CO2 (R744) for Data Centers: The Practical Journey to Sustainability

- Michael A. May, President & Chief Technology Officer, Effecterra Inc.
- Jacob Wolfe, USA Data Centers Representative, M&M Carnot

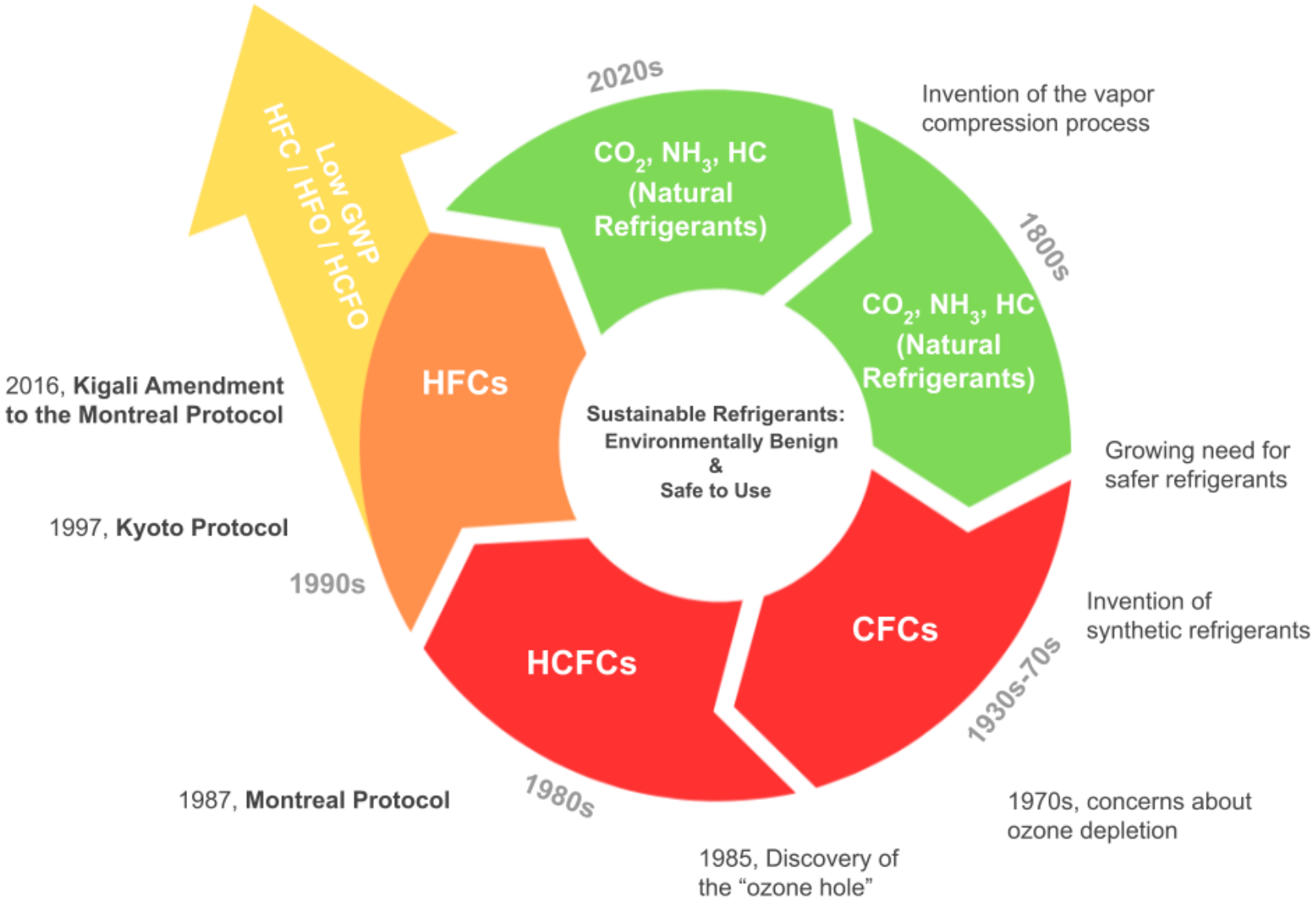

effecterra
US Policy Environment
&
Technology Alignment

A “Tipping Point” has been reached

- **Government Policy**
- **Corporate Climate Actions**
- **Societal Awareness**
- **Technology Development & Commercialization**

Over the last two decades, these forces have built demand and enabled solutions to mitigate direct GHG emissions.

A Brief History of Refrigerants



Refrigerant Leakage from HVAC/R assets is one of the main sources of direct GHG emissions.

What you leak is as important as *how much* you leak.

Refrigerants Regulatory Timeline

2014

European Commission

EU F-gas Regulation

Action on ozone-depleting refrigerants

2015

PARIS2015 UN CLIMATE CHANGE CONFERENCE COP21·CMP11

Keep Global Warming "to well below **2 degrees** C"

SBTI LAUNCH
FOR AMBITIOUS CORPORATE CLIMATE ACTION
Science-based emissions reduction targets

SCIENCE BASED TARGETS
DRIVING AMBITIOUS CORPORATE CLIMATE ACTION

2016

United Nations Treaty Collection

The Kigali Amendment to Montreal Protocol
International agreement to **phasedown hydrofluorocarbons (HFCs)**

2017

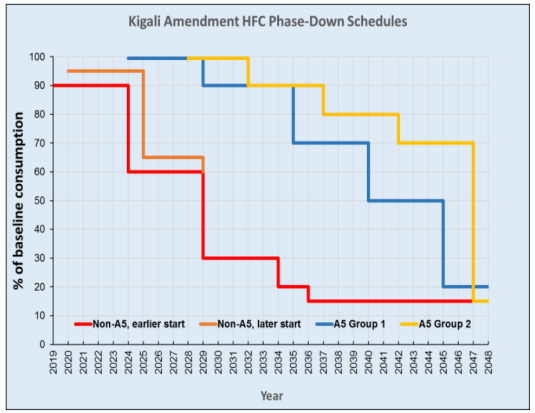


Image source: *United Nations*

'PROJECT DRAWDOWN' PUBLISHED
GLOBAL RESEARCH INITIATIVE
The most substantive solutions to global warming

DRAWDOWN
THE MOST COMPREHENSIVE PLAN EVER PROPOSED TO REVERSE GLOBAL WARMING

2018

HFC PHASEDOWN
American Innovation & Manufacturing (AIM) Act
A U.S. Environmental Protection Agency Program

'AIM ACT'
The American Innovation & Manufacturing Act
Directs EPA to address Hydrofluorocarbons

US STATES ACT ON HFCs
(following federal rollback)

CA adopts vacated federal rules. Several states follow suit.

CA adopts and WA, NY propose additional HFC regulations

UNITED STATES CLIMATE ALLIANCE

2020

US REJOINS
PARIS AGREEMENT

2021

SEC RULES TO ENHANCE & STANDARDIZE CLIMATE RELATED DISCLOSURES

INFLATION REDUCTION ACT

US RATIFIES KIGALI AMENDMENT

2022

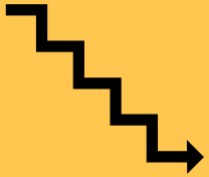
EPA United States Environmental Protection Agency

EPA ADOPTS HFC REGULATIONS
UNDER THE AIM ACT

effecterra.com

American Innovation & Manufacturing (AIM) Act

HFC Phasedown



- **Reduces HFC supply**.
- A cap-and-trade program for HFCs, based on their GWP.
- Will reduce availability of high-GWP refrigerants.
- **First big, drastic cut occurs in 2024 (in 5 months)**

Technology Transitions

High-GWP  Low-GWP

- **Reduces HFC demand**.
- Puts GWP limits on new equipment.
- **Most GWP limits will go into effect on 1/1/2025.**

Refrigerant Management

- **Reduces HFC demand**.
- The goal is to minimize leaks and maximize reclamation.
- Existing HVAC equipment will likely be affected.
- **EPA expected to propose a new regulation in 2023.**

US Policy has implemented a Carrot (Incentives) and **Stick (Regulations)** approach.

US Technology Investments

CHIPS and Science Act - Brain

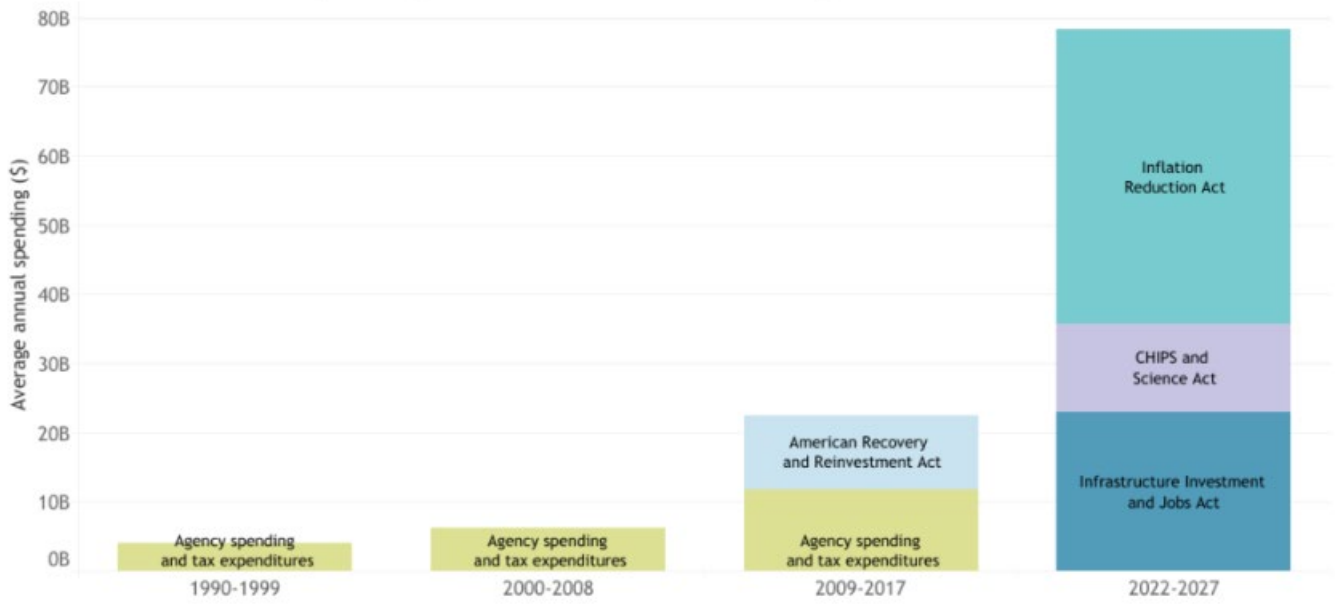
+

Infrastructure Investment & Jobs Act (IIJA) - Backbone

+

Inflation Reduction Act (IRA) - Engine

Over the past 2 years, we have seen historic investment in federal climate spending.
Over the next decade, spending on climate will more than triple historic levels



Notes:
Average annual spending, adjusted for inflation. Note that time periods shift from 2000-2008 to 2009-2017. This is to 1) consolidate the impact of the American Recovery and Reinvestment Act to one bar and 2) address missing data between 2018-2019.

