

ASHRAE Boston Chapter Meeting
Designing AC Refrigeration Systems
Lessons Learned
October 17, 2023



- Explanation of the refrigeration cycle.
- Compressors. Benefits and operating characteristics.
 - Reciprocating
 - Screw
 - Scroll
- Condenser types and benefits
 - Air cooled
 - Evaporative
- Expansion Valves
 - Thermostatic
 - Non- Balanced port
 - Balanced port
 - Electronic
- Evaporator Design
 - Fins per inch
 - Moisture carryover
 - Distributors

- Standard RTU Concerns
 - Capacity control at part loads

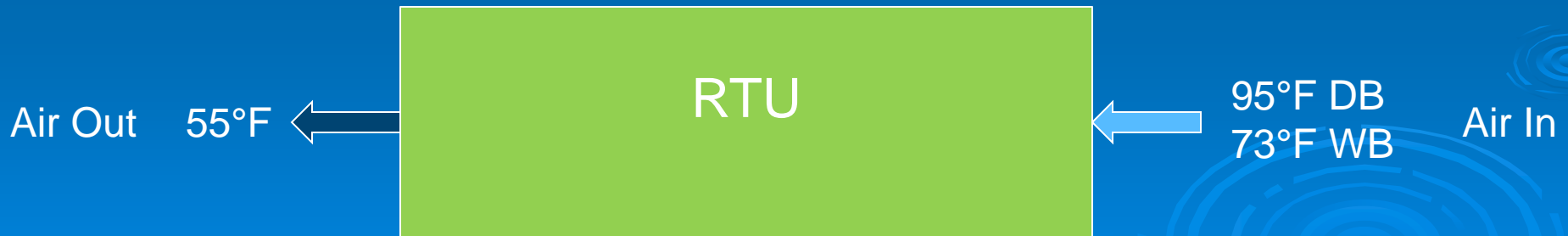
- Split Systems Concerns
 - Piping concerns
 - Receiver
 - Pump down solenoid valve
 - Oil Separator

- 100% Outdoor Air DX Unit Concerns
 - Interlaced evaporators vs. parallel or series
 - Precise capacity control
 - Compressor staging
 - Compressor unloading
 - Scroll- 66% or down to 20% (variable speed)
 - Hot gas bypass to evaporator
 - Tight head pressure control
 - Fan speed control vs. flooded condenser

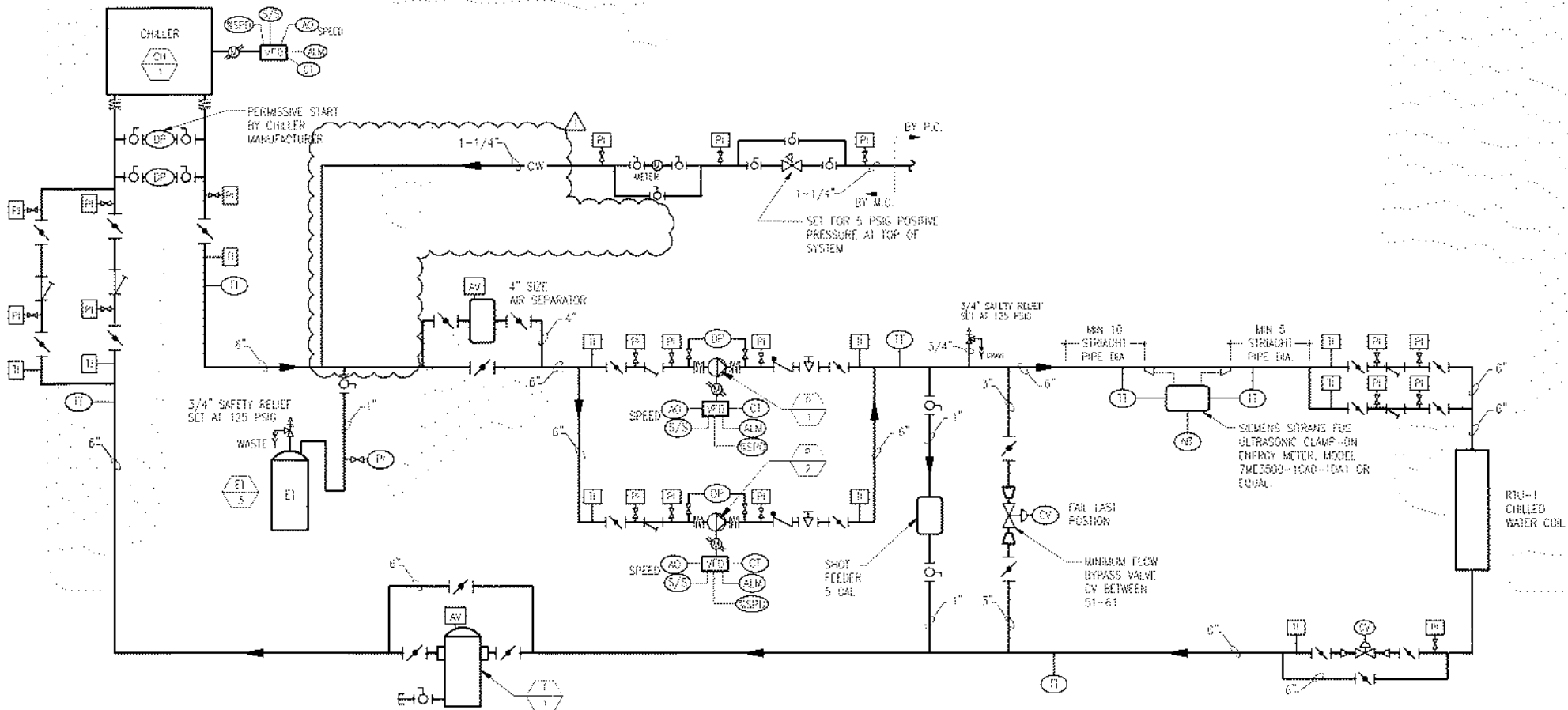
Heat Pump Comparison

Total Heating Cost					
System	\$/Yr	Savings/Yr vs Propane	Savings/Yr vs Brand X	Savings/Yr vs Electric	Energy Cost \$/Therm
Electric	\$ 11,567				8.9
Propane	\$ 8,596	\$ -		\$ 2,971	6.6
Brand X	\$ 4,309	\$ 4,287		\$ 7,258	3.3
Brand Z	\$ 3,048	\$ 5,548	\$ 1,261	\$ 8,519	2.4
Nat Gas 95%	\$ 3,133	\$ 8,434	\$ 1,176	\$ (85)	2.3
Nat Gas 85%	\$ 3,502	\$ 5,094	\$ (454)	\$ (369)	2.3

