Natural Refrigerant Alternatives for Industrial Refrigeration

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Emerson

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Vilter Manufacturing/Emerson
## Agenda

1. Why invest in natural refrigerants?
2. Ammonia applications
3. Key industrial refrigeration trends
4. CO\textsubscript{2} system architectures
5. Strategies for warm ambient operation
6. Summary
Why Invest in Natural Refrigerants?
Low-GWP Refrigeration?

Step 1: Elimination of ozone-depleting refrigerants (CFCs and HCFCs)
Step 2: Phase-down of global-warming refrigerants (HFCs)
Step 3: Ramp-up of CO$_2$ commercial refrigeration equipment

**Step 1, completed:**
Thinning of the ozone layer caused by CFCs and HCFCs (banned)

**Step 2, ongoing:**
Global warming damage caused by HFCs (phased down/usage bans)

**Step 3, ongoing:**
Natural refrigerants CO$_2$, propane, ammonia (ramping up)

CFC = Chlorofluorocarbon
HCFC = Hydrochlorofluorocarbons
HFC = Hydrofluorocarbons
Global Regulations Confusing Time for End Users

### F-Gas Regulations

<table>
<thead>
<tr>
<th>Section and Maintenance Role</th>
<th>GWP</th>
<th>Timing</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVAC</td>
<td>750</td>
<td>Jan. 2020</td>
</tr>
</tbody>
</table>

- Planting in the market: New equipment based
  - Commercial refrigeration and freezing: 250 Jan. 2022
  - Refrigeration and freezing for commercial use: 250 Jan. 2022
  - Refrigeration and freezing for commercial use: 250 Jan. 2022
  - Stationary refrigeration equipment: 250 Jan. 2022
  - Jumbo refrigeration equipment: 250 Jan. 2022

- Jumbo refrigeration equipment:
  - Refrigeration and freezing system for commercial use with a capacity of 2 MW (3.45 IMEP):
  - Replaces in the primary refrigeration circuit of a lounge, where installed

- Single split air conditioning equipment:
  - Refrigeration and freezing equipment: 250 Jan. 2022

### EPA’s Final Rule

**Phase-out Candidates**, **Likely Alternatives** and **Dates**

#### Phase-out Candidates

- R-22 (CFC-12)
- R-114 (HFC-134a)
- R-32 (HFC-134a)

#### Likely Alternatives

- R-410A (HFC-32/71/125/134a)
- R-407C (HFC-134a/125/143a)

#### Dates

- R-22: Jan. 2020
- R-114: Jan. 2020
- R-32: Jan. 2020

### EPA’s Final Rule and DOE Energy Regulation Timing

<table>
<thead>
<tr>
<th>Phase-out Candidates</th>
<th>Likely Alternatives</th>
<th>DOE Energy Regulation Timing</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-22</td>
<td>R-410A</td>
<td>July 1, 2020</td>
</tr>
<tr>
<td>R-114</td>
<td>R-407C</td>
<td>July 1, 2020</td>
</tr>
<tr>
<td>R-32</td>
<td>R-410A</td>
<td>July 1, 2020</td>
</tr>
</tbody>
</table>

### California Proposal for Regulating HFCs

- Governor’s 2015 order to reduce all GHGs (over 1990 levels)
  - 40% in 2030
  - 80% in 2050
- Draft strategy released September 2015
  - All sectors targeted for reduction
  - New commercial refrigeration equipment, <150 GWP
  - New HVAC equipment (comm. and tests), <750 GWP
- International and national actions inadequate: CA will follow EU, Australia, and Japan in taking additional measures
- Final proposal in “Spring 2016”

### Proposed product-specific controls in the refrigeration and air conditioning sector (March 2016)

<table>
<thead>
<tr>
<th>Product</th>
<th>GWP Limit</th>
<th>Proposed Timeline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobile air-conditioning</td>
<td>150</td>
<td>2021 model year</td>
</tr>
<tr>
<td>Stand-alone medium temp commercial refrigeration</td>
<td>650</td>
<td>2020</td>
</tr>
<tr>
<td>Stand-alone low temp commercial refrigeration</td>
<td>1500</td>
<td>2020</td>
</tr>
<tr>
<td>Chillers (air conditioning only)</td>
<td>700</td>
<td>2025</td>
</tr>
<tr>
<td>Domestic refrigeration</td>
<td>150</td>
<td>2025</td>
</tr>
<tr>
<td>Mobile refrigeration</td>
<td>2200</td>
<td>2025</td>
</tr>
</tbody>
</table>
### Proposed Status Changes: Refrigeration & Air Conditioning