Values are based on RMI estimates using agency spending data from the Government Accountability Office (GAO), tax expenditure data from the Joint Committee on Taxation (JCT), and internal analysis on 2021-2022 legislation (Infrastructure Investment and Jobs Act, CHIPS and Science Act, Inflation Reduction Act). Spending from the American Recovery and Reinvestment Act is based on a White House memo on clean energy spending from 2010.

The averages for the Infrastructure Investment and Jobs Act, CHIPS and Science Act, and Inflation Reduction Act include both appropriations and authorizations. Note that CHIPS funding estimates are based on authorizations.

We do not include agriculture, land, or resilience appropriations from the Inflation Reduction Act in this figure because they do not directly target clean energy technology supply chains.

US Policy has implemented a **Carrot (Incentives)** and Stick (Regulations) approach.

Corporate & Societal Environment

GHG Reductions Targets Are Now Expected

More than **70 countries**, including the biggest polluters – China, the United States, and the European Union – have set a net-zero target, covering about **76% of global emissions**.

There are currently **8296 companies**, **52 sub-national regions**, **1136 cities**, **1125 educational**, **593 financial**, **64 healthcare institutions,** and **29 other organizations** in the Race to Zero - committed to **halving emissions by 2030** and achieving **net zero carbon emissions by 2050 at the latest**.

3,821 companies have committed to take action with **1,817** setting a Science-based Target, and **1,399** committing to net-zero.

At least **one fifth of the world's 2,000 largest public companies** have committed to meet **net zero targets**. The companies together represent sales of nearly **$14 trillion**.

Data from Race to Zero and SBTi are from October 2022

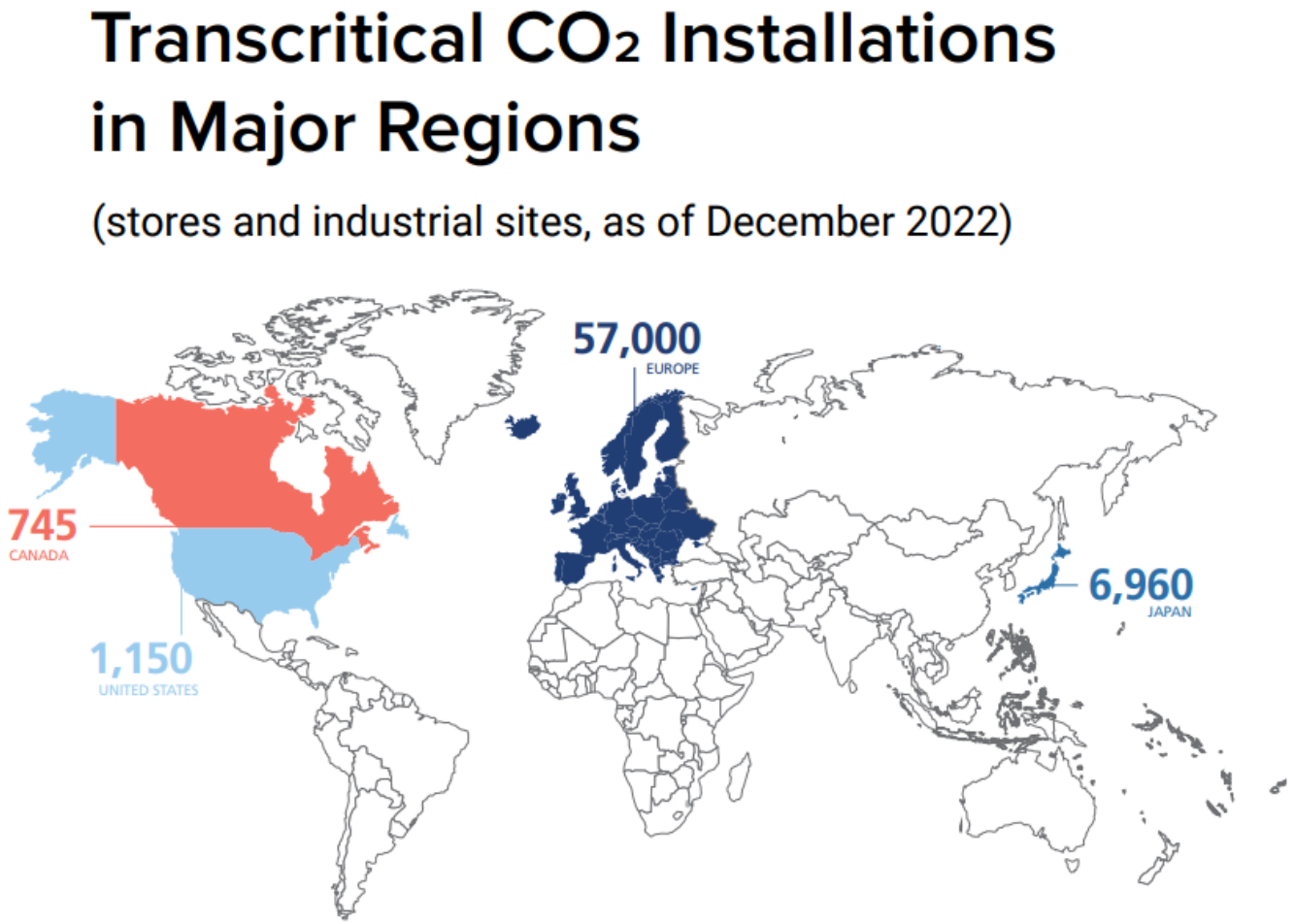
Refrigerant Summary

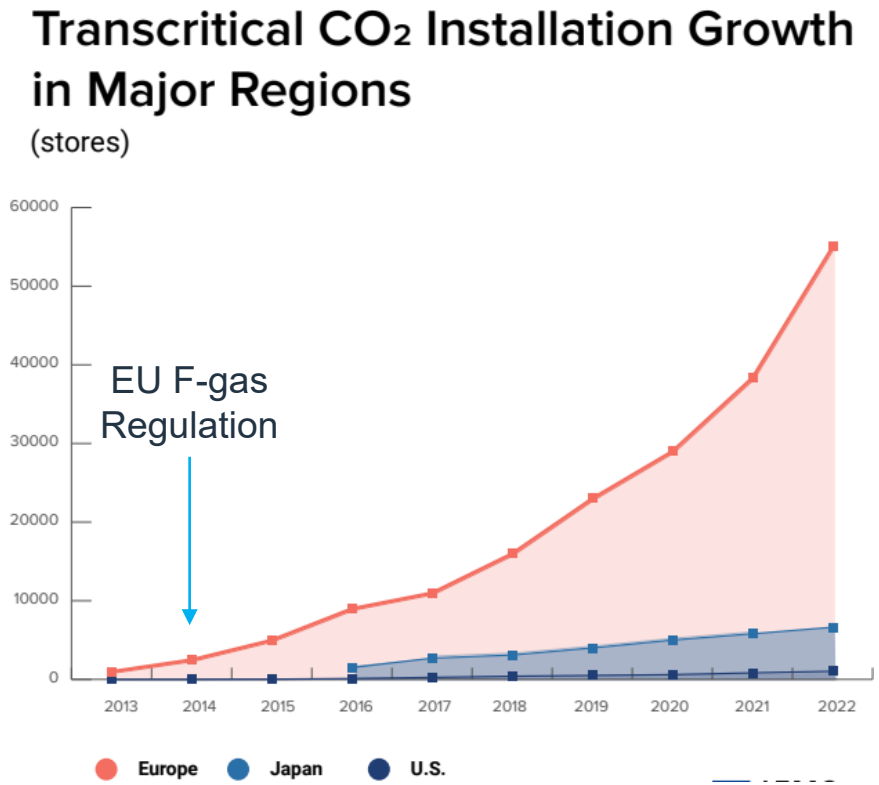
Refrigerant Category	Refrigerant(s)	Application	Ozone Depleting (Y/N)	Global Warming Potential (CO_2 = 1)
HCFC	R-22	All	Y	~1,800
Very High GWP HFC blends	R-404A, R-507A	Refrigeration	N	~4,000
High GWP HFCs & blends	R-410A, R-407A, R-134a, R-448A/R-449A	HVAC & Refrigeration	N	~1,400 - 2,200
Mid GWP HFCs & blends	R-32, R-513A, R-454B	HVAC & Refrigeration	N	~400 – 700
HFOs	R-1234yf, R-1233zd, R-1234ze	Motor vehicle AC, Chillers	N	<10
Natural	R-290, R-717, R-744	All	N	<10

- In the **EU**, most HFOs may be banned as toxic, environmentally harmful chemicals *(designated as PFAS under the REACH Regulation)*.
- In the **US**, regulatory action on HFOs as PFAS has not been announced but can happen. Several **US states** are taking the PFAS issue seriously.

Out of the available options, natural refrigerants are the most environmentally sustainable, future-proof refrigerants.

