Transitioning to Alternative Refrigerants: Implications for Heat Exchanger Design

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Who are we?

Serving the HVAC&R industry through cutting edge research, state-of-the-art software, and performance measurements and verification new technologies that can reduce energy consumption and address growing environmental concerns.

Defend and grow markets for copper based on its superior technical performance and its contribution to a higher quality of life worldwide. Members include copper mining and fabricating companies

Presenters:

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Contents

Introduction

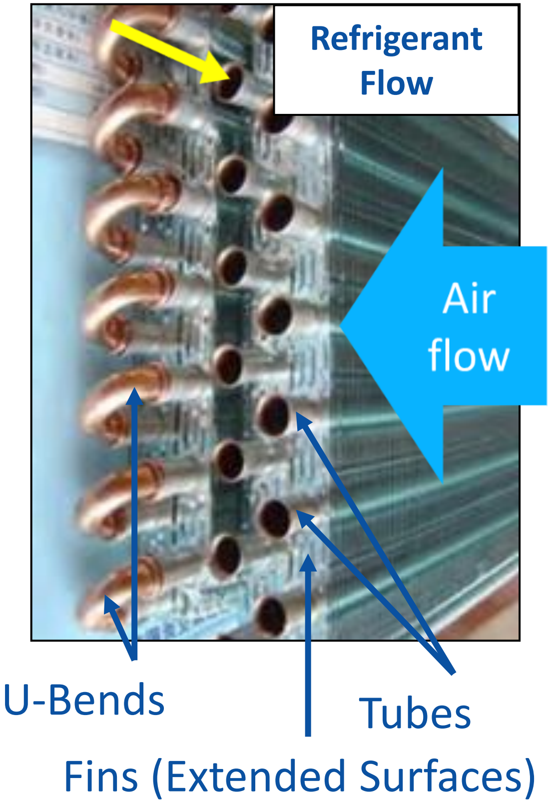
Previous Webinars

All Webinars are available on OTS website:

1. Advantages of Small Diameter Copper Tube Fin Heat Exchangers
2. Construction of Small Diameter Copper Tube Fin Heat Exchangers
3. Effective Design of Small Diameter Copper Tube Fin Heat Exchangers
4. Optimization, Cost and Health Benefits of Copper Tube Plate Fin Heat Exchangers
5. Transitioning to Alternative Refrigerants: Implications for Heat Exchanger Design
6. Small Diameter Copper Tube Fin Heat Exchangers and the Impacts of Frost

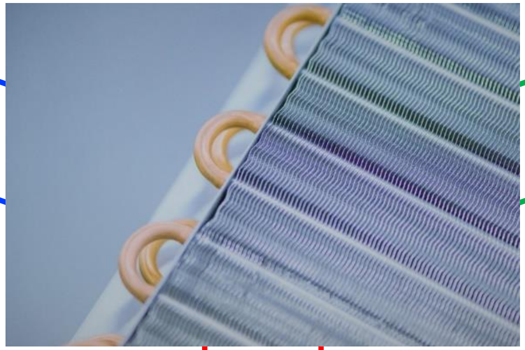
Heat Exchangers: Air-to-Fluid Tube-Fin

Parts and Working fluids



Refrigerants

Motivation: what drives heat exchanger design?



Energy Efficiency

- Energy consumed in buildings
    - COP
    - Billing Cost
    - Primary energy use
    - CO_2 emissions
- Partial load

Environment and Safety

- Direct refrigerant emissions
- Footprints (e.g. CO_2, end-of-life equipment)
- Material (resources)

Cost

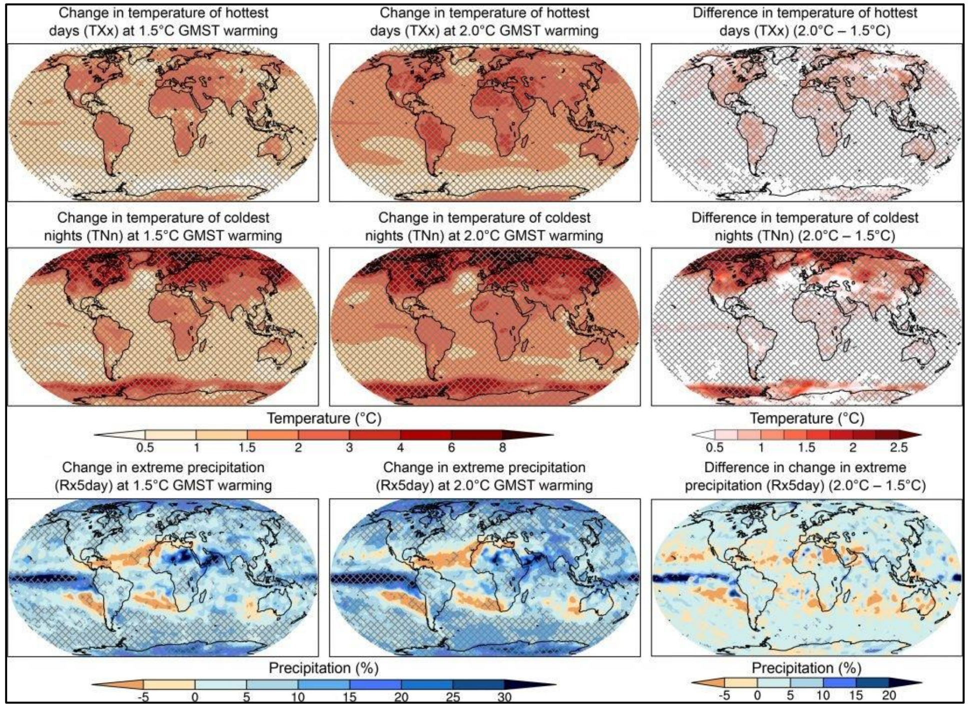
- Material
- Tooling
- Size / Weight

Motivation

Why change refrigerants again?