<table>
<thead>
<tr>
<th>End-Use (New Equipment)</th>
<th>Proposed Change of Status Date*</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Centrifugal chillers</td>
<td>January 1, 2024**</td>
</tr>
<tr>
<td>• Positive displacement chillers</td>
<td>January 1, 2024**</td>
</tr>
<tr>
<td>• Cold storage warehouses</td>
<td>January 1, 2023</td>
</tr>
<tr>
<td>• Refrigerated food processing and dispensing***</td>
<td>January 1, 2021</td>
</tr>
<tr>
<td>• Household refrigerators and freezers</td>
<td>January 1, 2021</td>
</tr>
</tbody>
</table>

*Refer to proposed rule for specific substitutes and dates. Would change status for various HFCs and HFC refrigerant blends with GWPs ranging from about 900 to 4,000.

**Narrowed use limits apply as of January 1, 2024 for military marine vessels and for human-rated spacecraft and related support equipment.

***Separate end-use category within retail food refrigeration end-use.

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*Slide from Tom Land, U.S. EPA, ATMOsphere America, June 17, 2016*
Alternatives for Refrigeration Applications

- **R-410A like**
- **R-404A & R-407/22 like**
- **R-134a like**
- **R-123 like (v. low pr.)**

- **CO₂**
- **NH₃**
- **R-32**
- **R-123**

- **HFC/HFO Blends**

- **GWP level**

- **Qualitative; not to scale**
Holistic Facility Approach Can Minimize “Unintended Consequences”

Key variables:
- Toxicity, flammability, working pressures
- Heat transfer, latent heat
- Revenue, first cost, total cost of ownership
- $CO_2$ emissions, climate change

Stakeholders:
- Legal, operations
- Energy mgr., design eng.
- CEO, merchandising, finance
- Sustainability officers

Trends:
- Lack of technicians, performance specs and service contracts
- Utility incentives, continuous commissioning, integrated HVACR
- Millennials, fresh, urban stores
- Natural refrigerants, regulations

Equipment
Energy
Economics
Environment
## Refrigerants: Impact Comparison

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>R-404A</th>
<th>R-507A</th>
<th>R-22</th>
<th>R-290 Propane</th>
<th>R-744 CO₂</th>
<th>R-717 Ammonia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ozone depletion potential (ODP)</td>
<td>0</td>
<td>0</td>
<td>0.04</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Global warming potential (GWP)</td>
<td>3,922</td>
<td>3,800</td>
<td>1,810</td>
<td>3</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Safety group</td>
<td>A1</td>
<td>A1</td>
<td>A1</td>
<td>A3</td>
<td>A1</td>
<td>B2</td>
</tr>
</tbody>
</table>

Reference: ASHRAE Handbook
Ammonia Applications

- Food and beverage processing:
  - Dairy, meat processing, breweries, baked goods, frozen foods
- Refrigerated cold storage
- Recreational ice:
  - Hockey rinks, curling, ice skating paths
  - Olympic speed skating, ski jumps, bobsled tracks
- Ground soil freezing, mining HVAC
- HVAC, *district heating and cooling, heat pumps*
Ammonia Pros

**Cost-effective**
- Ammonia systems cost ~10–20% less than competitive systems using HCFCs and HFCs
- Less refrigerant and smaller pipes required due to less mass flow: *more than nine times more energy content (BTU/lb) than HFCs*
- Up to 25% more efficient in energy usage
- Excellent refrigerant for heat recovery
- Low-cost refrigerant and oils:
  - Mineral and semi-synthetic oils