CO_2 Technology Global Footprint



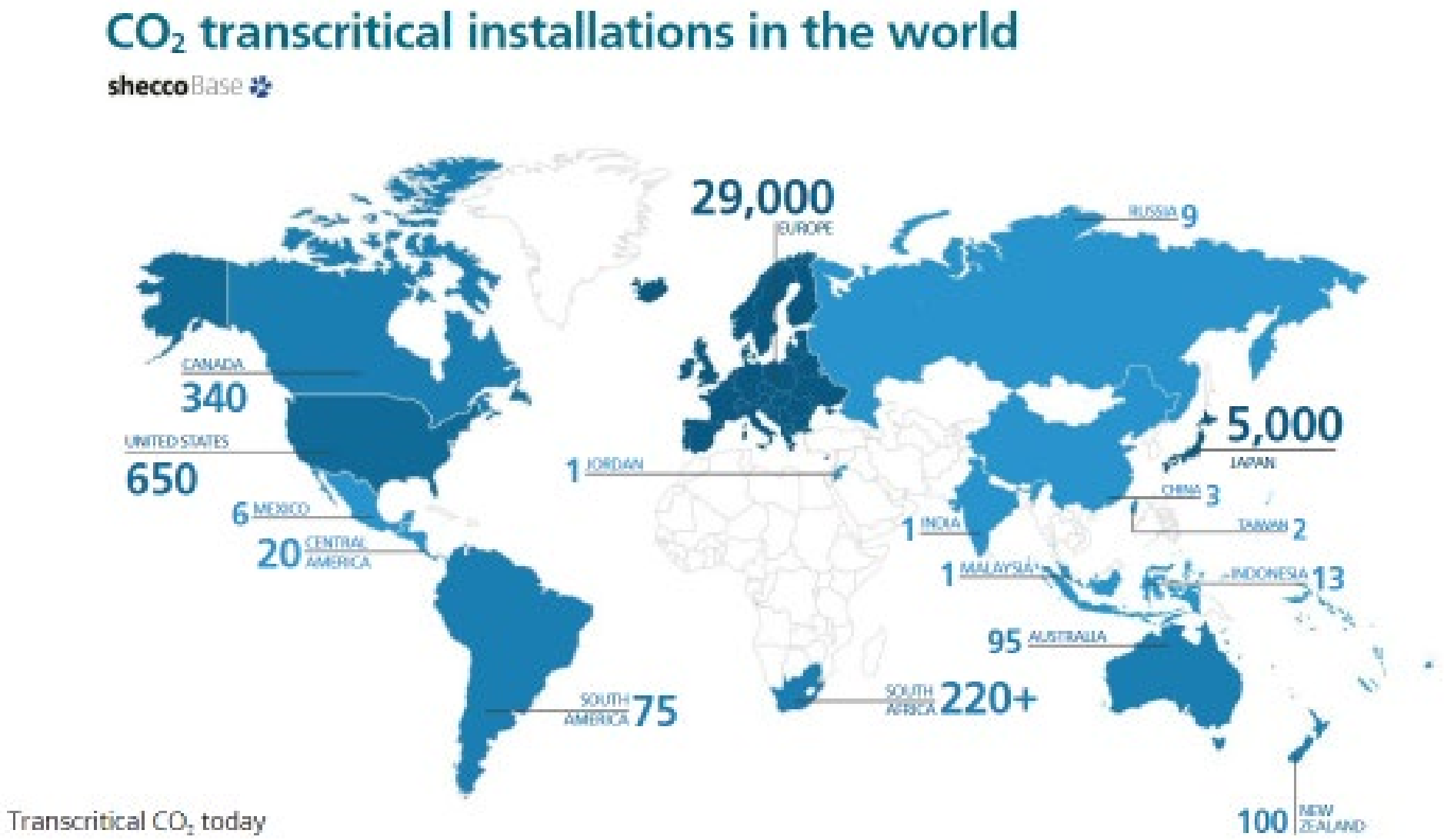


Exponential growth in CO_2 systems installed in the EU after the 2014 EU F-gas Regulation. AIM Act Regulations will likely do the same in the US.

CO_2 Technology related to HVAC/R applications is proven.

Source: ATMO Market Report 2022

CO2 Technology global footprint



CO2 Technology related to HVAC/R applications is proven.

M&M CARNOT

CO2 (R744) for Data Centers: The Practical Journey to Sustainability

Carnot Aquilon and Cumulus Data Center Cooling

By Jacob Wolfe, LEED AP

North American DC Representative

History

Carbon Dioxide : History of a Refrigerant

1850

Alexander Twining proposed CO_2 as a refrigerant in his British patent

1866

TSC Lowe (American) introduced CO_2 compressor

1866

First refrigeration system running on R-744

1920-30

Systems in subcritical operation

1928

CFC arrival on the market

1950

R-744 completely phased out

1989

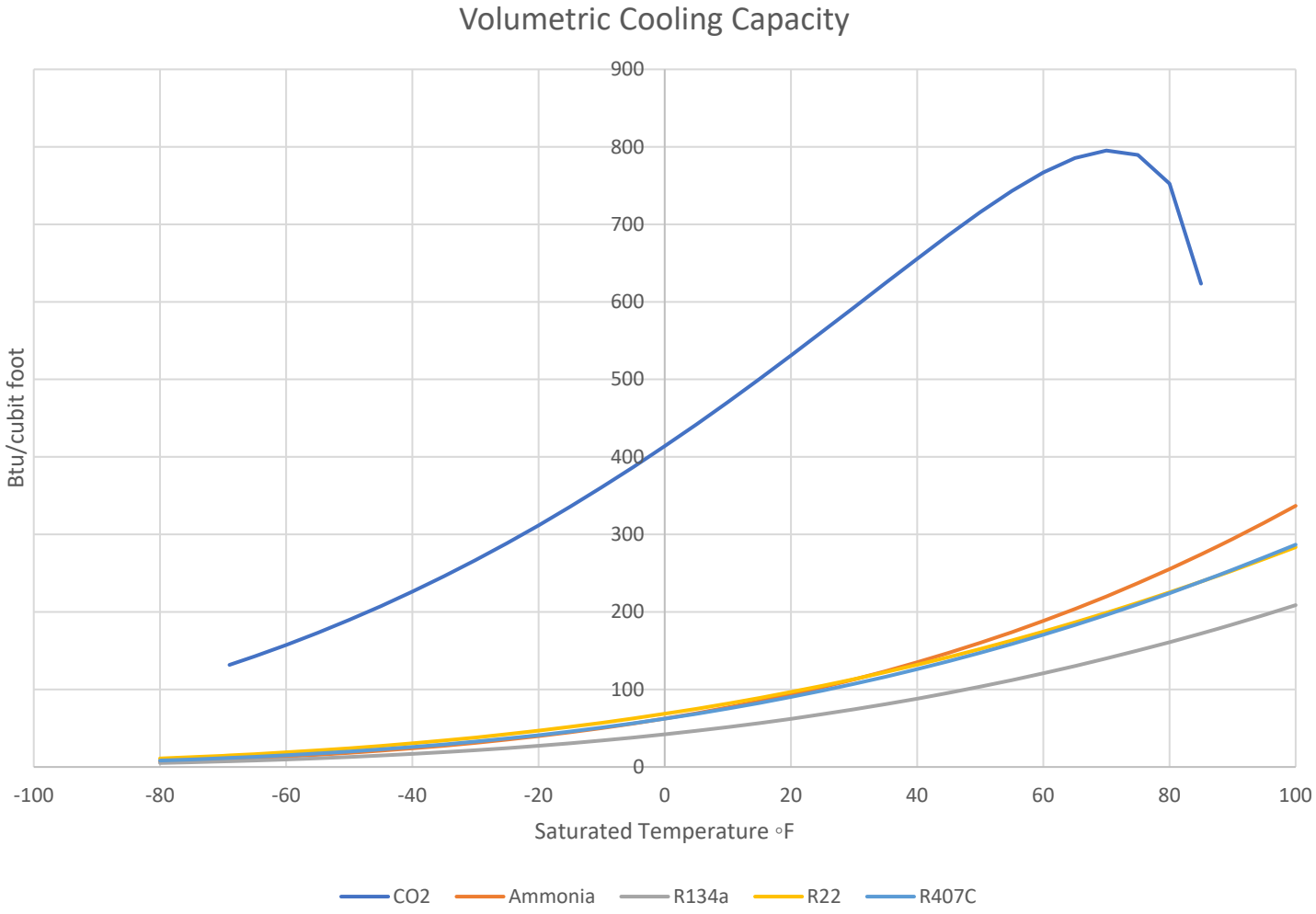
Montreal Protocol

1990

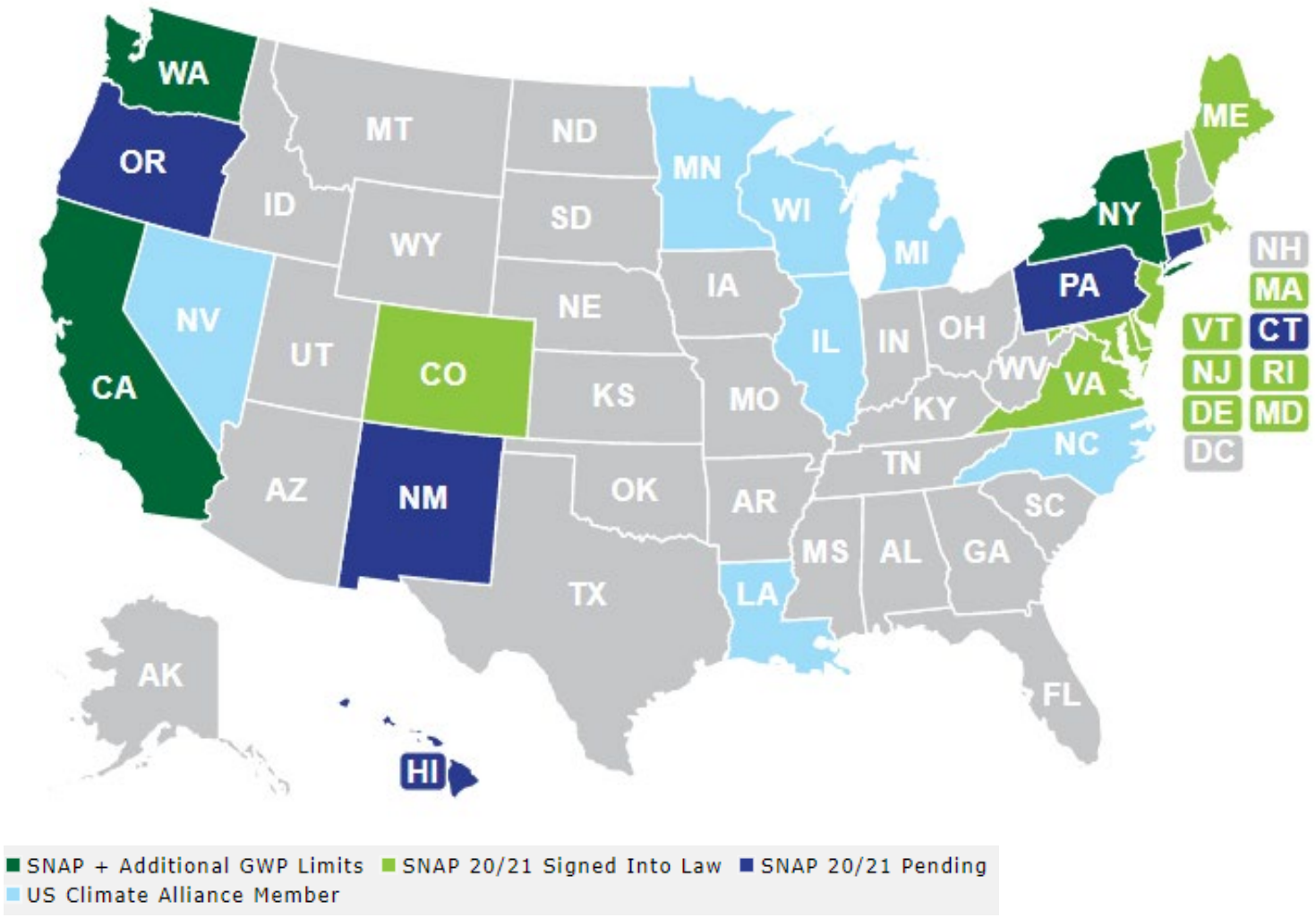
Renewed Interest in The early 90's

CO_2 Volumetric Cooling Capacity

- CO_2 Volumetric cooling capacity is 4 to 5 times greater than other refrigerants
- Smaller compressors
- Smaller components
- Less refrigerant charge
- Smaller equipment footprint



