no bypass loss)
- State of the art HGD
  - ➢ Separate HGD compressor
  - ➢ Controlled liquid drain
  - ➢ Smart defrost controller
- Safe, leak-tight
- Steel/stainless steel



Conclusions

- While there are a limited number of Transcritical CO_2 systems in existence (Industrial Refrigeration) today, the number is growing
  - Experience has been positive
  - Inquiries are accelerating
- The next few years will provide strong evidence as to the viability of Transcritical CO_2 Systems in Industrial Refrigeration applications. But there are a number of strong points already in its favor:
  - Many of the open regulatory related questions regarding the use of Synthetic refrigerants and ammonia disappear from the conversation when the subject is Transcritical CO_2
  - Many companies are investing heavily in the future of industrial refrigeration Transcritical CO_2 components: compressors, adiabatic condensers, expansion valves, controls, etc.
  - Energy consumption, while still a concern, can be balanced with technology advances and heat reclaim in Transcritical CO_2 systems
  - Total cost of ownership, at first glance, appears favorable for Transcritical CO_2

This is today’s view seen through a wide-angle lens

Ultimately, The Market will dictate the specific requirements as well as the ultimate success of Transcritical CO_2 Systems in Industrial Refrigeration

And, that’s where you come in!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Thank you very
much!