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<table>
<thead>
<tr>
<th>Refrigerant (+20°F / 86°F)</th>
<th>R404A</th>
<th>R507A</th>
<th>R22</th>
<th>R744 CO₂</th>
<th>R290 Propane</th>
<th>R717 Ammonia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net Refrigerating Effect (Btu/lb)</td>
<td>51.1</td>
<td>49.4</td>
<td>71.3</td>
<td>55.7</td>
<td>124.1</td>
<td>478.5</td>
</tr>
<tr>
<td>COP</td>
<td>5.59</td>
<td>5.56</td>
<td>6.11</td>
<td>3.51</td>
<td>5.99</td>
<td>6.25</td>
</tr>
<tr>
<td>Evap. Pressure (psia)</td>
<td>70.5</td>
<td>72.9</td>
<td>57.8</td>
<td>421.9</td>
<td>55.8</td>
<td>48.2</td>
</tr>
<tr>
<td>Cond. Pressure (psia)</td>
<td>206.1</td>
<td>211.7</td>
<td>172.9</td>
<td>1046.2</td>
<td>183.7</td>
<td>169.3</td>
</tr>
<tr>
<td>Discharge Temp (°F)</td>
<td>94.3</td>
<td>93.5</td>
<td>118.0</td>
<td>142.3</td>
<td>94.8</td>
<td>179.8</td>
</tr>
</tbody>
</table>

Reference: ASHRAE Handbook
Ammonia: A Natural Refrigerant

Natural refrigerant, environmentally friendly:
• One of the most abundant gases in the environment
• Exists all around us (air, water, soil, produced by our kidneys)
• Approx 1.7 times lighter than air
• Breaks down rapidly in the environment
• NH₃ (R-717): nitrogen and hydrogen

• Ozone-depletion potential (ODP) = 0
• Global warming potential (GWP) = 0

Human production: 198 million tons annually (2012)
• Second-most produced chemical (after petroleum)
• ~80% is produced for fertilizer
• NH₃ R-717 refrigerant 99.98% pure — ~2% of total production
• Cheap, affordable refrigerant

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<td>0</td>
<td>0</td>
<td>0.04</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Global Warming Potential (GWP)</td>
<td>3700</td>
<td>3800</td>
<td>1810</td>
<td>1</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Safety Group</td>
<td>A1</td>
<td>A1</td>
<td>A1</td>
<td>A1</td>
<td>A3</td>
<td>B2</td>
</tr>
</tbody>
</table>

Reference: ASHRAE Handbook
150 Years of Ammonia Refrigeration

Well known:

- Ammonia used for more than 150 years in refrigeration
- 1850s in France, 1860s in U.S., first patents in 1870s
- Consistently used for large industrial refrigeration for over 100 years
- Most common refrigerant for food and beverage production, cold storage, recreational refrigeration
- Proven safe track record
Vilter Manufacturing

- **Vilter™** is a division of Emerson
- Founded in 1867 in Wisconsin
- Currently in Cudahy, Wis.
- Products include:
  - Recips, single-screws, packaged systems for:
    - Refrigeration, heat pumps
    - Smart vapor management, gas compression for CHP

![Images of 450XL, Single Screw, SVM Unit, Package Systems]
Key Industrial Refrigeration Trends

**Safety and environmental requirements**
- OSHA requirements
- Low-charge ammonia systems
- Moving ammonia out of occupied spaces
- Cascade systems using CO\(_2\) in the low stage
- Booster transcritical CO\(_2\) architecture for MT and LT
- Increased use of R-744 (CO\(_2\)) and a volatile secondary fluid

**Increased emphasis on total cost of ownership**
- Equipment cost
- Maintenance costs
- Energy cost (improved performance of CO\(_2\) at LT such as -40 °F)
Key Industrial Refrigeration Trends

Safety and environmental requirements

- Low-charge ammonia systems
  - OSHA requirements, 10,000-lb threshold

The burden of compliance will continue to be significant, with OSHA’s National Emphasis Program (NEP) inspections, audits and regulation changes related to the OSHA 1910.119 PSM program and the U.S. Environmental Protection Agency’s (EPA) 40 CFR Part 68 Risk Management Plan.