STATES WITH HFC LEGISLATION/REGULATIONS



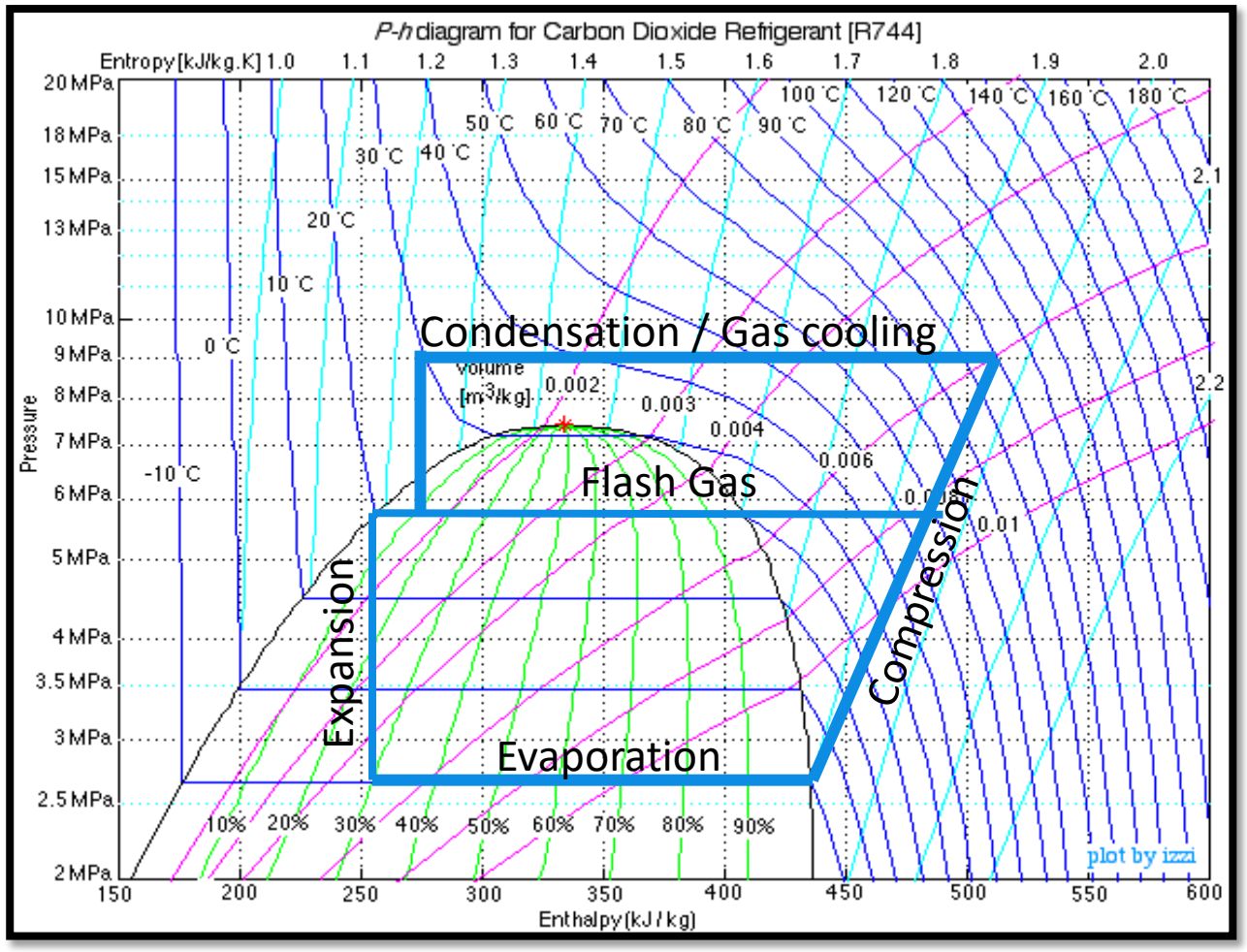
Source: https://nasrc.org/hfc-policy

- California: 750 GWP limit (manufacturing date)
  - January 2023 for PTAC and Window AC
  - January 2024 for Chillers-Comfort Cooling
  - January 2025 for Direct HVAC other than VRF
  - January 2026 for VRF
- Washington State like California
- 12 states (light and dark green) have banned R410A and R134a in new chillers on Jan. 1, 2024
- R410A and R134a Chillers for Industrial Process Cooling appear legal in all states, except CA and NJ, until EPA rules hit on Jan. 1, 2025

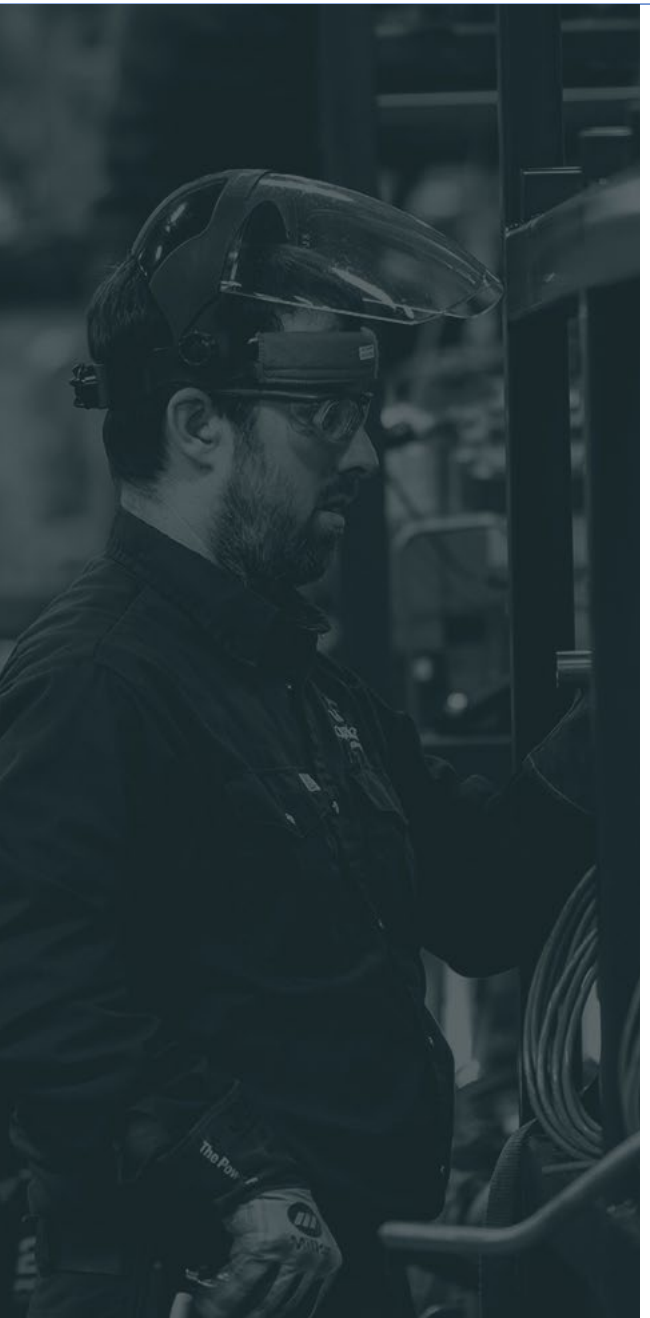
CO_2 Operation: 3 Modes

1. Transcritical
2. Subcritical (Condensing)
3. Free Cooling (Economizer)

CO_2: Transcritical Compression Cycle

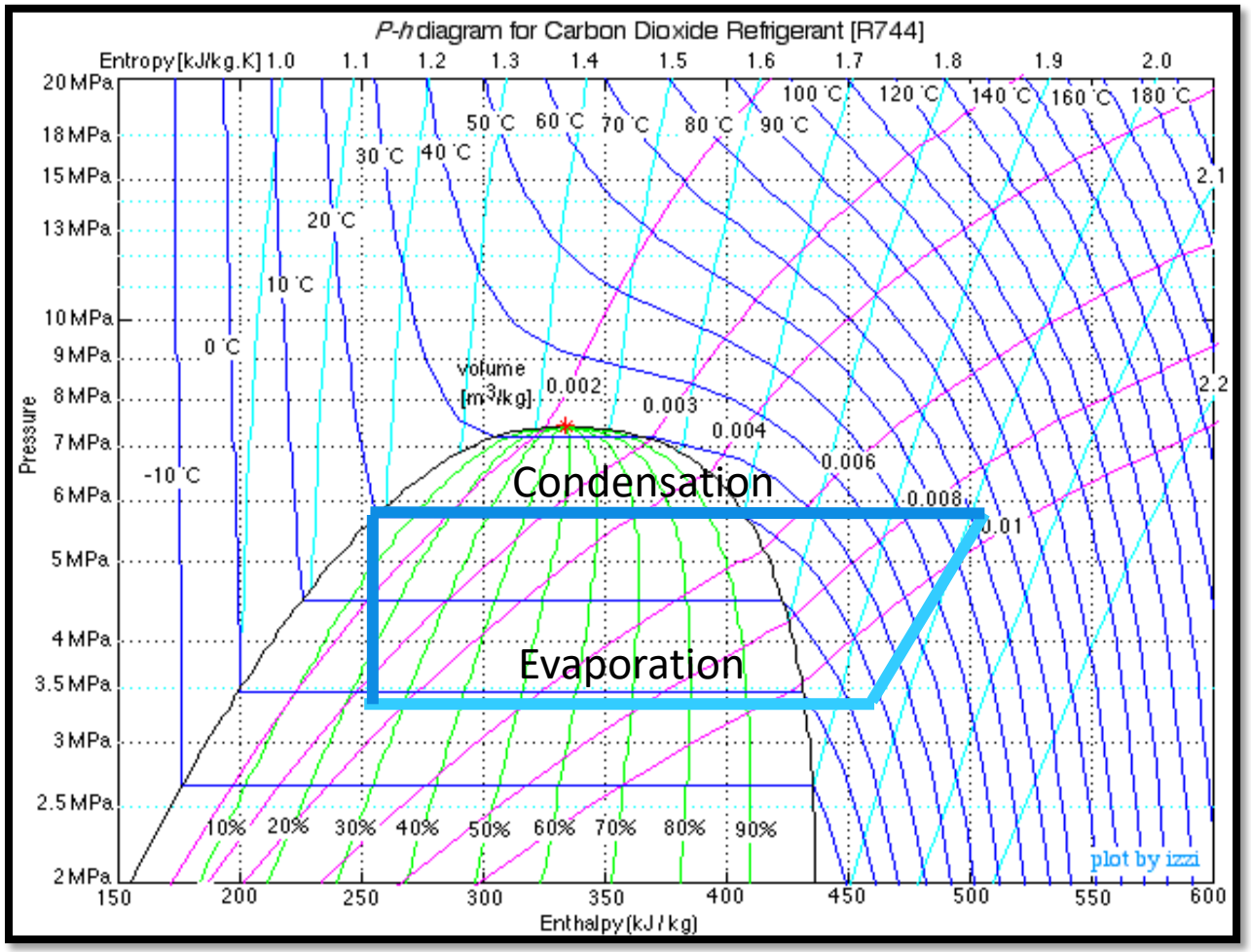


- Operation mode when the heat rejection is done at temperatures under CO_2's critical temperature
- Condenser becomes a gas cooler
- Less efficient than certain synthetic refrigerants
- Usually a small portion of the year
- ***Possibility of adiabatic gas cooling to eliminate transcritical operation***