HVAC Engineers Understanding of a Refrigeration System



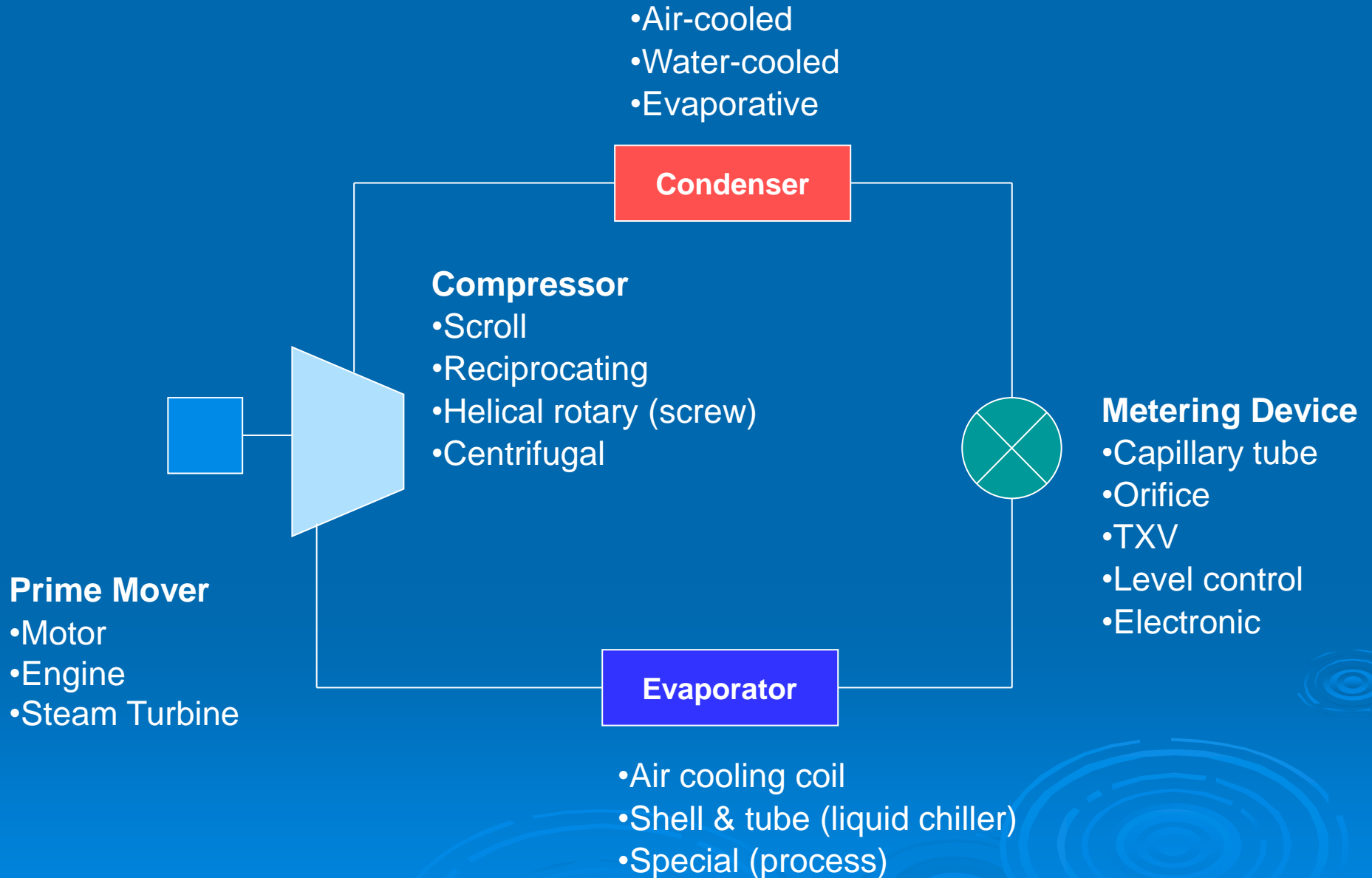
1RTU with Chiller



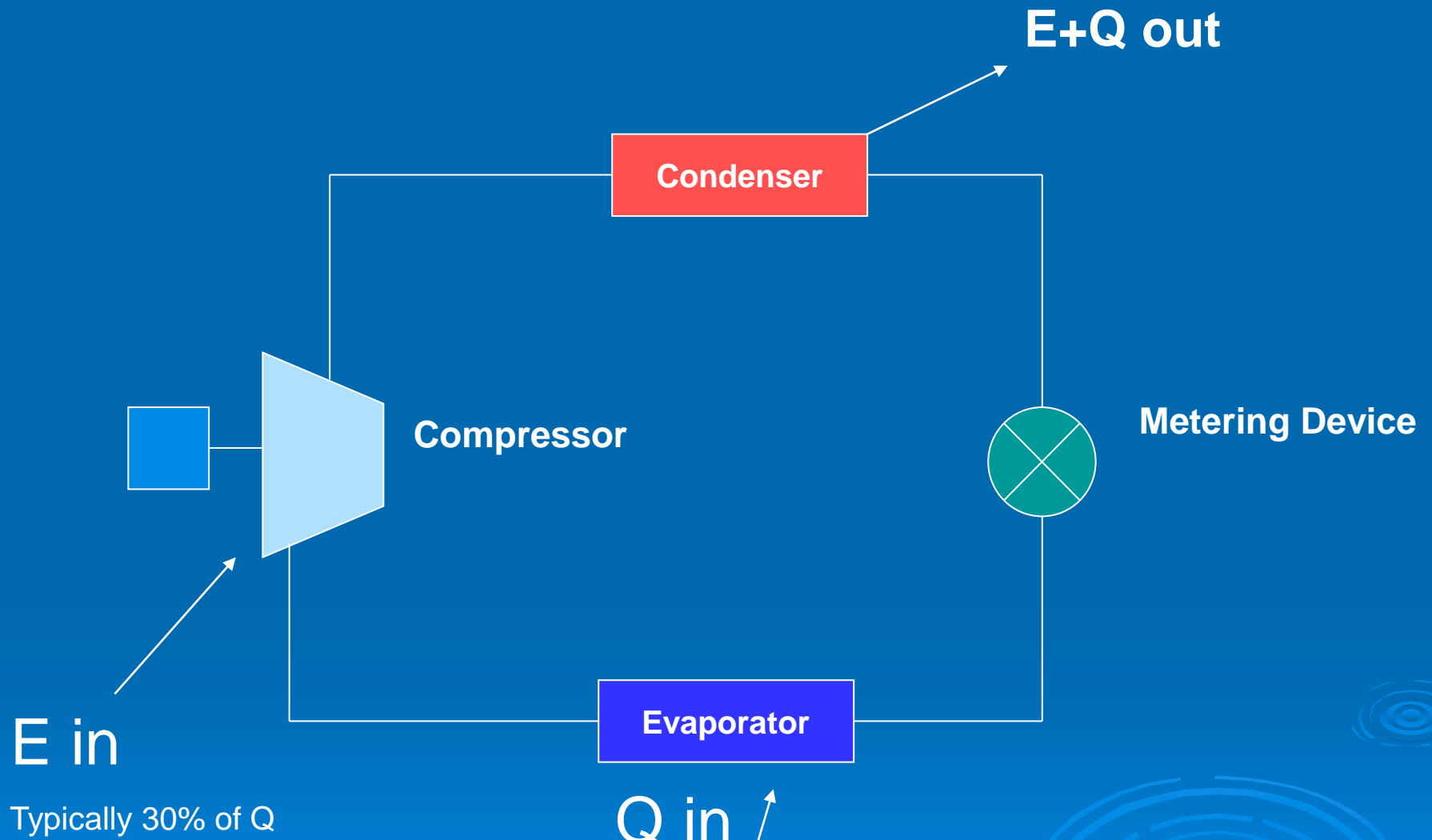
Frozen Coil



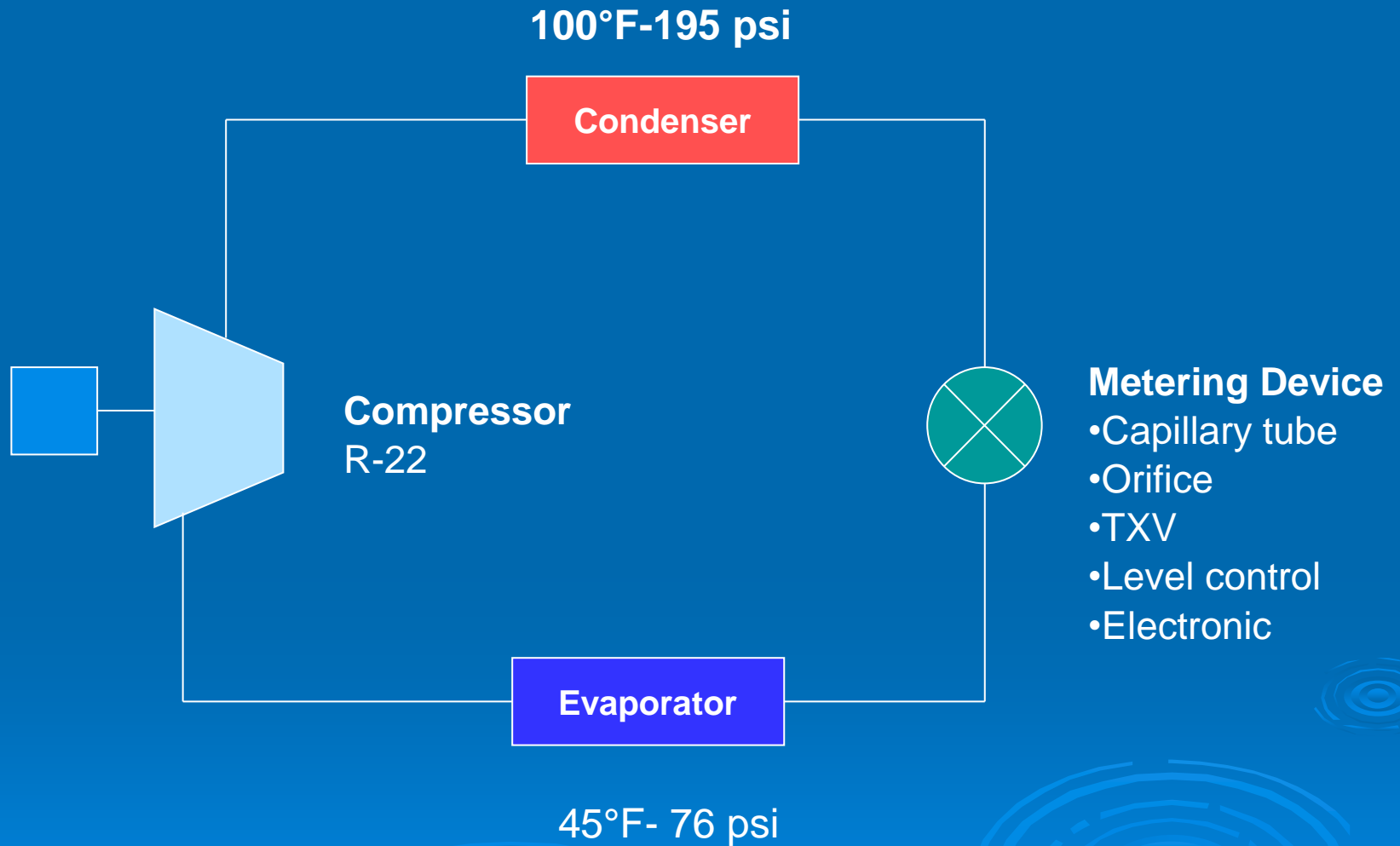
Basic Refrigeration System



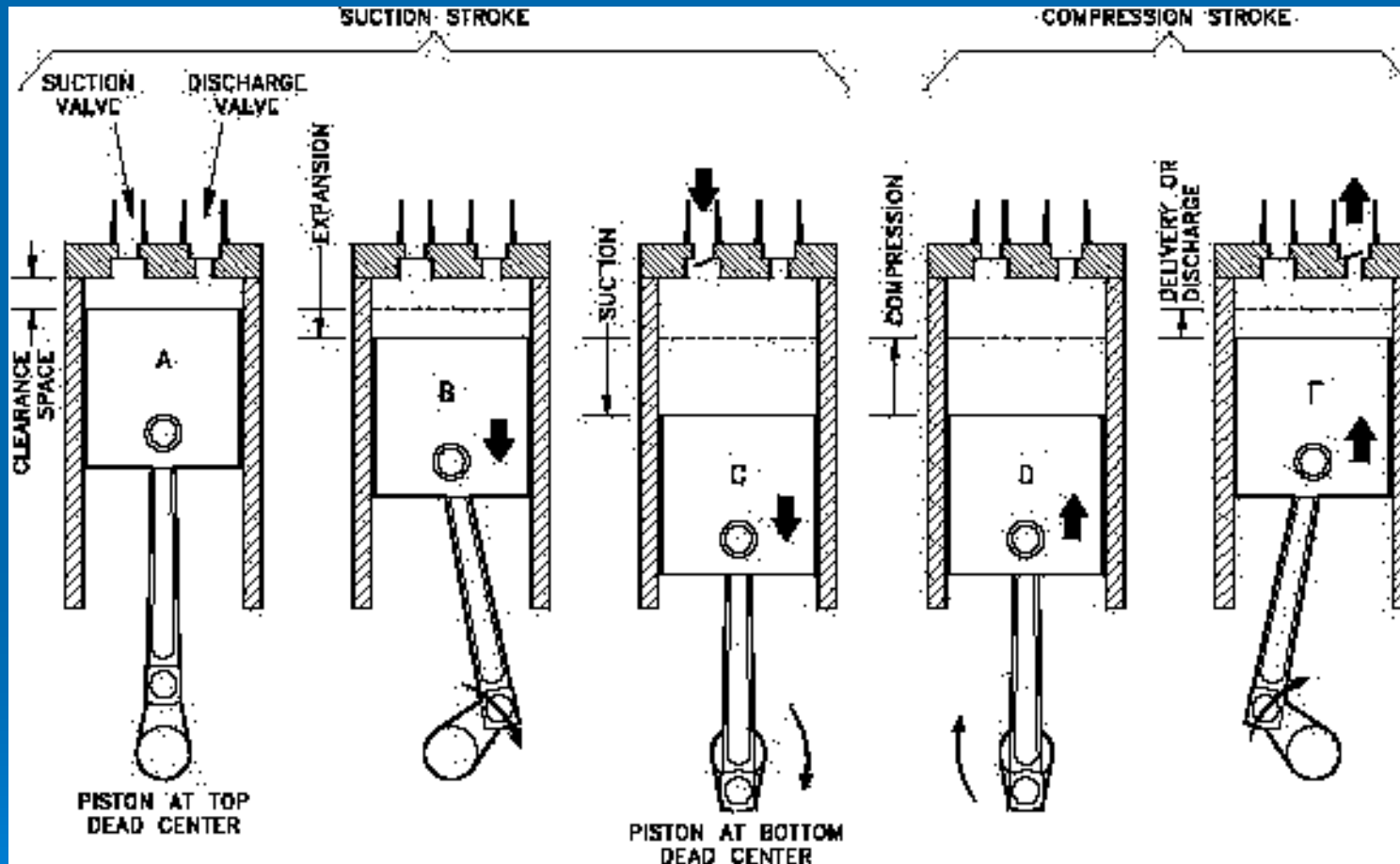