Motivation: The Big Picture

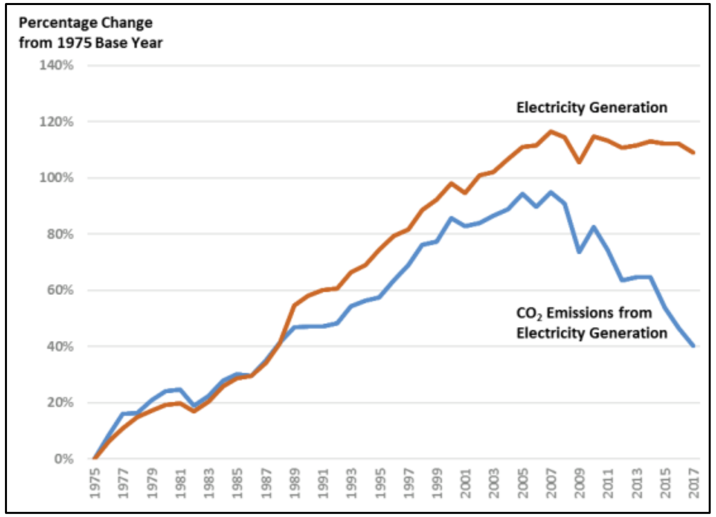
- **Avoid global temperature increase**
- **Refrigerants play a significant role**
  - **Kigali Amendment will avoid 0.5 ⁰C of global temperature increase**



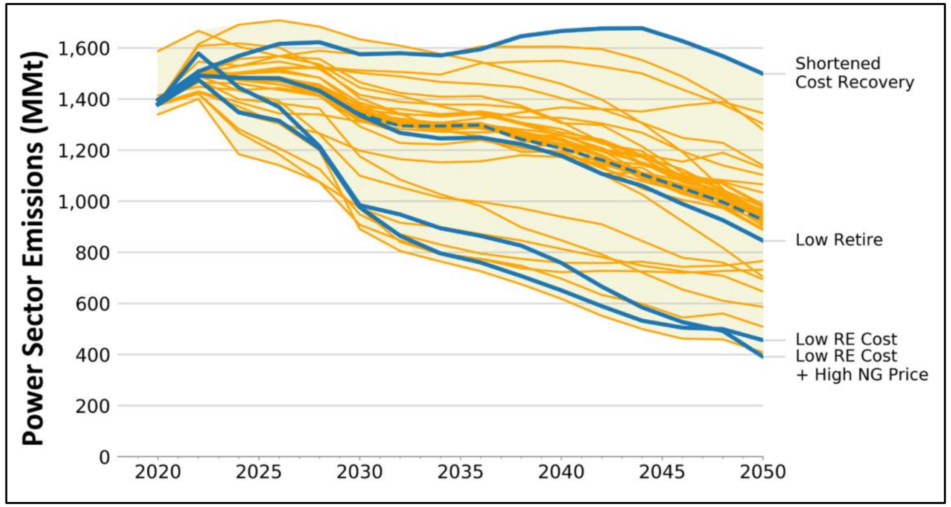
IPCC Special Report: Global Warming of 1.5 C (2019). Projected changes in extremes at 1.5°C (left) and 2°C (middle) of global warming compared to the pre-industrial period (1861–1880), and the difference between 1.5°C and 2°C of global warming (right).

How Important are Refrigerants?

- **Common HVAC perspective: Indirect emissions from energy consumption far outweigh refrigerant direct emissions.**
- **Things have changed:**
  - **Electric power sector emission have drastically dropped in the last decade**
  - **US grid will continue to decarbonize**



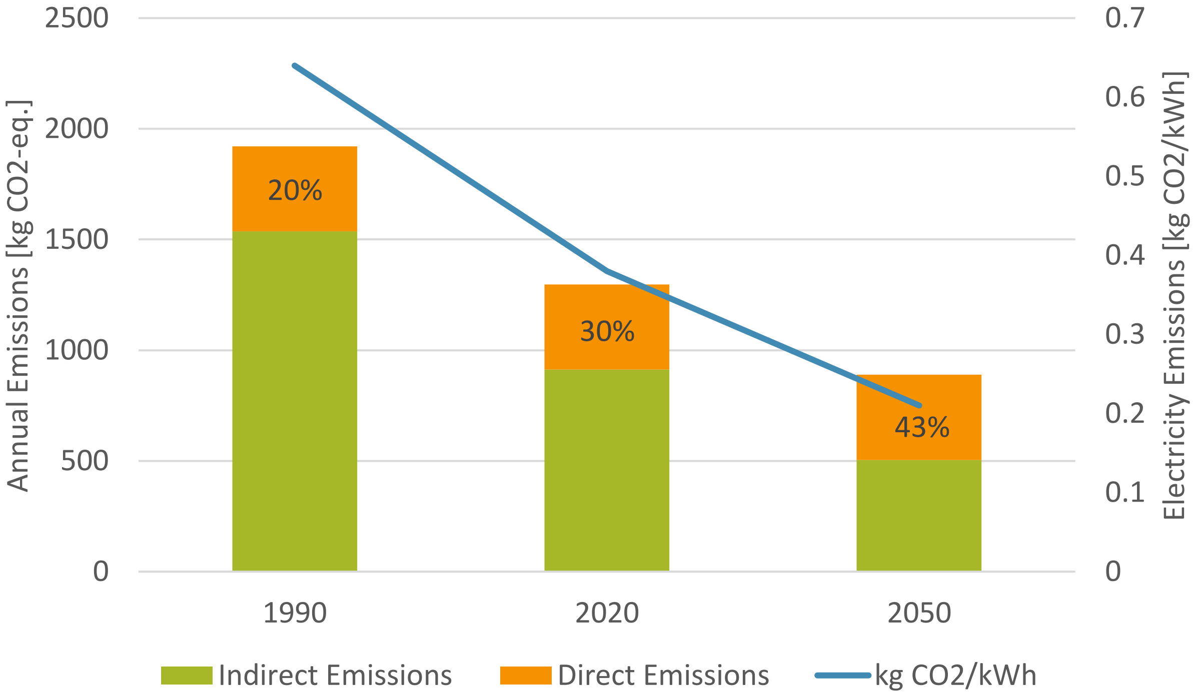
Congressional Research Service (2019). U.S. Carbon Dioxide Emissions in the Electricity Sector: Factors, Trends, and Projections.