CO_2: Subcritical Compression Cycle

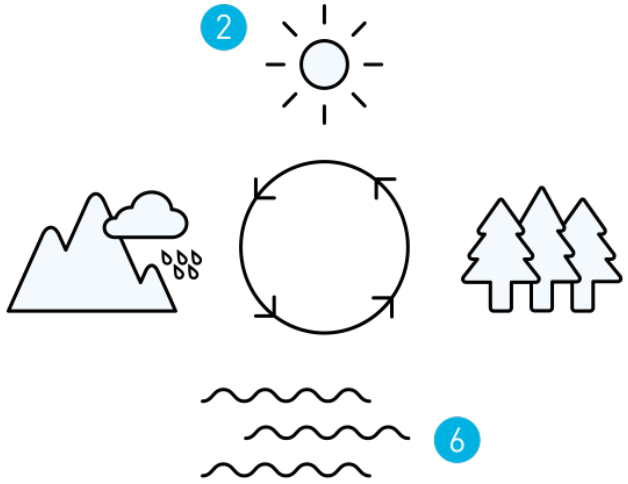
- Operation mode when the heat rejection is done at temperatures under CO_2's critical temperature
- 30.98C / 87.76F
- High pressure gas condenses at the condenser
- Between 55-72bar (800psi-1040psi)



CO_2 FREE-COOLING (Economizer) CYCLE

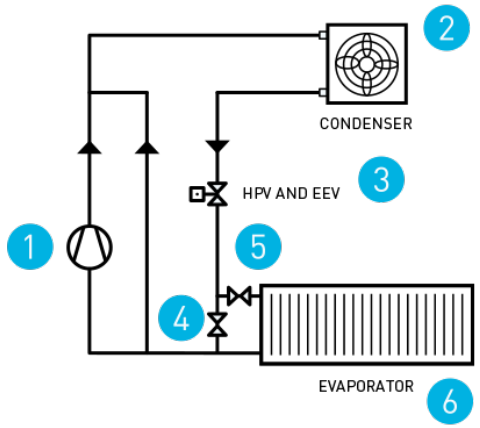
Thermosiphon (Gravity)

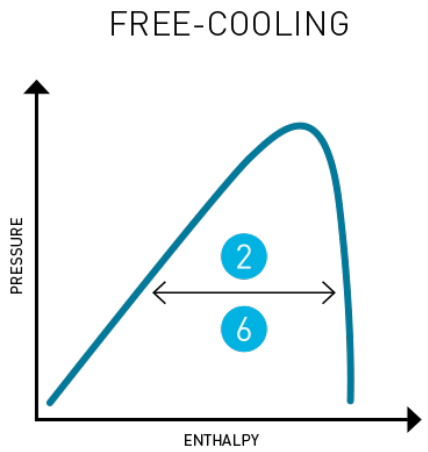
NATURAL
RAIN CYCLE

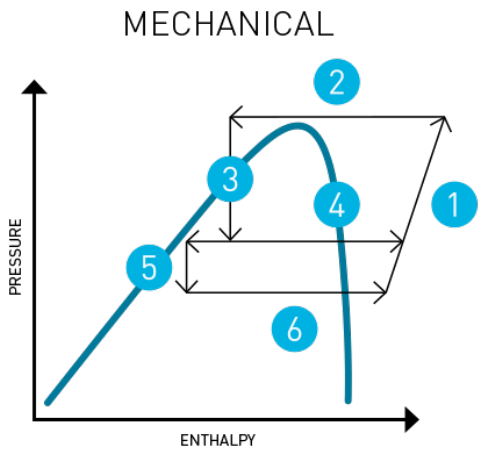


2: CONDENSATION
6: EVAPORATION

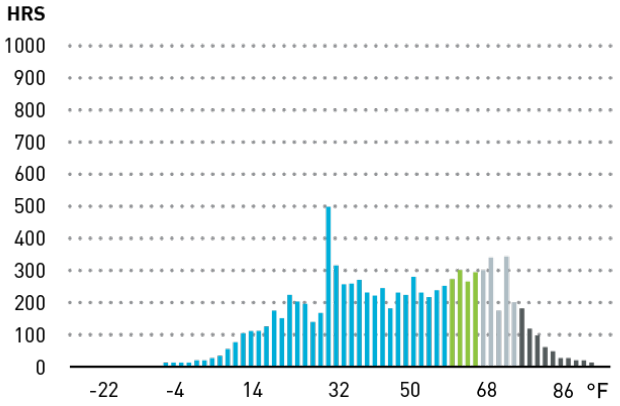
FREE COOLING IN PH DIAGRAM



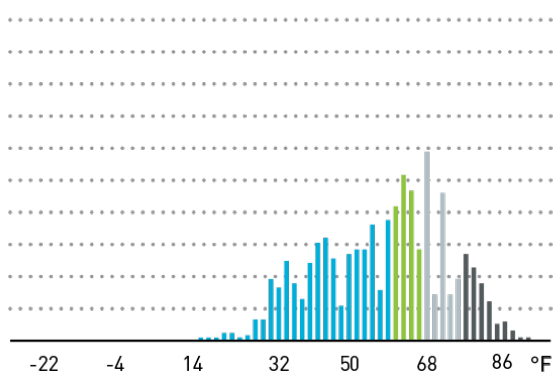




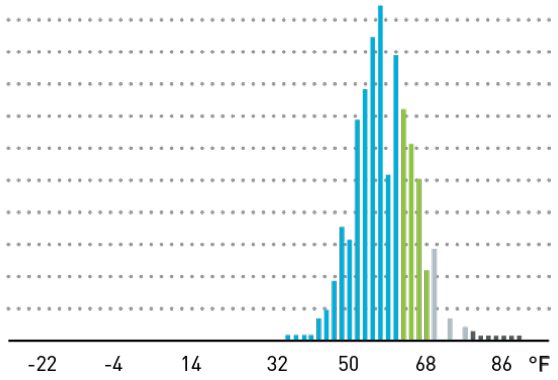
CO_2 Advantages: Rain Cycle Free-Cooling™



MONTRÉAL



NEW YORK

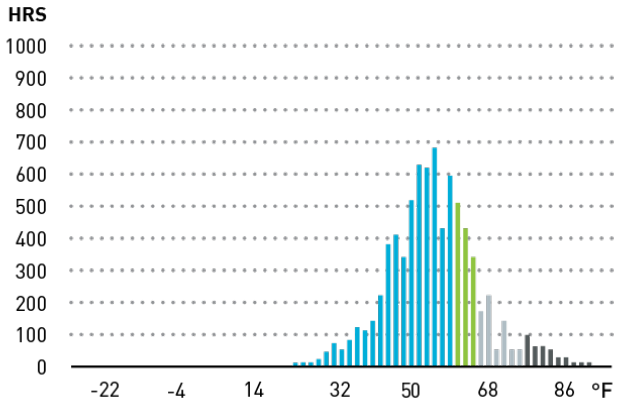


SAN FRANCISCO

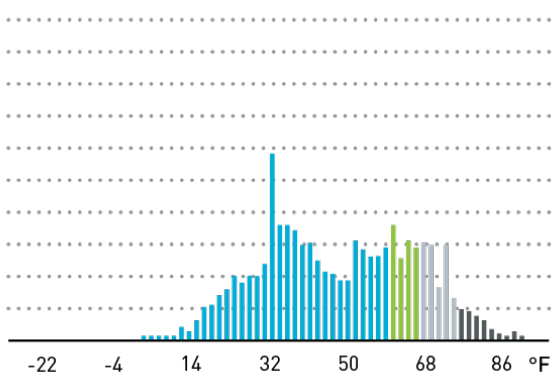
FREE COOLING OPERATION
MECHANICAL MODULATION
SUBCRITICAL OPERATION
TRANSCRITICAL OPERATION

kW [kW] TOTAL POWER CONSUMPTION FOR 80% LOAD
pPUE POWER UTILISATION EFFECTIVENESS

Notes : Data for Cumulus 10 (40kW) with an IRC12 "Naturally Cooled by Carnot," based on a supply air temperature of 24°C (75°F) and outdoor air temperature of 35C (95°F).