Basic Refrigeration System



Basic Refrigeration System

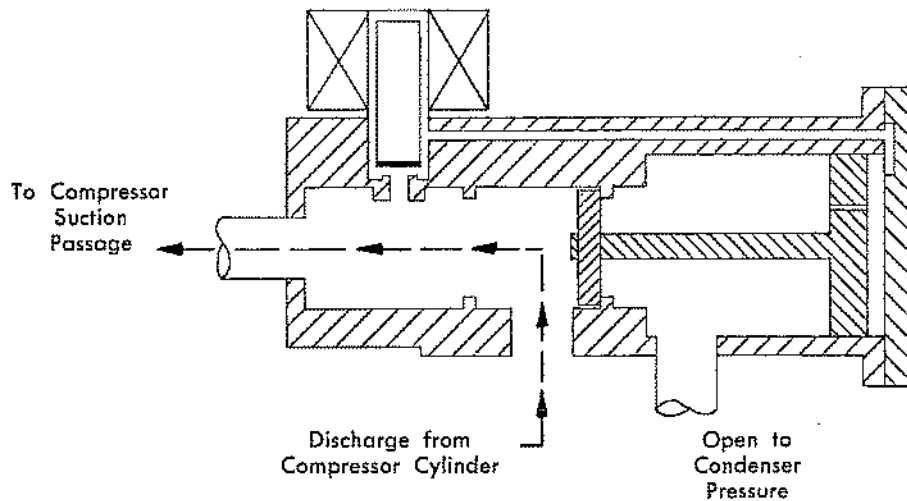


Reciprocating Compressor



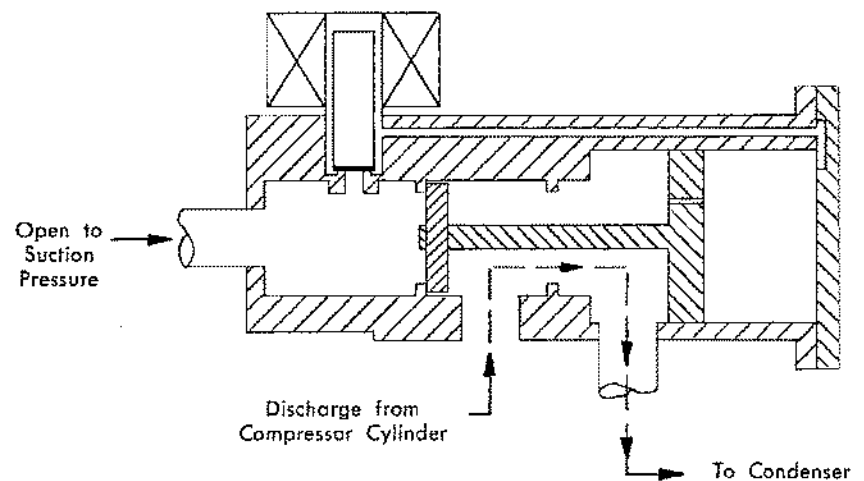
Reciprocating Compressor Unloader

ENERGIZED



COMPRESSOR UNLOADING VALVE

DE-ENERGIZED



Screw Compressor