Cole, Wesley, Sean Corcoran, Nathaniel Gates, Trieu Mai, and Paritosh Das. 2020. 2020 Standard Scenarios Report: A U.S. Electricity Sector Outlook. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-77442.

Simplified Example: 3-ton AC

- 4 kg R-410A, 4% annual leak rate, 15% end of life, 1924 GWP (AR5)
- 15 SEER, 1000 cooling hours/year = 2400 kWh/yr



Present/Past values: EIA March 2021 Monthly Energy Review
Future values: NREL Standard Scenario Mid-case

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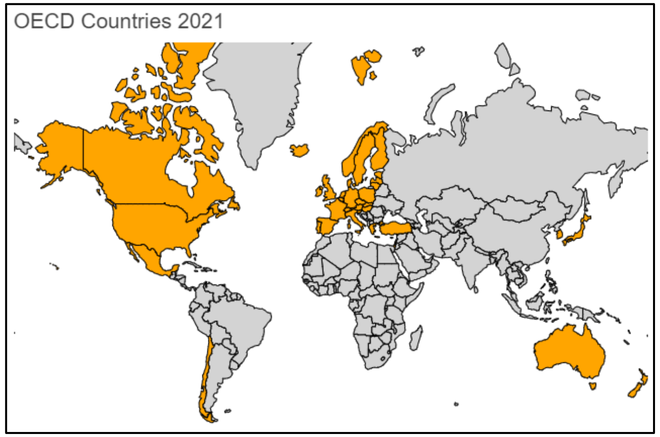
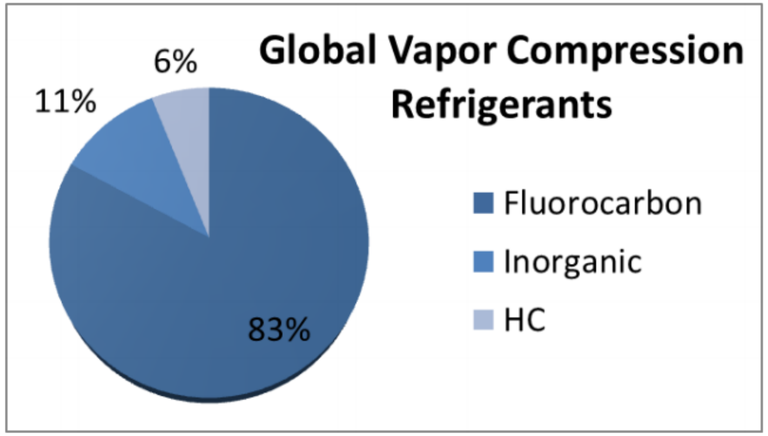
Refrigerant Market Growth

- 2010–2050: 4.5X increase in air conditioning for non-Organization of Economic Coordination and Development (OECD) countries, and 1.3X increase for OECD countries.





Refrigerants: Market Trends and Supply Chain Assessment, 2020. Chuck Booten, Scott Nicholson, Margaret Mann National Renewable Energy Laboratory Omar Abdelaziz Oak Ridge National Laboratory

- Widespread electrification efforts: adoption of heat pumps, heat pump water heaters.

If we use "business as usual technologies", we don't win!