SEATTLE

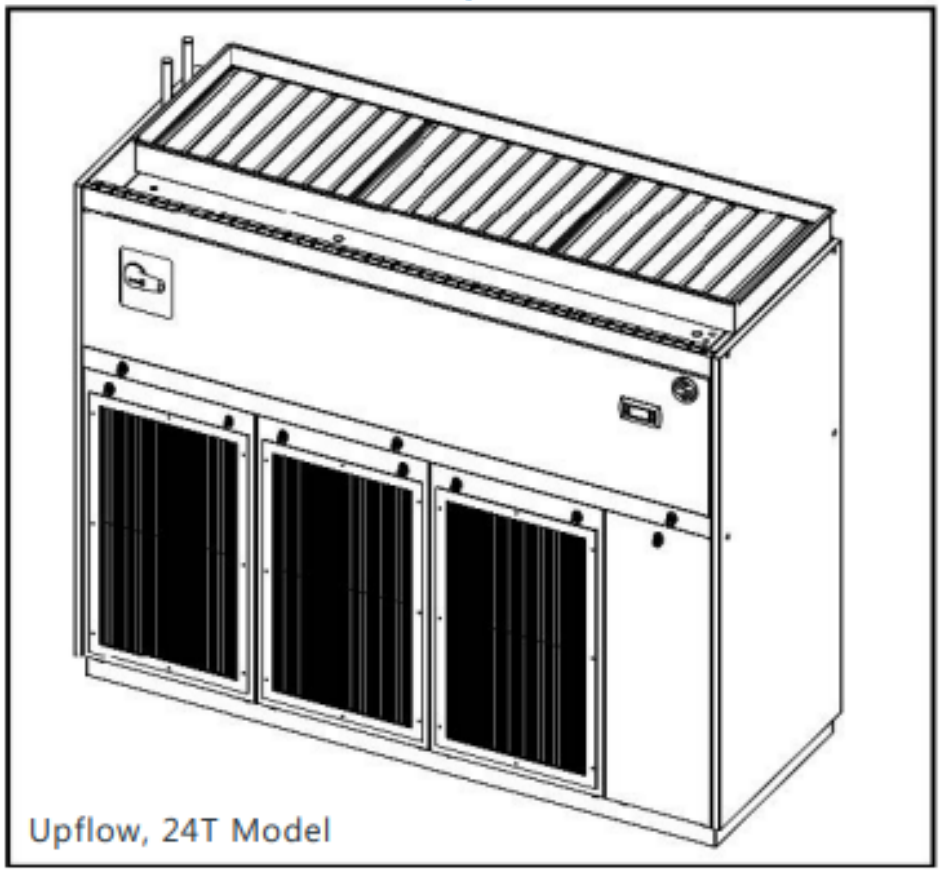


TORONTO

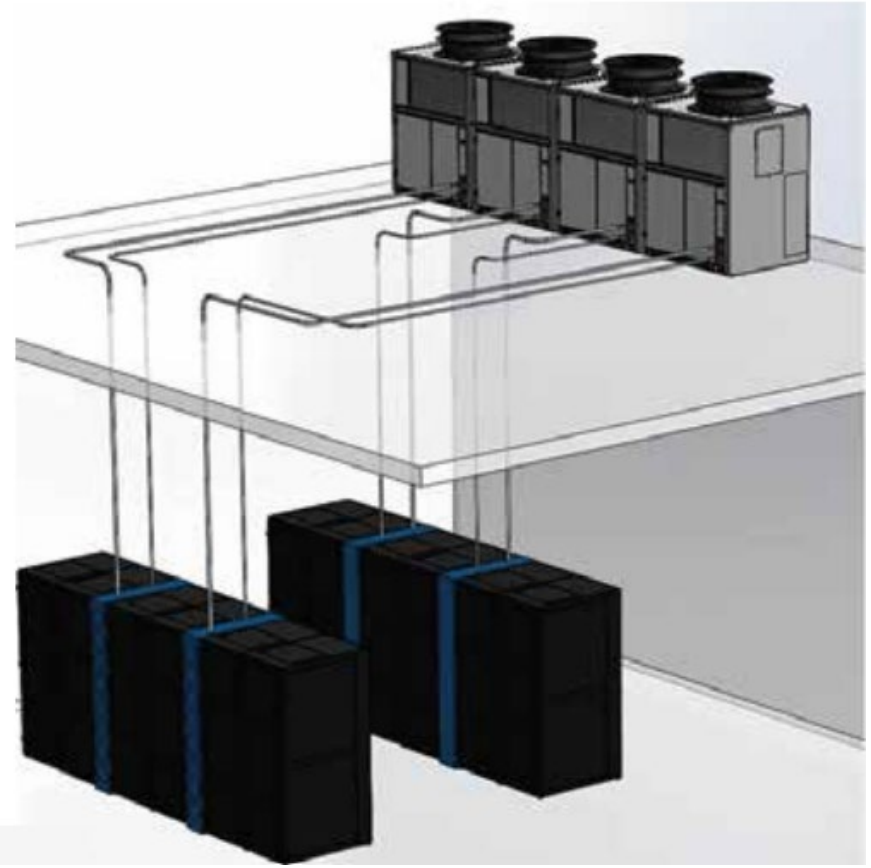
Product Offerings

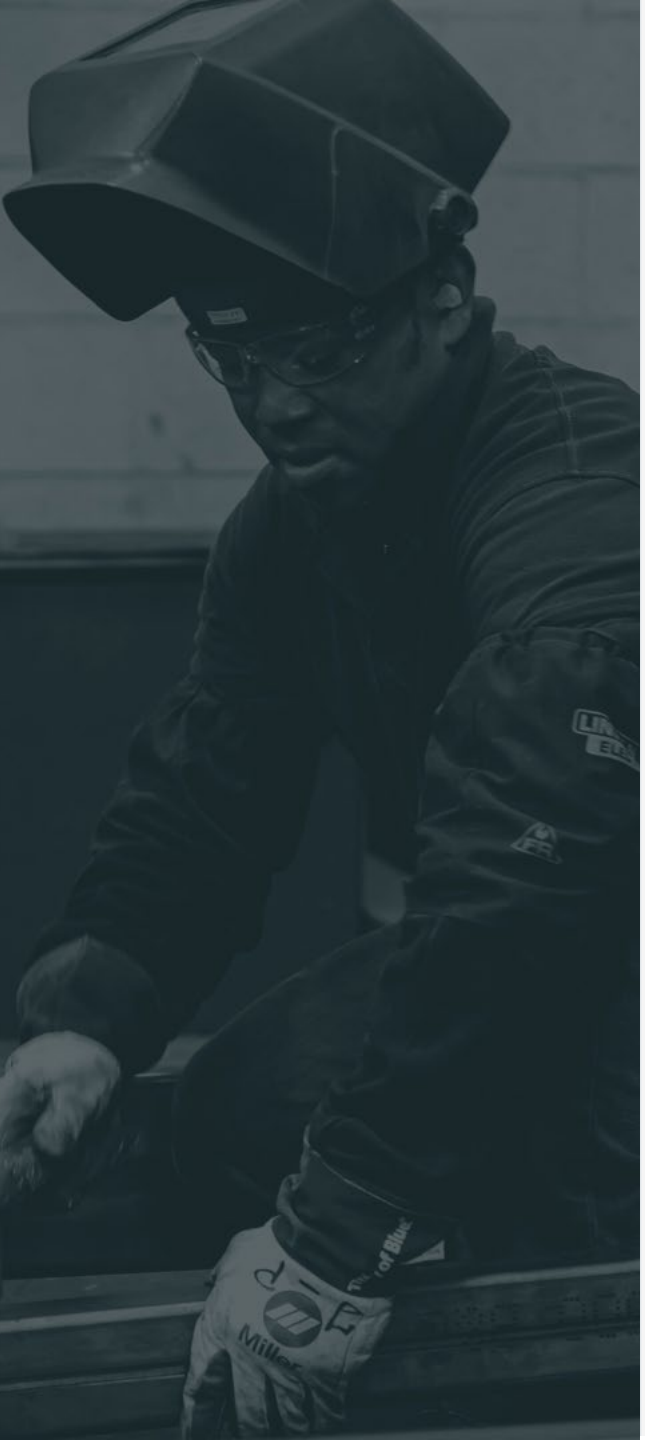
TWO (2) TYPES OF STANDARD UNITS

CRAC Perimeter: 52kW, 84kW, 105kW, 168kW capacities (275kW coming soon)



InRow: 40kW capacity (100kW coming soon)

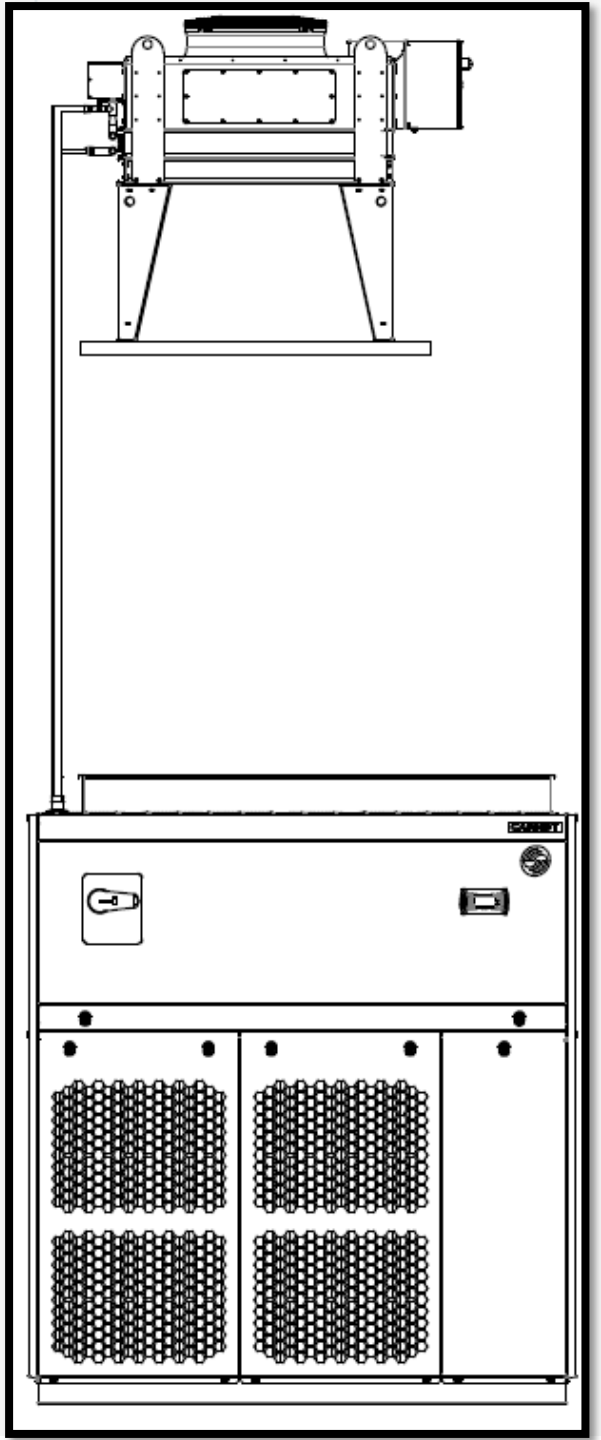




AQUILON CRAC with Air Cooled Gas Cooler

Unit Description

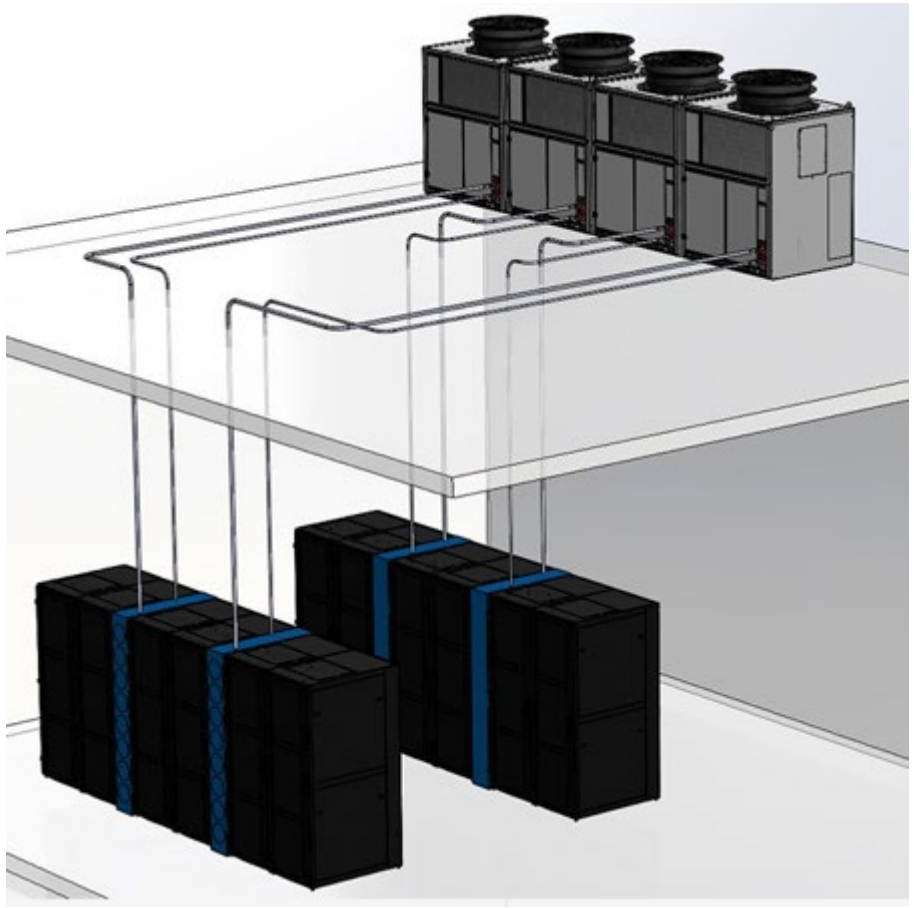
- Operates in compression mode and free cooling mode
- Gas Cooler installed higher than the CRAC unit outside
- CRAC Unit available in upflow and downflow configuration