PSM programs (process safety and risk management)
CO₂ System Architectures — Booster vs. Cascade vs. Secondary
Key Industrial Refrigeration Trends

Safety and environmental requirements

– Low-charge ammonia systems
  • OSHA Requirements
– Moving ammonia out of occupied spaces

Pumped CO₂ Secondary
Metro Distribution Centre, Laval, QC: Ammonia/Secondary CO\textsubscript{2} System

Facility
- 240,000 sq. ft. cold storage warehouse
- 1000 TR ammonia refrigeration with efficient Emerson/Vilter single-screw compressors
- Distributed CO\textsubscript{2} brine throughout the building

Emerson solution
- Vilter compressors delivered superior part-load efficiency
- Expensive VFD drives would have been required with competitor’s twin-screw compressors

End user benefits
- Reduced ammonia charge
- Lower compressor and facility energy costs
- Non-ozone depleting refrigerants with zero global warming potential
- Vilter dual-slide valve technology avoids more than $100,000 of compressor VFD drives
Key Industrial Refrigeration Trends

- Safety and environmental requirements
  - Low-charge ammonia systems
    - OSHA requirements
  - Moving ammonia out of occupied spaces
  - Cascade systems using CO₂ in the low stage
Selecting the Best System — Booster vs. Cascade vs. Secondary

- **Secondary**
- **Cascade**
- **Transcritical booster**
Introduction to Cascade — Simple Systems

**Simple cascade system comprises:**

- Low stage provides the cooling load
  - It uses CO\(_2\) and is always subcritical
- High stage absorbs heat from the condensing CO\(_2\) at the cascade HX
- CO\(_2\) condensing temperature is always below the critical point
- High stage is usually a simple, close-coupled system
- Typically applied in warm climates
Combination of Secondary and Cascade (Limited Condensing Temp)

• Safety and environmental requirements
  – OSHA requirements
  – Low-charge ammonia systems
  – Moving ammonia out of occupied spaces
  – Cascade systems using CO$_2$ in the low stage
  – Increased use of R-744 (CO$_2$) and a volatile secondary fluid
The CO₂ would typically be cooled to -30 °F (200 psig) for the LT load and +20 °F (407 psig) for the MT load. The high-stage system is a simple chiller type system, typically running on an HFC or HC or ammonia.
140 mm Single Screw

- Maximum Speed: 5,400 RPM
- Maximum Design Pressure: 400 PSIG
- Maximum Shaft Power: 273 HP
- Three Different Sizes/One Frame (140 mm)
  - 93 CFM (3,600 RPM) *32 tons
  - 139 CFM (5,400 RPM) *48 tons
  - 104 CFM (3,600 RPM) *36 tons
  - 156 CFM (5,400 RPM) *54 tons
  - 116 CFM (3,600 RPM) *40 tons
  - 174 CFM (5,400 RPM) *60 tons
    *20F SST, 95 SDT
- Inverter Capacity Control
- Economizer Port
Pressure-Temperature Relationship

Fig. 1.3

Pressure-Temperature Relationship of Various Refrigerants

- CO₂
- R404A
- R134a
- R717

Bar (psia)

- 14.7 psia

Temperature (°F)

-180 (-118)
-120 (-84)
-60 (-51)
0
60
120
180
240
300

Temperature (°C)

-118
-84
-51
-18
15
49
82
115
149

Positive Pressure
Vacuum
Triple point
Critical point
Liquid and gas density are the same ONLY at critical point.

Pressure-Enthalpy Diagram, CO$_2$

https://www.youtube.com/watch?v=gCTKteN5Y4
## Development of the HP Reciprocating Compressor

<table>
<thead>
<tr>
<th></th>
<th>552 (56 CFM)</th>
<th>554 (112 CFM)</th>
<th>558 (224 CFM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-30 °F SST/23 °F SDT</td>
<td>48 TR</td>
<td>97 TR</td>
<td>193 TR</td>
</tr>
<tr>
<td>-58 °F SST/ 23 °F SDT</td>
<td>23 TR</td>
<td>46 TR</td>
<td>92 TR</td>
</tr>
</tbody>
</table>
Supermarket Refrigeration