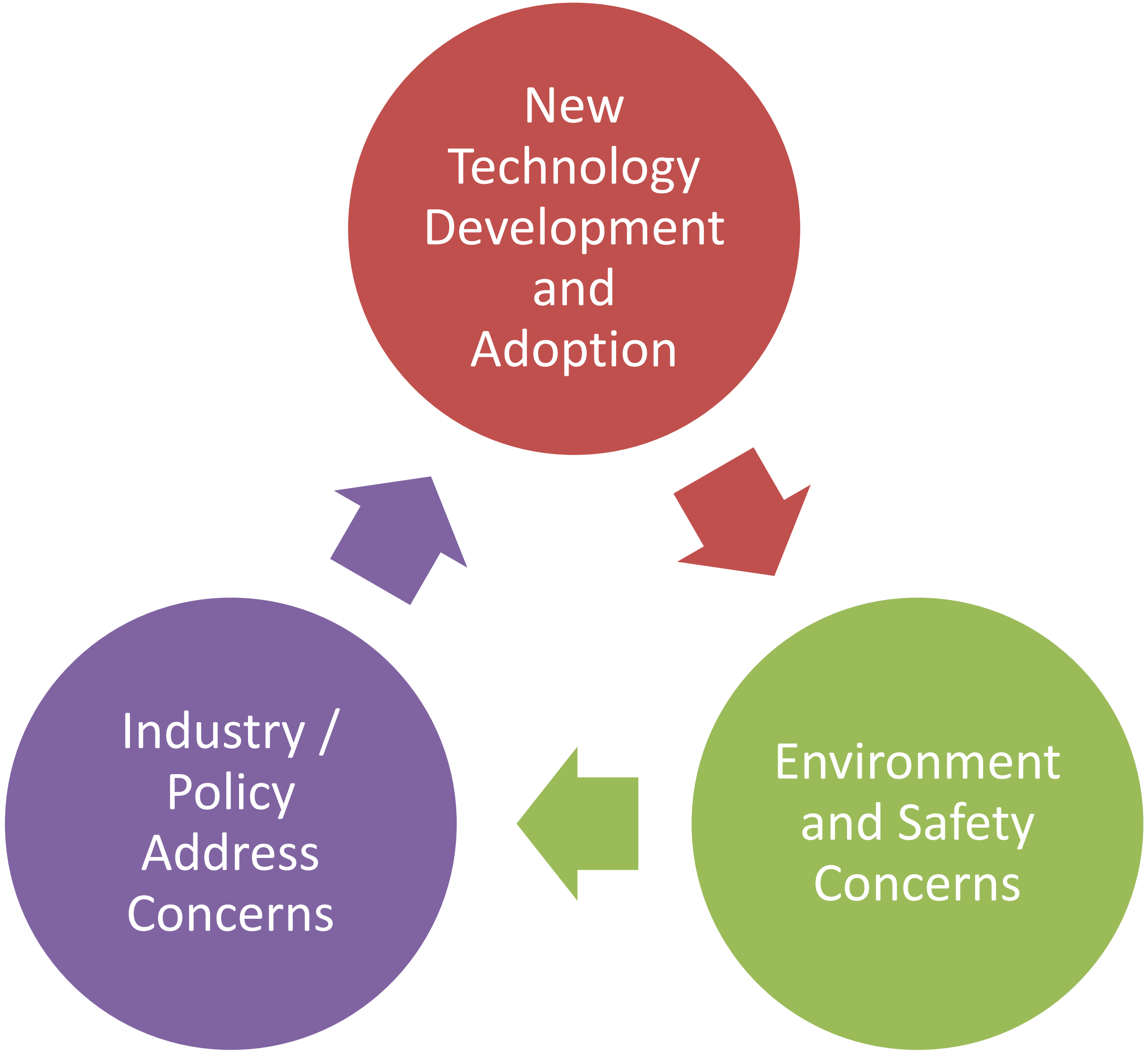
Alternative Refrigerants

Modern Definition

Historical Context

- 1800s – 1920s: First refrigerants were natural refrigerants, HC: ammonia, methyl chloride, CO2, etc
  - High levels leakage were assumed, and deemed too dangerous (flammability, toxicity)
- 1920s: CFC (R-11, R-12) production advancements allowed widespread adoption to alleviate safety issues associated with typical natural refrigerants
  - Low toxicity, low flammability
- 1970s: it was discovered that CFCs and HCFC have high ozone depletion -> Montreal Protocol in 1987 -> HFCs
- 1990s: HFCs were discovered to have high GWP
- Today: Transitioning to “modern” alternative refrigerants (HFO, HC, natural)

Alternative Refrigerant Cycle



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Alternative Refrigerants: Modern Definition

Modern definition of alternative refrigerant:

- Toxicity: low, depends on application
- ODP: 0
- Flammability: low, depends on application
- GWP: “low”
- Useful working range

Policy

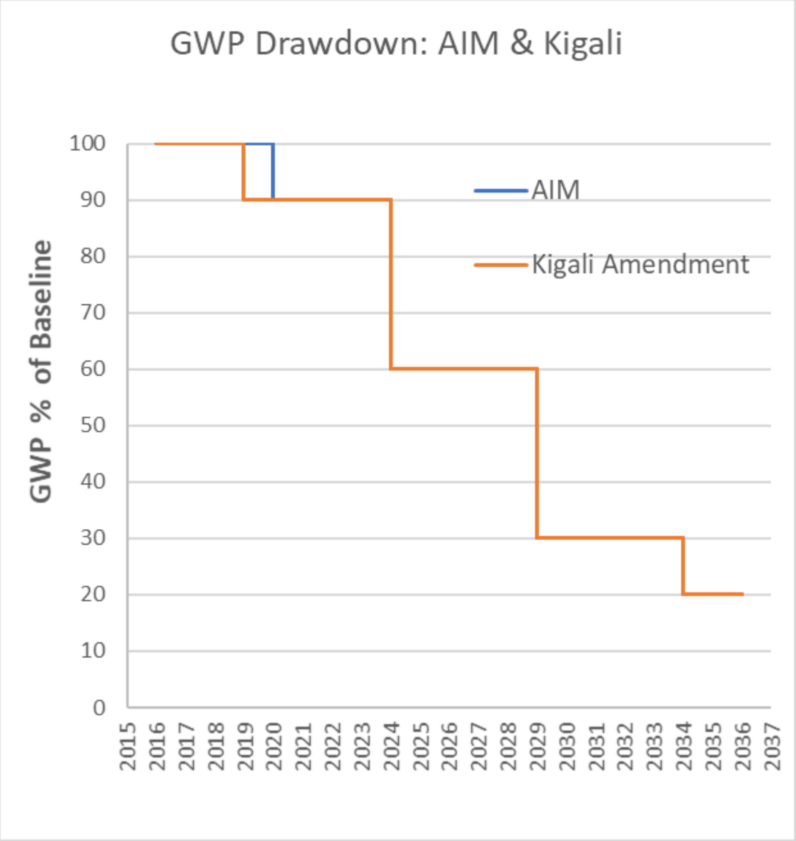
Policy: Overview

International: Montreal Protocol (1987)

- Phase out chemicals that deplete the ozone layer
- Kigali Amendment (2016): avoid 0.5 ^{o}C of warming by 2100
  - Phase down of HFC by 80% by 2045 or 87% by 2047

United States, Federal: American Innovation & Manufacturing Act (AIM)

- Bill passed in December 2020 committing to 85% reduction of production and consumption of HFCs over the next 15 years- aligns US with Kigali Amendment
- Give EPA authority to phase down HFCs
- April 13, 2021: EIA, NRDC and other groups petitioned the EPA to use this authority
  - Reinstate SNAP Rules 20 and 21
  - Adopt California HFC rules