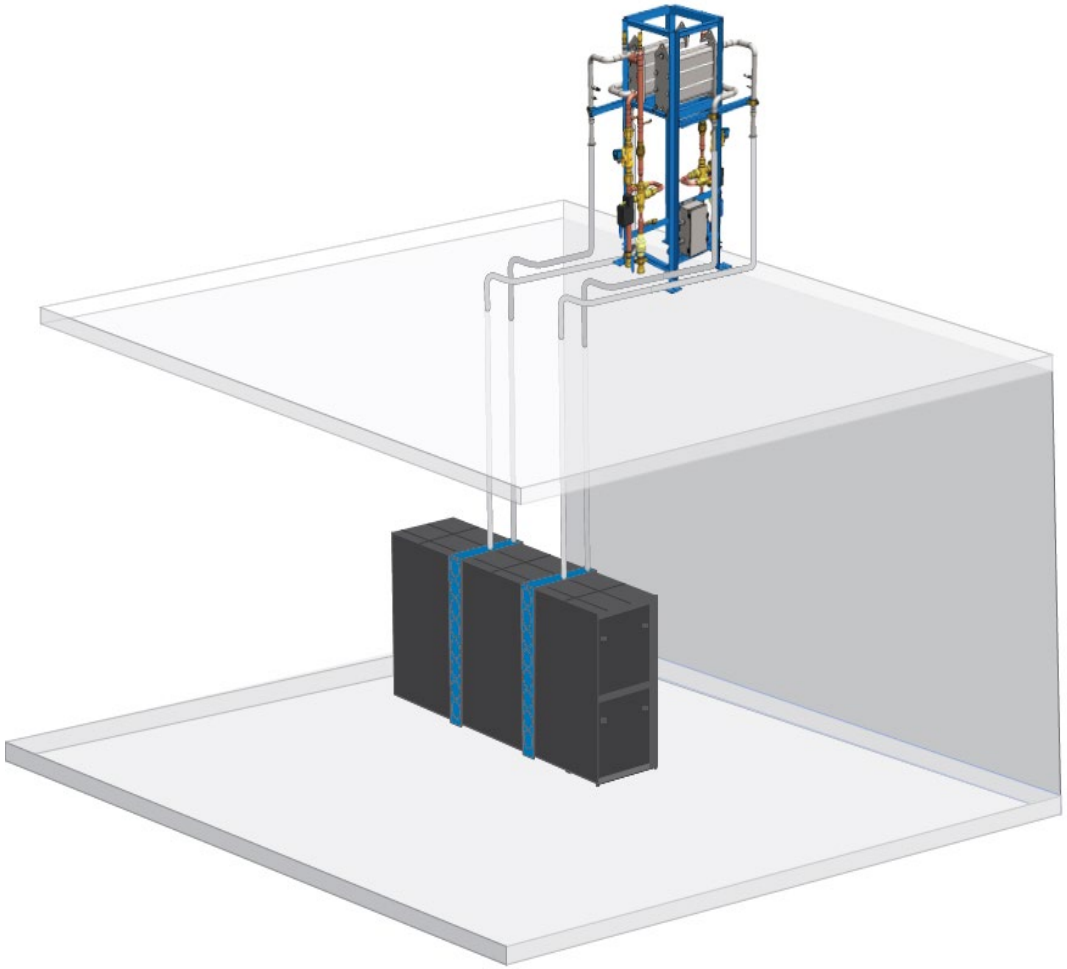
Cumulus (Natural Refrigerant In-Row system)
Capacity: 10TR (40 kW) → 1 unit (40 kW)

- Operational resilience
- No oil/water in the data room
- Energy savings over 70%

01 Option CO_2 / CO_2



02 Option CO_2 / Chilled Water



CO_2 Advantages: Rain Cycle Free-Cooling™

CRAC units

In Row units

M&M CARNOT™

Electrification: WSHP & ASHP

CO_2 Transcritical Heat Pumps with Heat Recovery

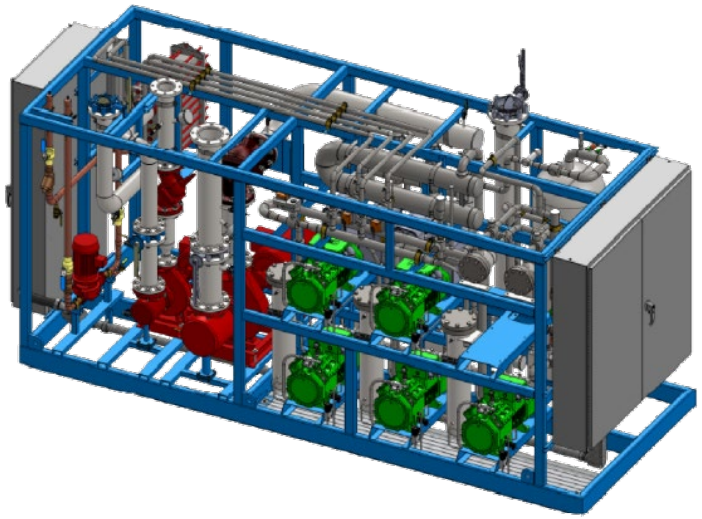
- **Complete and integrated solution**

– Process or HVAC chilled water loop

- Water, glycol, brine
- Down to -40°F process temp.

– Process or HVAC hot water loop

- Water, glycol, brine
- Combined EER (COP) up to 55 (16)



– Direct CO_2 to Domestic hot water loop

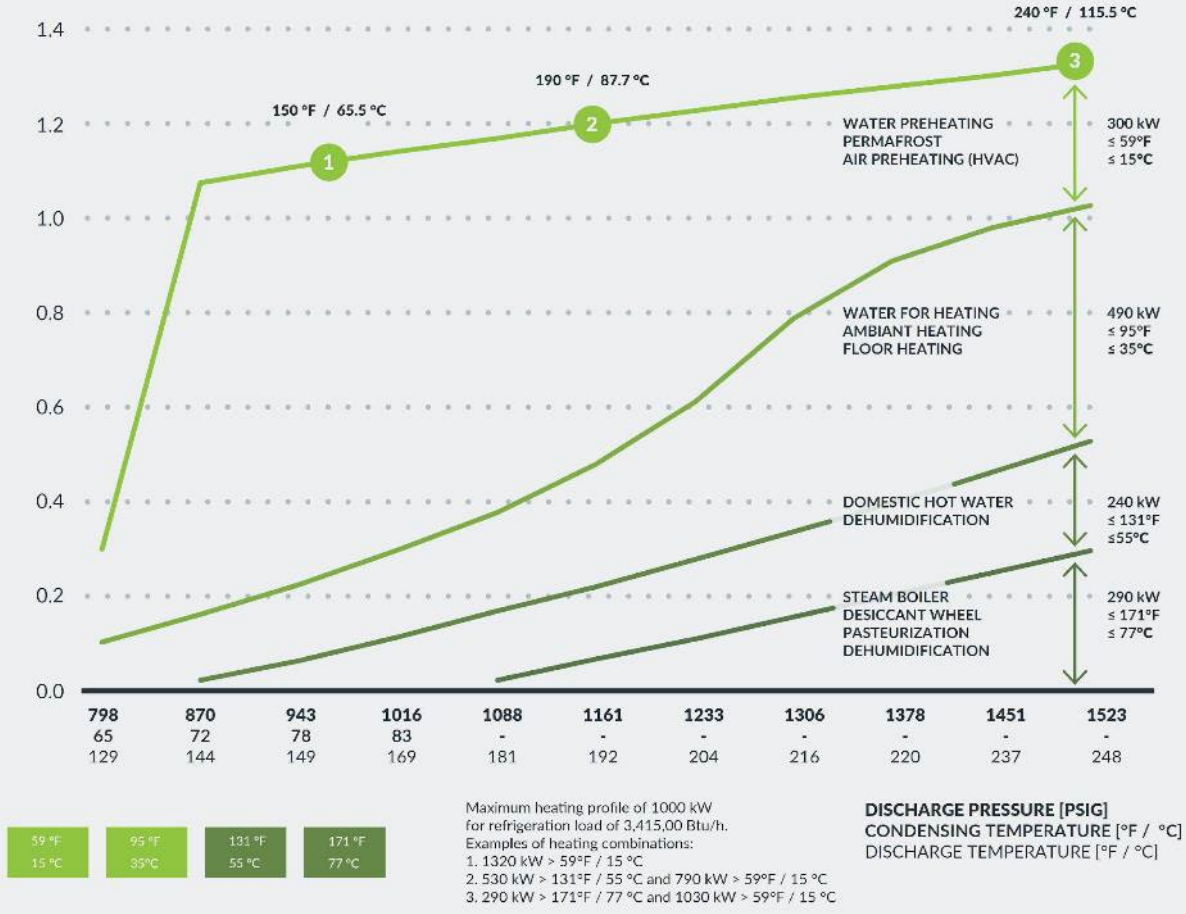
– Reduced foot print

– Full redundancy on key components

– Optional integrated pump skid

– Optional patented Rain Cycle Free-Cooling™

HEAT RECOVERY AVAILABLE WITH CARNOT CO_2 TRANSCRITICAL SYSTEMS



RCIntelligent is a smarter way to use the rejected energy of your process: system is composed of various components that recover energy rejected by the process in a smart and strategic way.

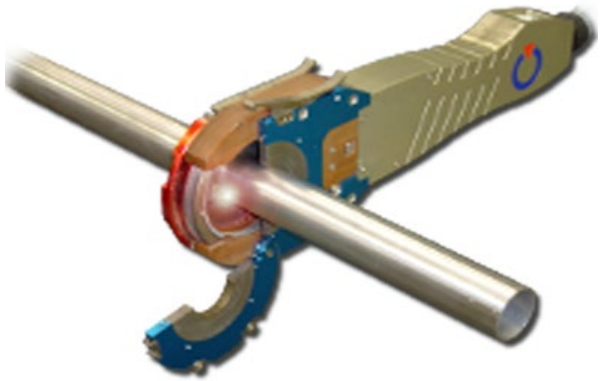
CO_2 TC Chillers

BEFORE

AFTER

Installation

- Stainless Steel Tubing per ASTM A249 TP304
- Orbital Welding (GTAW)
- No fittings: Tubes bended for direction change