Features

- CO\textsubscript{2} transcritical booster system
- 2,500 sq. ft. supermarket/C-store
- Independent temp. and humidity control
- Remote condenser located in environment chamber
- Environmentally controlled chamber
  - Temperature: -30 to 130 °F
  - Humidity: 20 to 90%
- Full system integration; refrig. & HVAC

Helix Innovation Center
Environmental Chamber

- Four climate-controlled chambers
- Temperature range: -30 to 130 °F
- Humidity range: 20 to 90%
Being retrofitted to adiabatic

Environmentally controlled chamber

Temperature: -30 to 130 °F
Humidity: 20 to 90%
Vilter 175-Ton R-134a Chiller to Cool

- Capable of simultaneously pulling four chambers down to 20 °F
- Glycol used as heat transfer medium in the chamber

Same single-screw design as industrial CO₂ heat pump models
Two Vilter 50-Ton CO₂ Low-Temp Cascade Units

Pull-down environmental chamber temperature to -30 °F

550 Series sub-critical CO₂ LT open-drive models on test since Sept. 2015
Selecting the Best System — Booster vs. Cascade vs. Secondary
Transcritical Systems Can “Transition” From Subcritical to Supercritical

Figure 6. R744 pressure enthalpy chart showing subcritical and transcritical systems
CO$_2$ Transcritical Booster Operation
HPLD — For Larger Capacities; Worldwide First CO$_2$ Transcritical Single-Screw Compressor

Specifications
- Max Discharge Pressure: 1,600 PSIG
  - 2,000 PSIG Being Developed
- Max Speed: 4,500 RPM
- Displacement: 128 to 243 cfm (7 Sizes)

Applications
- Transcritical CO$_2$ (Testing)
- Subcritical CO$_2$
- Heatpump
- Gas Compression
Emerson Industrial Compressors — Future

Transcritical CO₂ Single-Screw
- Seven displacements (128 to 243 CFM)
- MT: 158 to 300 tons, 243 CFM +23F SST / 95 °F GC out
- LT: 125 to 239 tons (-25 °F/ 30 °F SDT)
- Max. suction pressure: 650 PSIG
- Max. condensing pressure: 1600 PSIG
- Currently designing 2,000 PSIG
- Max. speed: 4,500 RPM

• Capacity control: VFD
• Volume control: fixed plug
• Economizer: Yes
• Liquid injection: Yes
HPLD vs. Standard Design

Parallel Compression

MT Compressor
5 x 4MTLS28ME (largest semi)
5 x 27 tons = 135 tons (+23 °F SST/95 °F GC)

Parallel Compressors
2 x 4MTLS15ME
2 x 21 tons = 42 tons (+40 °F SST)
Total: 177 tons

HPLD With Economizer Port

1 Only 145 CFM HPLD = 179 tons
(+23 °F SST / 95 °F GC)
Wide Applications Available

CO2 TEMPERATURE RANGE

-49 °F / -45 °C

248 °F / 120 °C
Pressure Enthalpy Diagram for CO$_2$ Heat Pump
CO$_2$ Heat Pump Provides Versatility

District Heating

River Access Can Provide Substantial Increase in Efficiency

Snow Melt Capability
Strategies for Warm Ambient Operation

Low-GWP
Climatic Impact of CO₂ System Architectures
Five Ways of Improving Efficiencies in Warm Ambient Regions

- Spray nozzles
- Evaporative or adiabatic gas coolers
- Parallel compression
- Sub-cooling
- Ejectors
Summary of Options

100% ammonia system
- CO₂ pumped as volatile brine
  - Low-temp only

CO₂ transcritical booster system
- CO₂ pumped as volatile brine
  - Low-temp
- CO₂ pumped as volatile brine
  - Medium-temp onl

Ammonia/CO₂ cascade with MT pumped secondary
- CO₂ pumped as volatile brine
  - Medium-temp
- CO₂ pumped as volatile brine
  - Low-temp

Ammonia compressor

CO₂ pumped as volatile brine
- Low-temp only
- Medium-temp only

+20 °F

-40 °F

MT cooler
- CO₂ direct expansion
- Low-temp

Compressors
Questions?

For further details, contact

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Antonio.Delourdes@Emerson.com
414-486-2634

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