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Policy: State Level

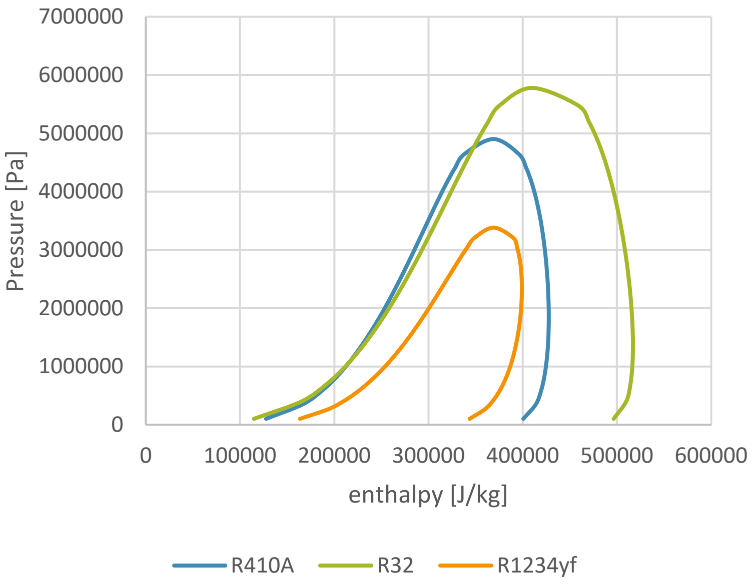
- Significant New Alternatives Policy (SNAP): Federal, but adopted voluntarily by states
  - Rule 20, 21 and 23
  - California, Washington, New Jersey, Colorado, New York, Vermont, Massachusetts, Maryland, Virginia
- California Air Resources Board (CARB)
  - Adopted SNAP, and is looking at additional regulation for GWP limits in new systems in new facilities
  - Proposal to regulate GWP in new systems in existing facilities

	End Use	GWP Limit	Effective Year
	Air conditioning equipment	750	2023
	Chillers: 35F and above	750	2024
	Chillers: 35F to -10F	1500	2024
	Chillers: -10F to -58F	2200	2024
New Facilities (+50 lbs)	Refrigeration: Cold Storage	150	2022
	Refrigeration: Ice Rinks	150	2024
	Refrigeration: Industrial Process	150	2022
	Refrigeration: Other	150	2022
Existing Facilties (+50 lbs)	Refrigeration: Ice Rinks	750	2024
	Refrigeration: Industrial Process	2200	2022

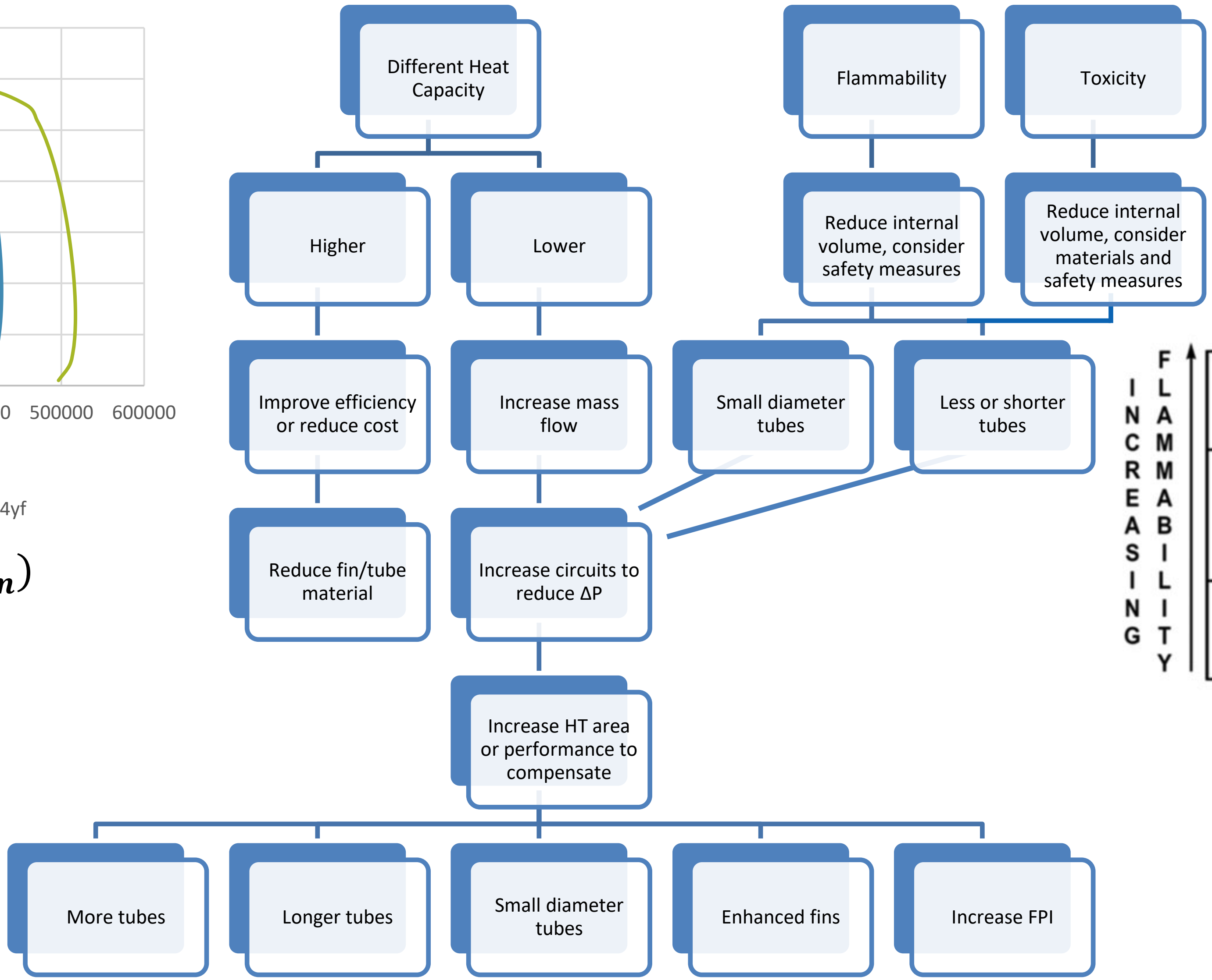
CARB Proposed Legislation

Design Process

Refrigerant Transition Forces



$$Q = \dot{m}(h_{out} - h_{in})$$



SAFETY GROUP

INCREASING FLAMMABILITY ↑		
Higher Flammability	A3	B3
Lower Flammability	A2 / A2L	B2 / B2L
No Flame Propagation	A1	B1
	Lower Toxicity	Higher Toxicity