Requirements

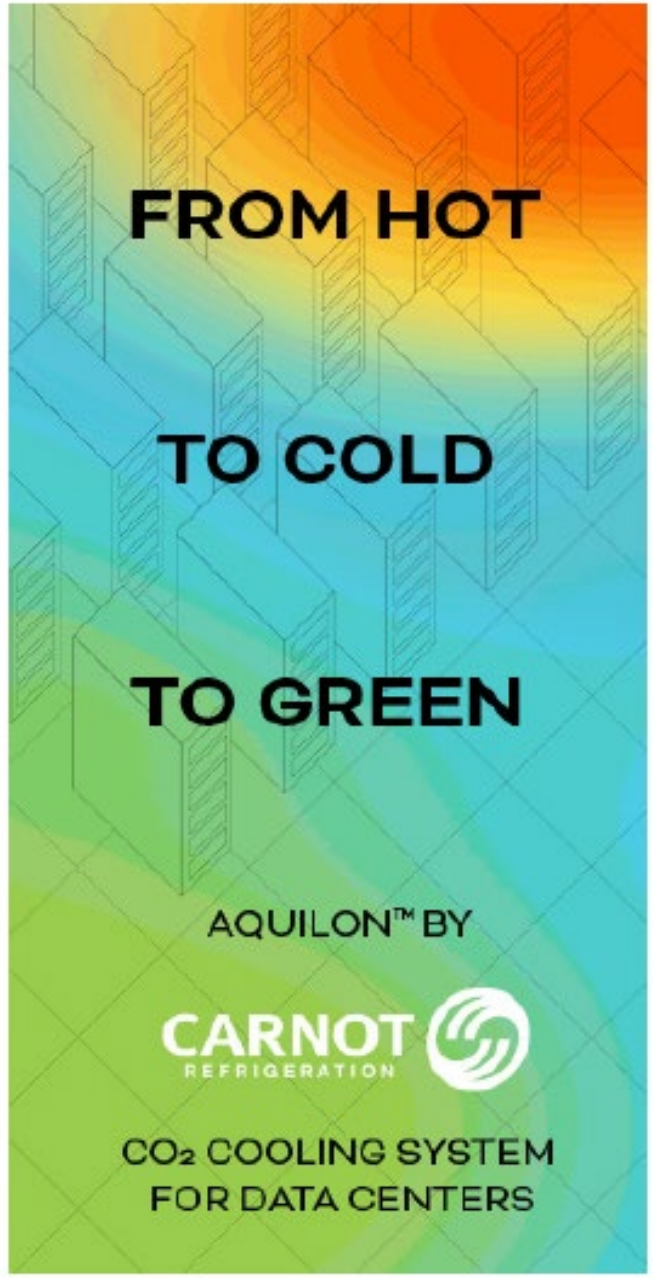
- Installation requirements same than for standard refrigerants
  - CSA
  - B52
  - Authority Having Jurisdiction

R744 – SAFETY RULES

- CO_2 – R744 is odorless and colorless and naturally present in the air at a concentration of about 400ppm
- Long term exposure limit – 8 hours – 5,000 ppm
- Short term exposure – 15 minutes – 15,000ppm
- Makes sure room meets ventilation exhaust and detection codes
- Room should be equipped with CO_2 sensor to alarm at elevated CO2 concentrations.
- CO_2 is heavier than air, CO_2 sensors should be mounted as low as possible near the unit if required.

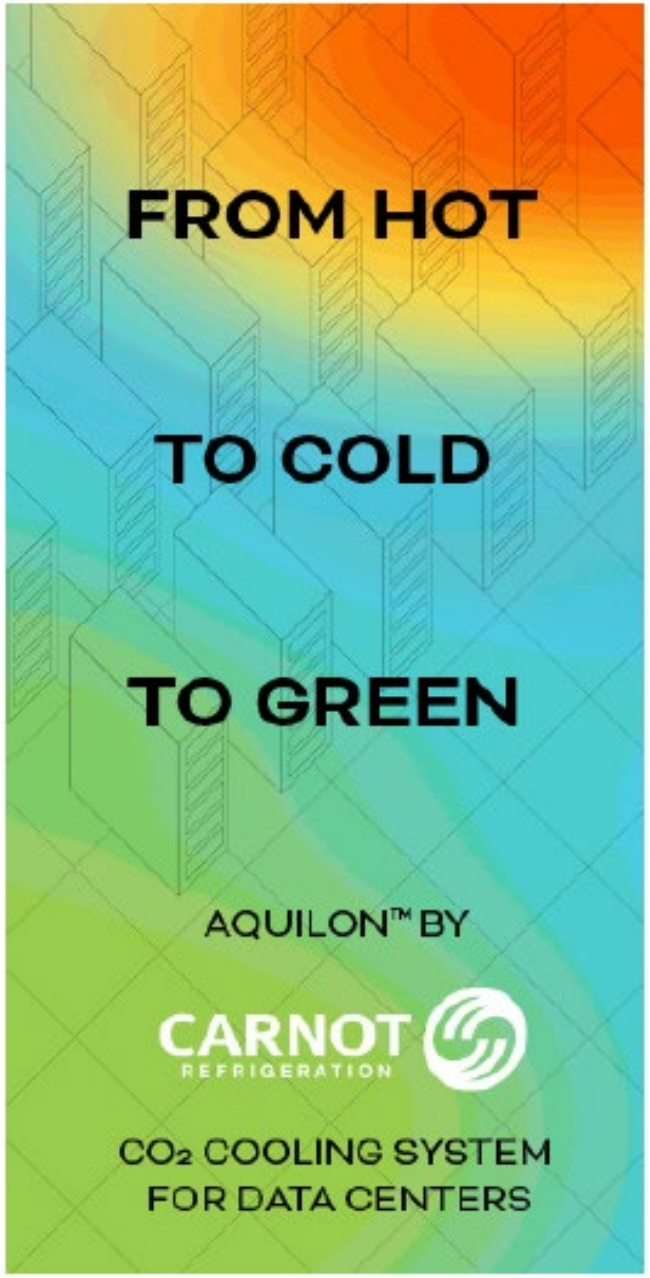
Frequently Asked Questions

- Do you need a recirculation pump for CO_2 – R744?
  - ✓ Ans: No! This is due to the Thermosiphon Principle for free cooling, gravity returns refrigerant to evaporator
- Is there a maximum elevation difference between the evaporator and gas cooler?
  - ✓ Ans: No. The higher the distance, the stronger the pressure. For every 1°C = 30psi
- Are we able to perform well in high ambient regions?
  - ✓ Ans: Yes, it will perform on design days in transcritical mode. An Adiabatic Gas Cooler is available to lower the amount of transcritical hours saving energy.



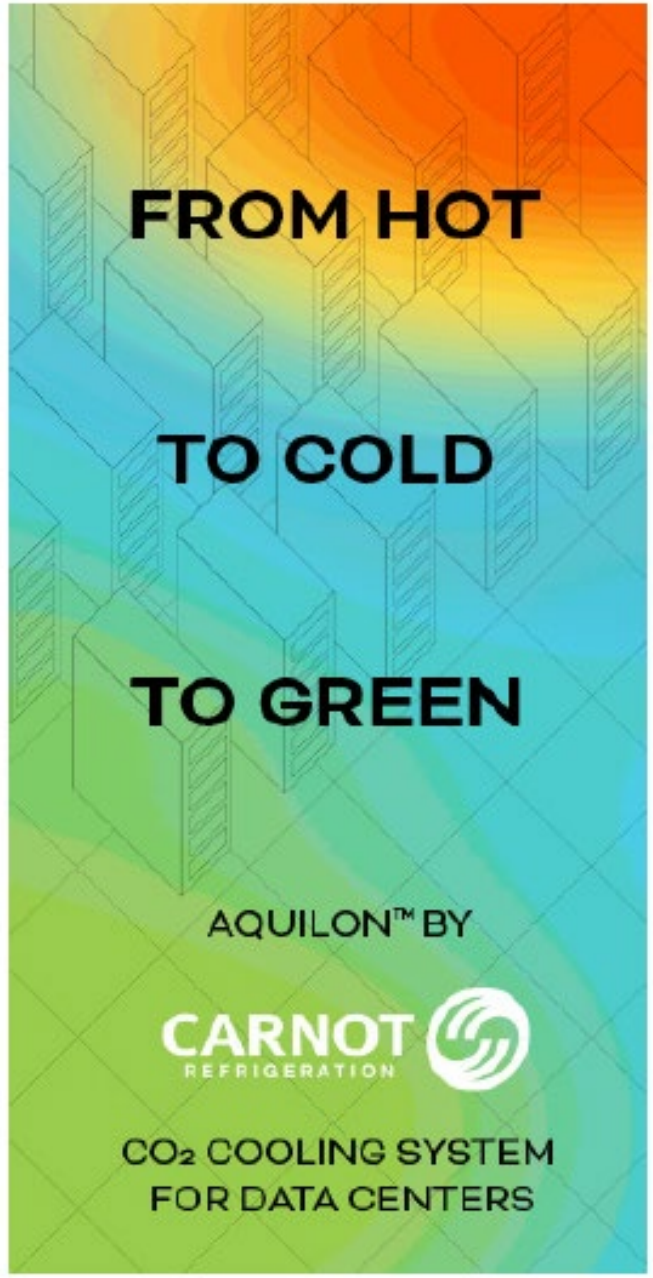
Frequently Asked Questions

- Should I be concerned about the high pressures for CO_2 – R744?
  - ✓ Ans: No! There are hundreds of installations for DC's and other markets (refer to case studies). The relief valve provides protection when operating in transcritical mode.
- How do the sizes of the units compare?
  - ✓ Ans: CO_2 has a higher heat capacity vs synthetics. Allows smaller HX, less charge for a smaller footprint
- Are components readily available?
  - ✓ Ans: Yes, CO_2 is standard in many industries. Lead times are running 24-30 weeks depending on quantities



Frequently Asked Questions

- How does the installation cost for CO_2 – R744 compare to a traditional synthetic installation?
  - ✓ Ans: Roughly the same given a qualified technician. SS tubes are smaller and there are less joints and no traps with bended tubing.
- What is the life cycle of the equipment?
  - ✓ Ans: 25+ years, with recommended installation and maintenance, SS is high quality, robust refrigerant piping, and orbital welding and less components, all play a factor increasing lifespan.



Case Studies

BELL Canada – Great for Replacement Market

- Elimination of any future phase-outs by using R-744, a natural refrigerant
- Significant decrease of Bell Canada's energy consumption related to the cooling (150,000 kwh / AQ15 unit, with an air return of 24°C / 75.2°F)
- Improvement in reliability and efficiency
- Reduction of maintenance costs (due to its simplicity)
- Positive cost-benefits ratio and overall profitability (ROI: 3 years)
- GHG reduction compared with older leaking systems
- Cooling Energy savings up to 80% (compared to older existing installations).

https://carnotrefrigeration.com/en/case-studies/data-center-cooling

Hannaford - Shodack Landing, New York

- One of the world's largest refrigerated spaces (250,000ft^2/23,226m^2) to use a transcritical system

- CO_2 was safest to replace R-22
- Technicians trained at factory
- Used adiabatic GC's to save energy

<u>Higher Pressures just a perception:</u>

- "It operates at a higher pressure, so right away people become nervous of those numbers," he said. "But it's a relative number. Your forklift carries a lot more pressure just in the hydraulic system, and nobody's worried about that." – Jim Baisley, Hannaford

https://accelerate24.news/regions/north-america/hannaford-pioneers-transcritical-co2-again/2020/

Carnot Data Center Chiller w/ Heat Reuse

- Downtown Office Space
  - 6 Chilled water CRAH units – Total 80 Tons (280kW)
  - Replaced chillers w/ Synthetic Refrigerant
  - Natural Gas Boilers for Comfort HVAC
  - Chilled Water loop temperature 13.3/6.7C ~44/56F
  - 10L/s or 160gpm
  - Heat Recovery – 300kW
    - 42.8C to 55C Hot Water (109F-131F)

Columbus Blue Jackets Arena – 2023/24 Season

https://r744.com/columbus-ohio-blue-jackets-to-be-first-nhl-team-to-use-co2-based-ice-rink-system/

Questions?

- Michael A. May, President & Chief Technology Officer, Effecterra Inc.

  Phone: 713.305.2484 | email: michael.may@effecterra.com

- Jacob Wolfe, USA Data Centers Representative, M&M Carnot

  Phone: 717.668.1154 | email: jacob.wolfe@mmcarnot.com