Screw Compressor



Screw Compressor

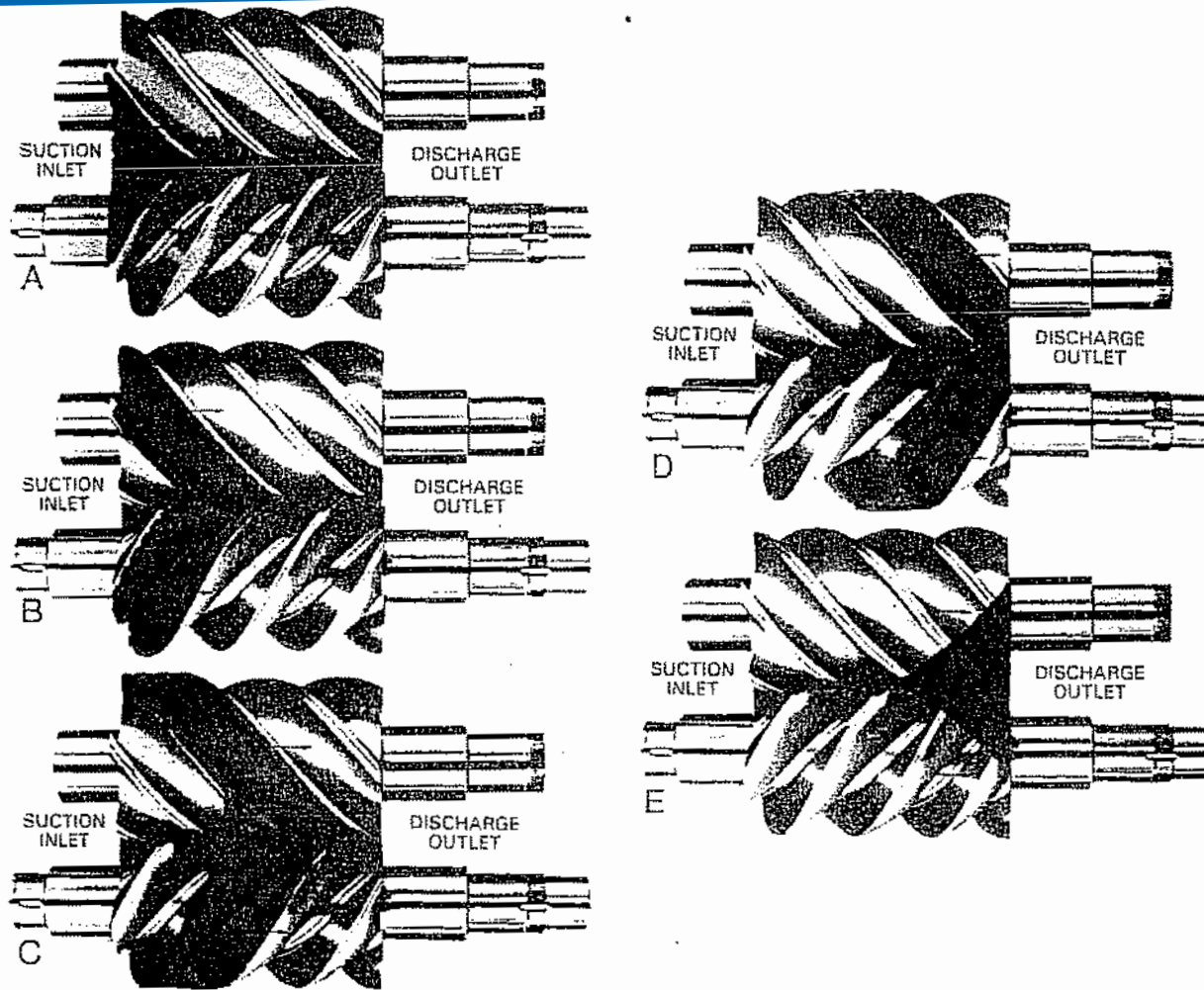
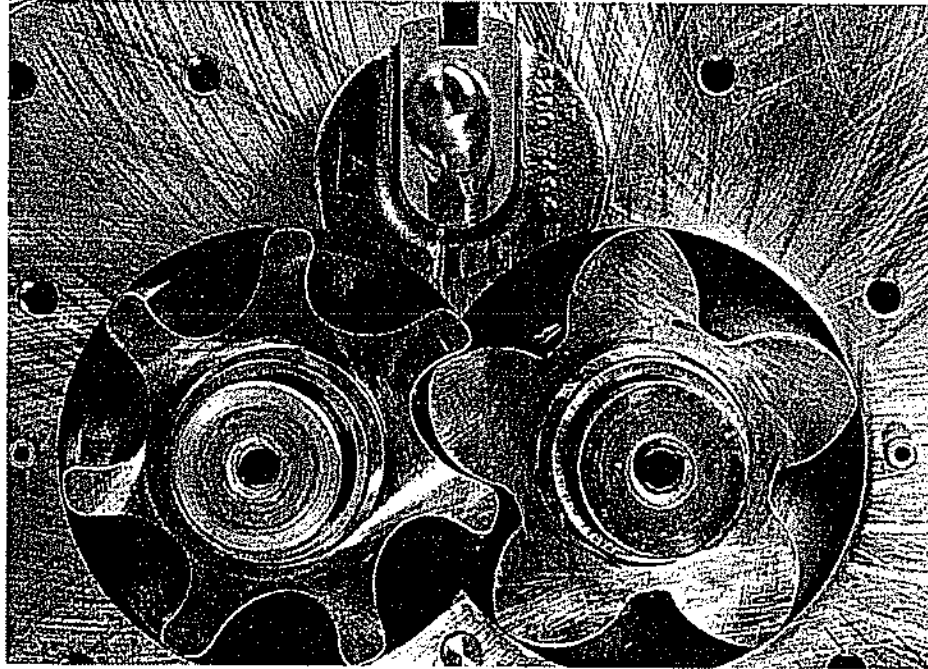


Fig. 4-60. Basic operation of screw-type compressor. Revolving rotor compresses vapor. A—Compressor interlobe spaces being filled. B—Beginning of compression. C—Full compression of trapped vapor. D—Beginning of discharge of compressed vapor. E—Compressed vapor fully discharged from interlobe spaces. (Dunham-Bush, inc.)

Screw Compressor



End view showing male and female rotors and slide valve on an 85-ton intermediate compressor.