INCREASING TOXICITY →

Design Balance

More fins

- Not always possible (tooling, condensate/frost)
- Increases air ΔP, fan power
- Additional material

More circuits

- Additional materials and labor
- Refrigerant distribution

More or longer tubes

- Potentially impacts enclosure design/tooling
- Additional material

Smaller diameter tubes

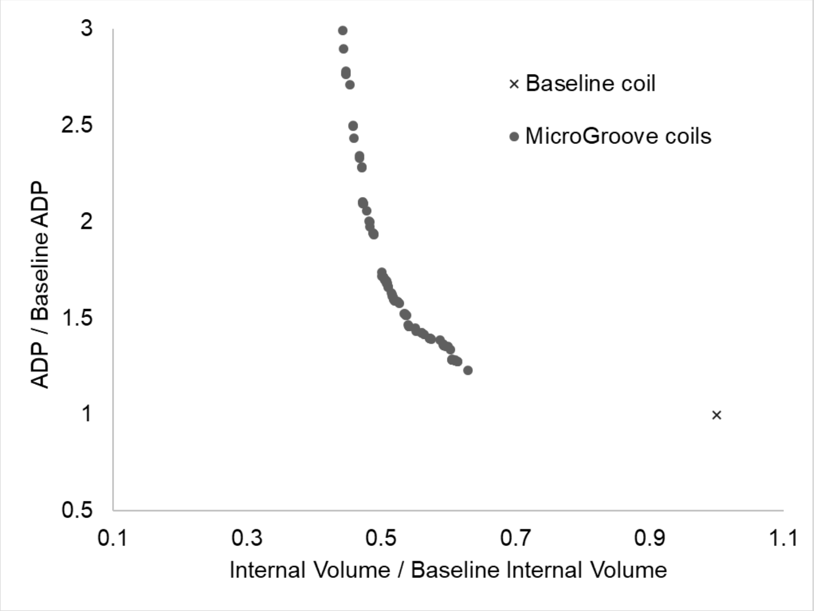
Enhanced fins

- May require different HX tooling - CAPEX

Case Studies

Case Study 1: Minimize Charge

- Seeking replacement for 6.35mm OD coil to minimize flammable isobutane charge



- Rigorous: design optimization

- Simple: retain dimensions

	Baseline	Proposed Design
Tube Diameter (mm)	6.5	5
Tubes per Bank	8	8
Tube Banks	2	2
Horizontal Spacing (mm)	22.75	22.75
Vertical Spacing (mm)	26	26
Tube Length (in.)	17	17
Fin Type	Flat	Flat
Fin Density (fins per inch)	7	7
Fin Thickness	0.19	0.19

Cotton, N., Rhoads, A., Bortoletto, A., Shabtay, Y. Optimization of MicroGroove Copper Tube Coil Designs for Flammable Refrigerants. International Refrigeration and Air Conditioning Conference. Purdue 2018

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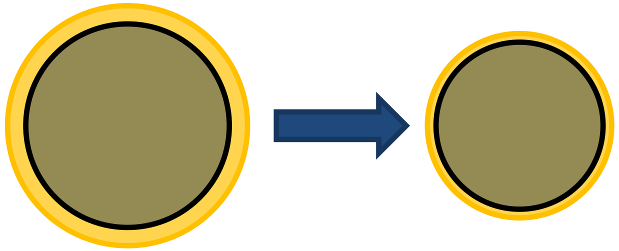
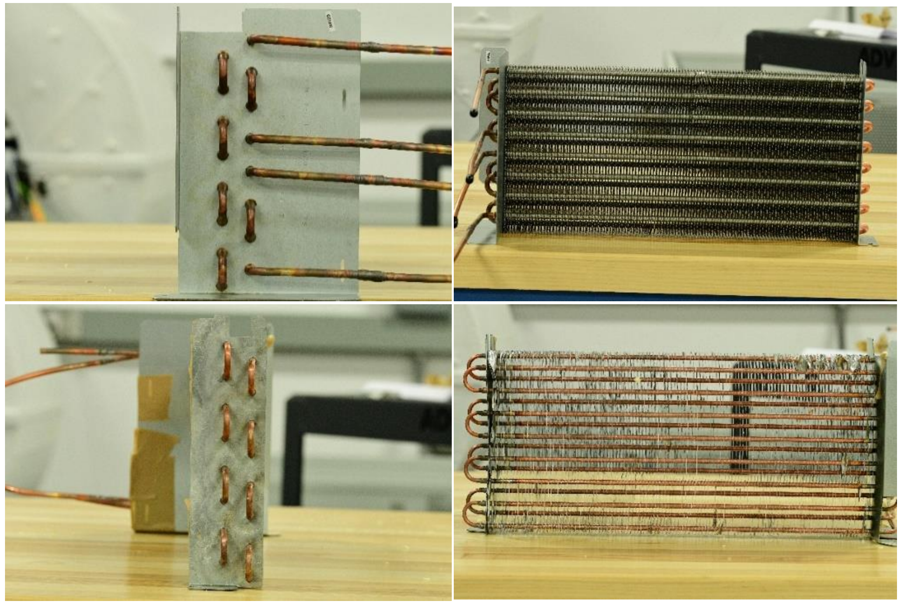
Case Study 1 (Cont.)

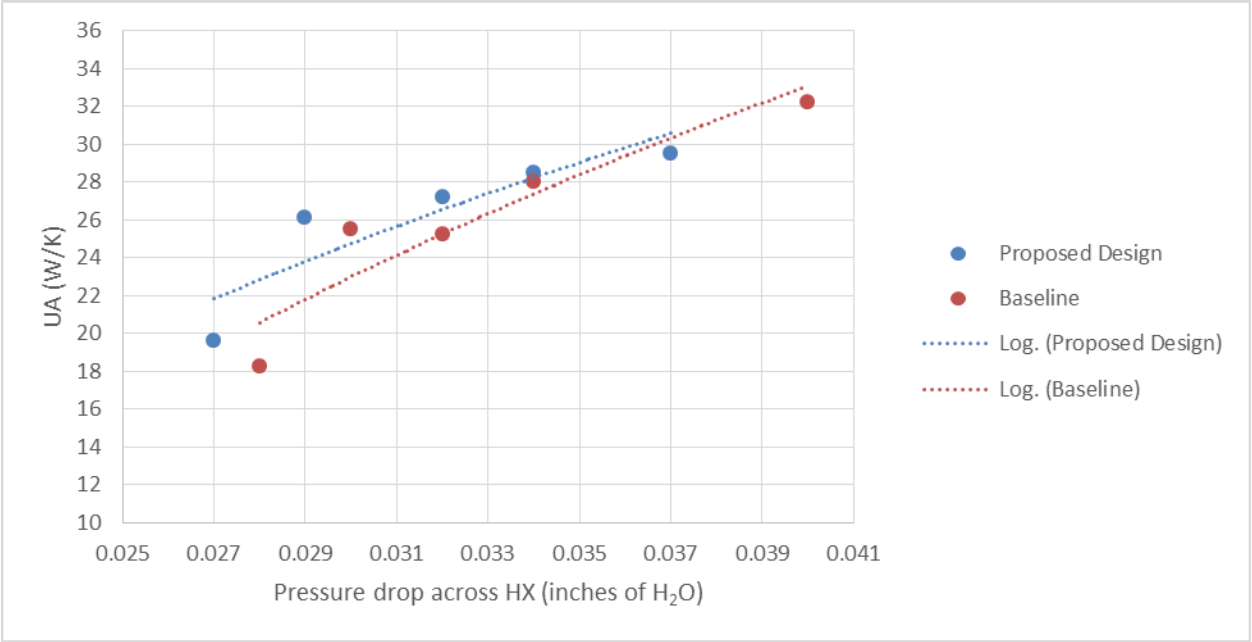
- **Results:**
  - 5.5 mm → 4.5 mm ID: <u>33% reduction in volume</u>



- **Prototyping:**

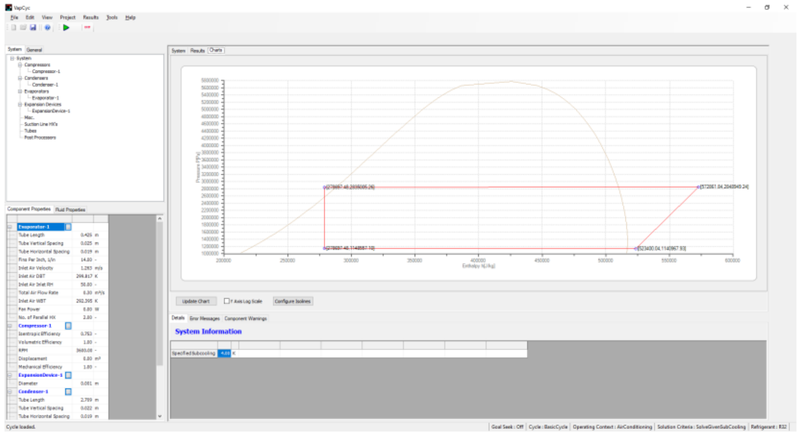


- **Calorimeter testing:**



Case Study 2: Residential AC

- R410A → R32 transition (677 GWP – AR5)
- Cycle details:
  - 7mm (0.28”) 1 Row Cu tube/ Al fin Outdoor coil
  - 9.52mm (3/8”) 4 Row Al Indoor coil
  - ~75% isentropic efficiency at AHRI A condition



Scenario	Refrigerant	Te [°C]	Tc [°C]	Qc [kW]	COP	Displacement volume [%]
Baseline	R-410A	11.4	45.4	10.5	4.04	100%
Drop-in	R-32	11.0	45.8	11.4 (+9%)	4.08 (+1%)	100%
Smaller Compressor	R-32	11.5	45.1	10.5	4.17 (+3%)	91%

- How much HX cost can be saved for equivalent efficiency?

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Case Study 2: Outdoor coil design

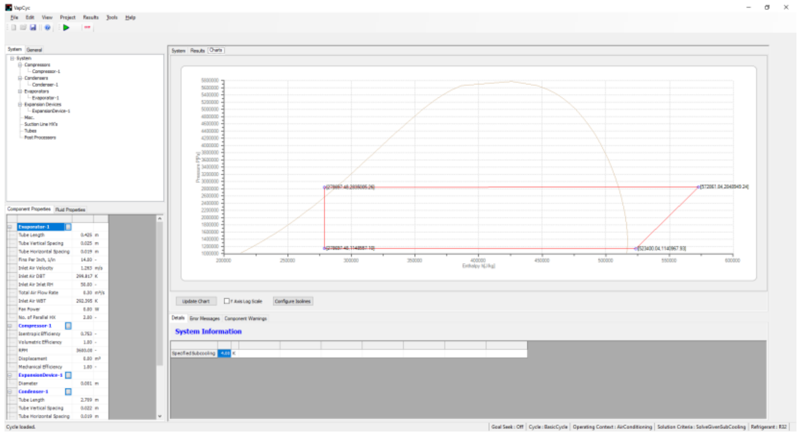
	Cost savings	Impacts on enclosure design/tooling	Air DP	Ref DP
Remove tubes	★★★	★★	↑	↑
Shorten tubes	★★	★	↑	↓
Reduce tube diameter	★★	★★★	↑	↑
Reduce fin density	★	★★★	↓	-