Scroll Compressor



(a) Vapour refrigerant enters an outer pocket



(b) The pocket is sealed off and compression starts

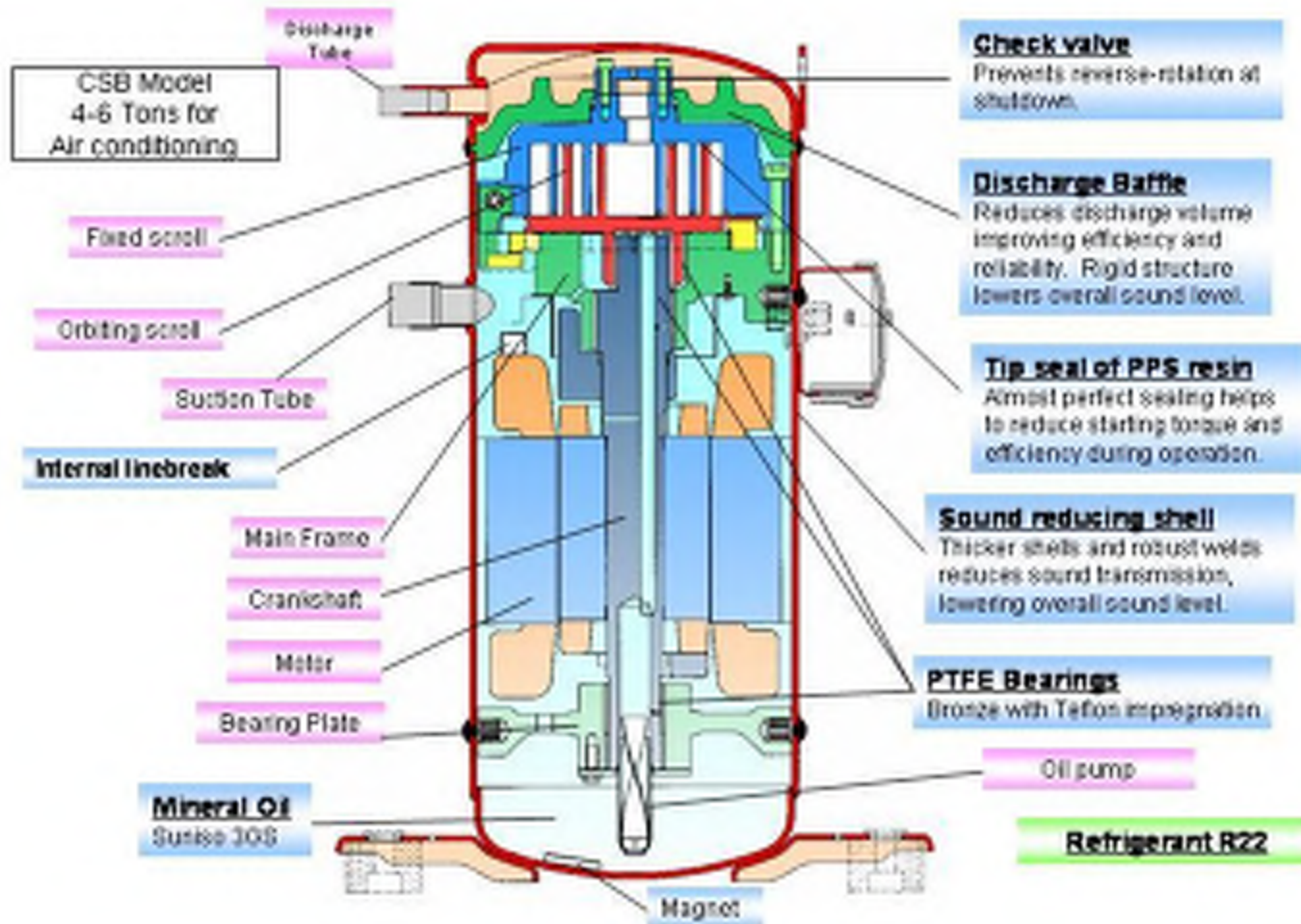


(c) The pocket is reduced in size

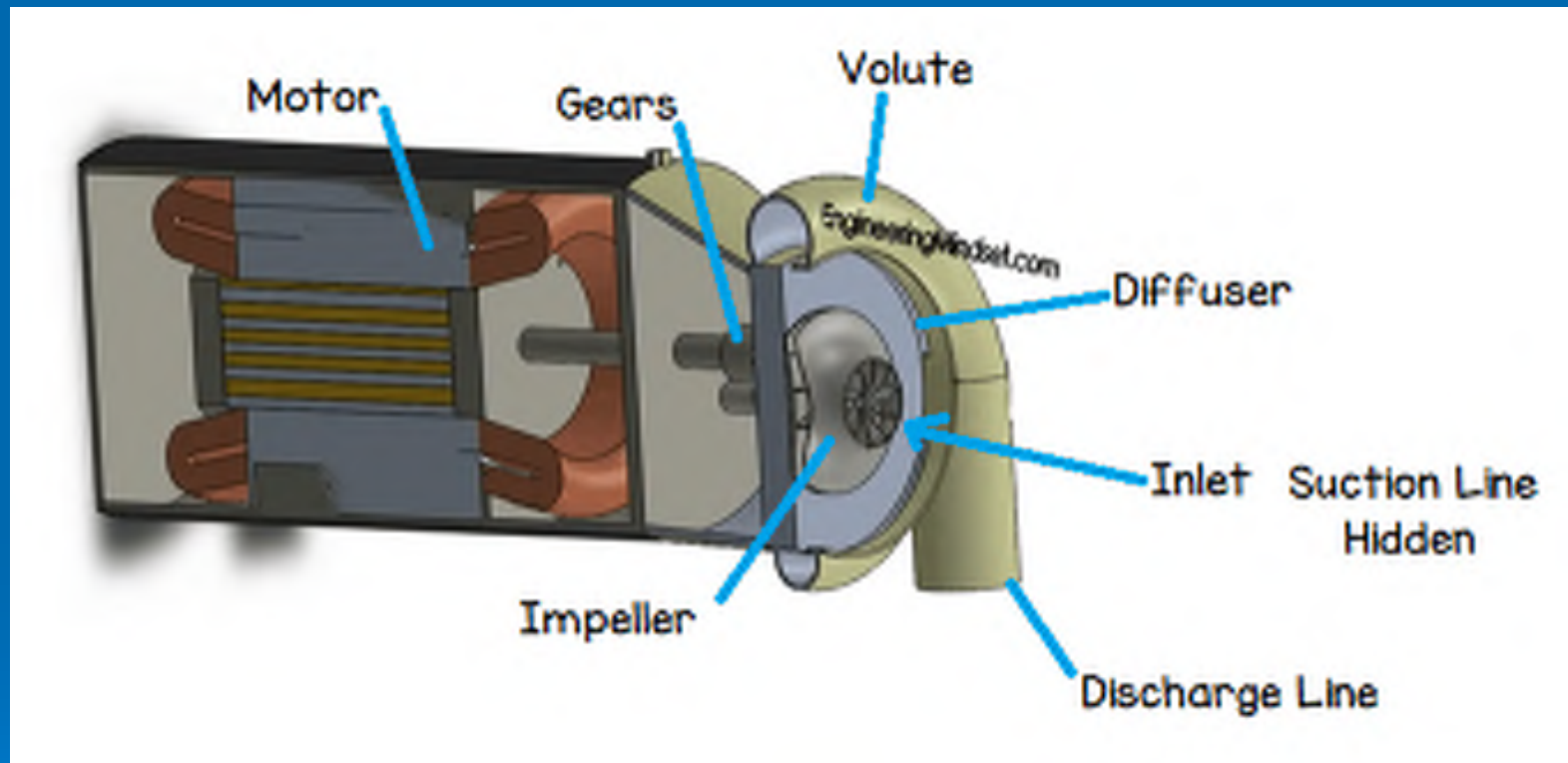


(d) As the pocket reaches the centre, the discharge port is uncovered and discharges the compressed vapour refrigerant

Scroll Compressor



Centrifugal Compressor



Compressor Efficiencies

Capacity %	Reciprocating	Helical Rotary	Scroll
	KW/Ton	KW/Ton	KW/Ton
100	0.87	0.70	0.80
50	50%	42%	72% (VFD)
25	35%	26%	65% (VFD)

Part Load Performance (% Power)