- **7mm: shortened tubes (~10%) and reduced fin density (~20%)**
- **5mm: reduced coil height and density**

Scenario	Refrigerant	Te [°C]	Tc [°C]	Qc [kW]	COP	Displacement volume [%]	Air DP	Ref DP	HX Mass
Baseline	R-410A	11.4	45.4	10.5	4.04	100%	100%	100%	100%
Smaller Compressor	R-32	11.5	45.1	10.5	4.17 **(+3%)**	91%	100%	68%	100%
Smaller 7mm OD coil	R-32	12.5	46.0	10.5	4.06	91%	91%	62%	84%
5mm OD coil	R-32	11.4	44.5	10.6	4.24 **(+5%)**	91%	115%	73%	50%

Case Study 2: Residential AC

- R410A → R1234yf (<1 GWP – AR5)
- Cycle details:
  - 7mm (0.28”) 1 Row Cu tube/ Al fin Outdoor coil
  - 9.52mm (3/8”) 4 Row Al Indoor coil
  - ~75% isentropic efficiency at AHRI A condition



Scenario	Refrigerant	Te [°C]	Tc [°C]	Qc [kW]	COP	Displacement volume [%]
Baseline	R-410A	11.4	45.4	10.5	4.04	100%
Drop-in	R-32	11.0	45.8	11.4 **(+9%)**	4.08 **(+1%)**	100%
Smaller Compressor	R-32	11.5	45.1	10.5	4.17 **(+3%)**	91%
Drop-in	R-1234yf	15.9	41.5	5.5 **(-48%)**	4.54 (+12%)	100%
Larger Compressor	R-1234yf	10.5	46.9	10.5	3.97 **(-2%)**	242%

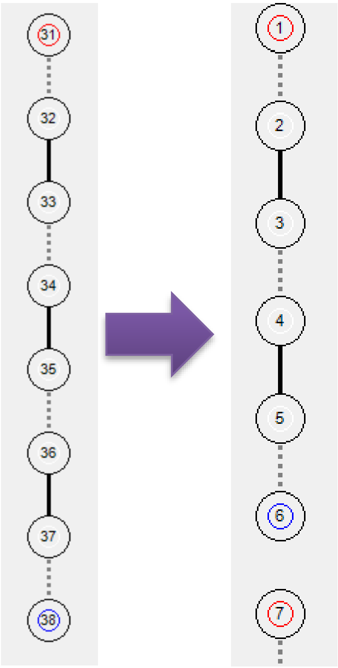
Heat Exchanger Design

Scenario	Refrigerant	Te [°C]	Tc [°C]	Qc [kW]	COP	Evap RDP	Cond RDP
Baseline	R-410A	11.4	45.4	10.5	4.04	100%	100%
Larger Compressor	R-1234yf	10.5	46.9	10.5	3.97	299%	252%

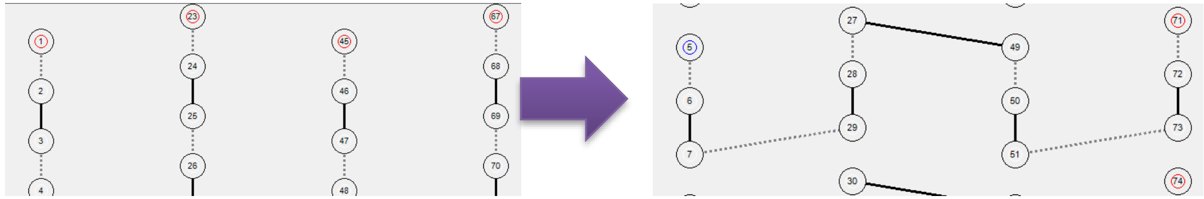
>2K sat temp drop

- **What can be done?**
- **First, reduce heat exchanger pressure drop. Evaporator most critical**
  - **Negative consequence – lower mass flux in tubes, lower HTC**
- **Then, add heat exchange area to compensate as needed**

Heat Exchanger Design



Scenario	Refrigerant	Te [°C]	Tc [°C]	Qc [kW]	COP	Evap RDP	Cond RDP
Baseline	R-410A	11.4	45.4	10.5	4.04	100%	100%
More circuits	R-1234yf	10.5	46.3	10.5	4.01 (-1%)	149%	135%
2 more tubes on OD coil	R-1234yf	10.5	46.2	10.6	4.05	149%	194%



"Soft Optimization"

Better to fully optimize: consider simultaneous changes to tube #s, circuit #s, FPI, other tube and fin type choices

Wrap-up

- Industry has proven track record of changing refrigerants
- Narrative that refrigerants “don’t matter” compared with energy consumption is wrong. More outdated as the grid continues to decarbonize
- New refrigerants offer the ability to significantly reduce environmental impacts: GWPs of 1,000 – 2,000+ down to < 10!
- New refrigerants can present a variety of design challenges
- Heat exchangers are a major mechanism to resolve these challenges
  - Flammability and toxicity: limit refrigerant charge quantity
  - Higher capacity/efficiency: optimize HXs to reduce cost
  - Lower thermal capacitance: more circuits or bigger tubes

Coming Next

Purdue Conference:

Design Optimization of 3mm and 5mm Copper Tube and Flat Fin Air-to-Water Heat Exchangers with Experimental Validation

Week of May 24

Webinar 6

Small Diameter Copper Tube Fin Heat Exchangers and the Impacts of Frost

June 2021: As copper tubes get smaller and smaller, the coils get denser and fin spacing gets narrower. This webinar will discuss the magnitude of potential performance degradation from water bridging and frost and explore possible mitigations.

THANK YOU!

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