Performance at 85°F Cond

Air Cooled Condenser



Evaporative Condenser

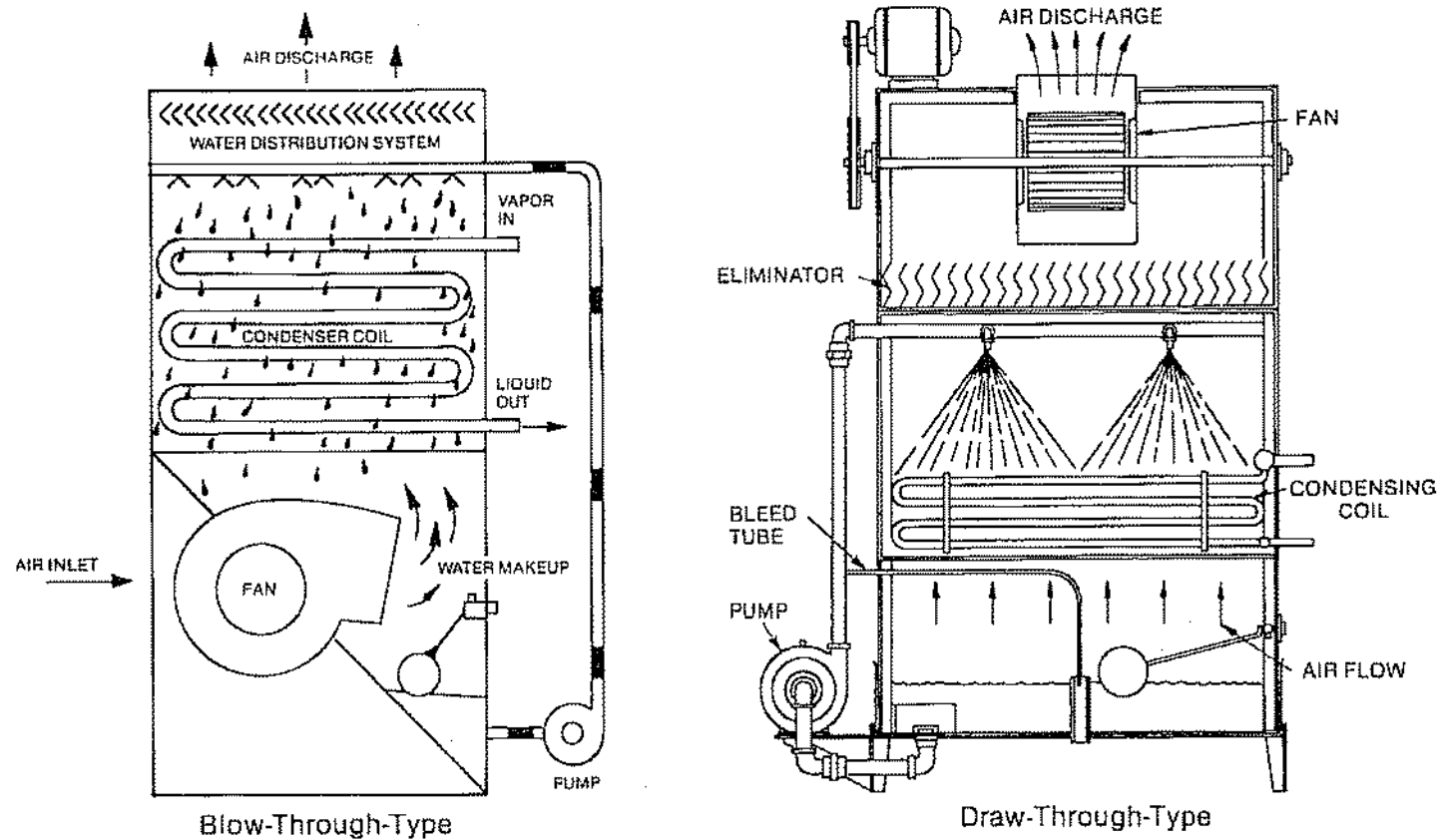
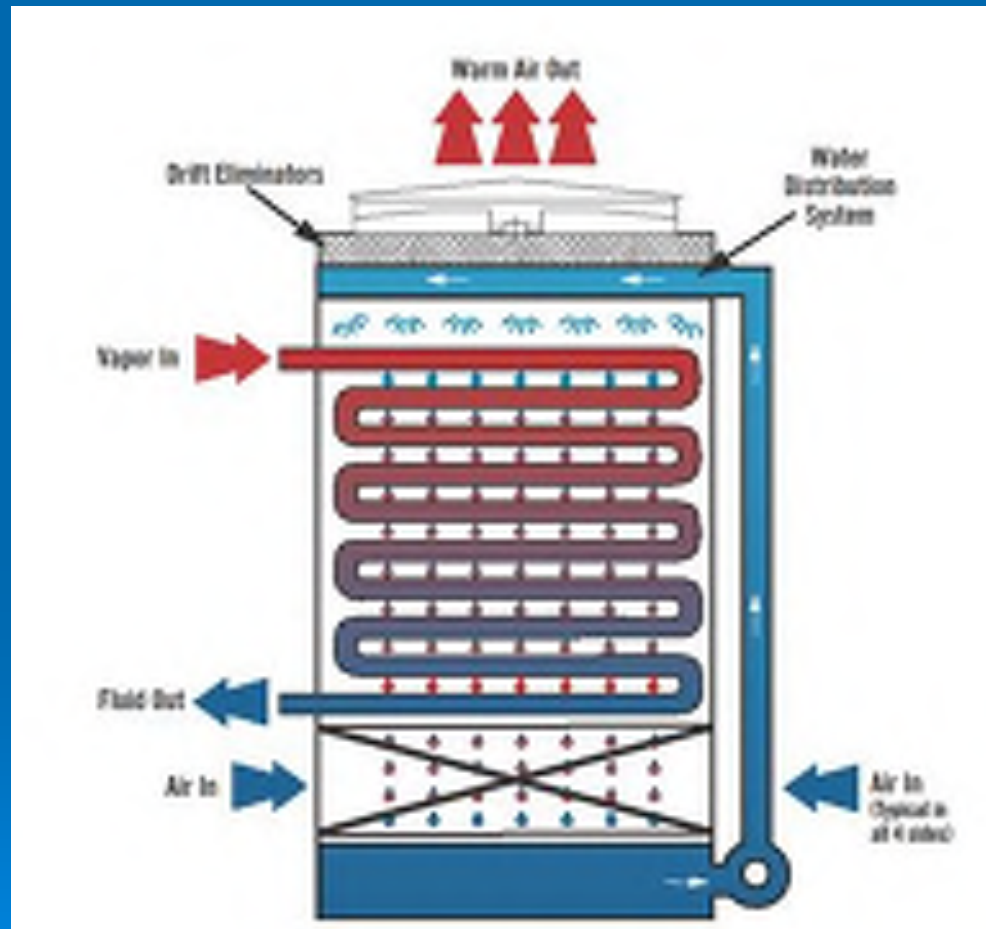


Fig. 11 Functional View of Evaporative Condenser

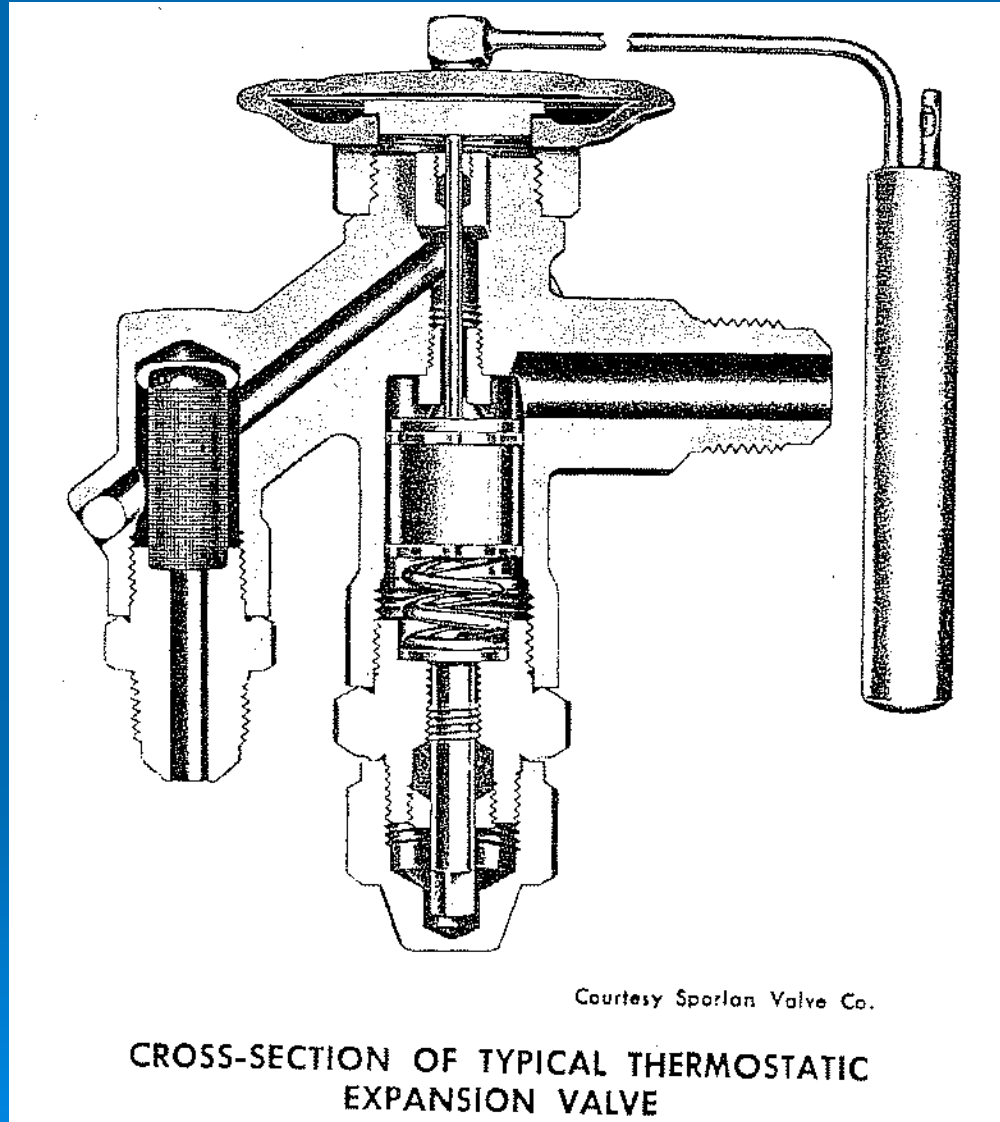
Evaporative Condenser



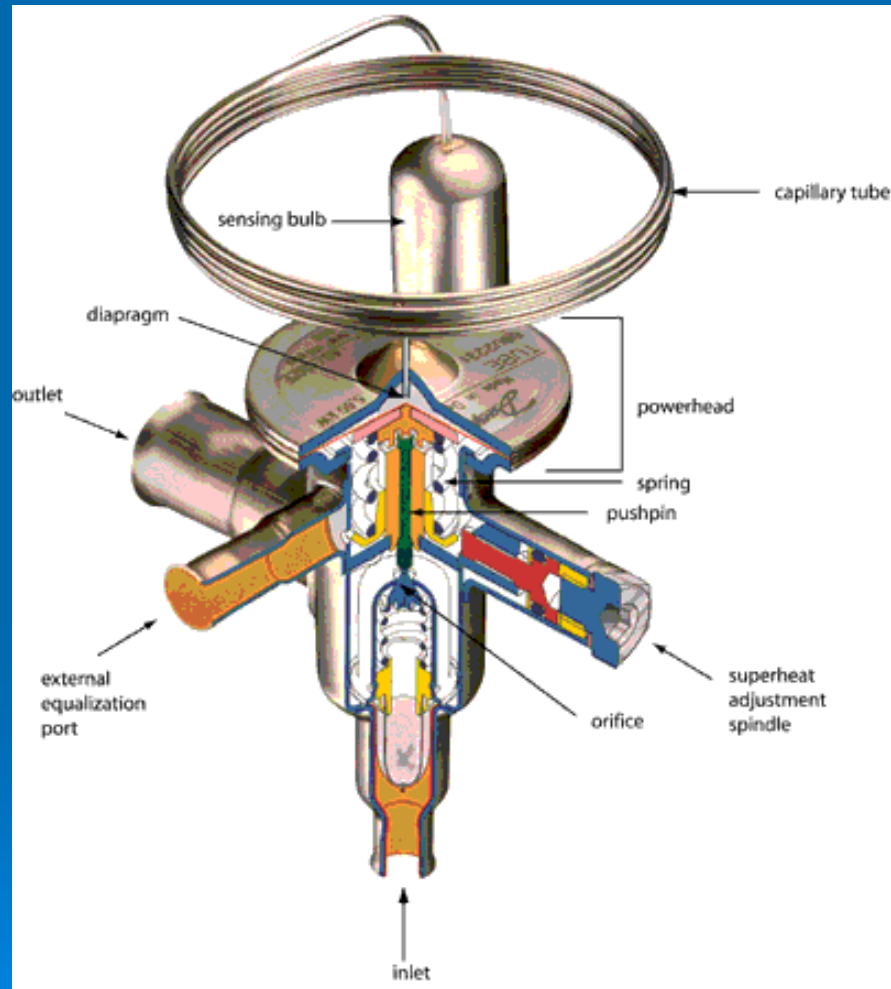
Condensers Efficiencies

R-22	Ambient temp	Sat. liquid temp	Ambient minus liquid	Head pressure
Air-cooled	95°F db	115°F db	20°F db	243 psi
Water-cooled	78°F wb	90°F db	12°F db	168 psi
Evap-cond	78°F wb	85°F db	7°F db	156 psi

Thermostatic Expansion Valve



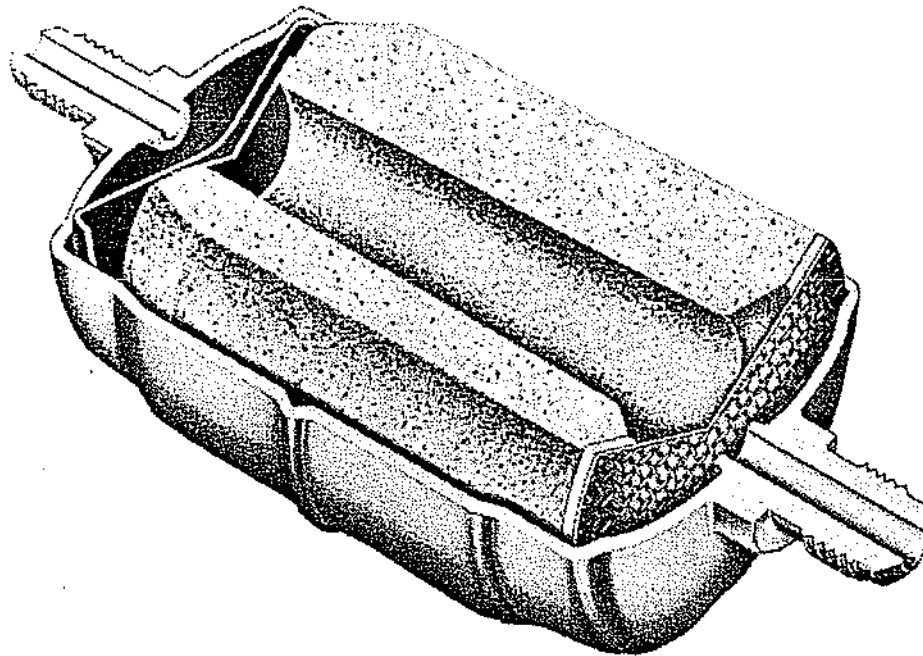
Thermostatic Expansion Valve



Oil Separator



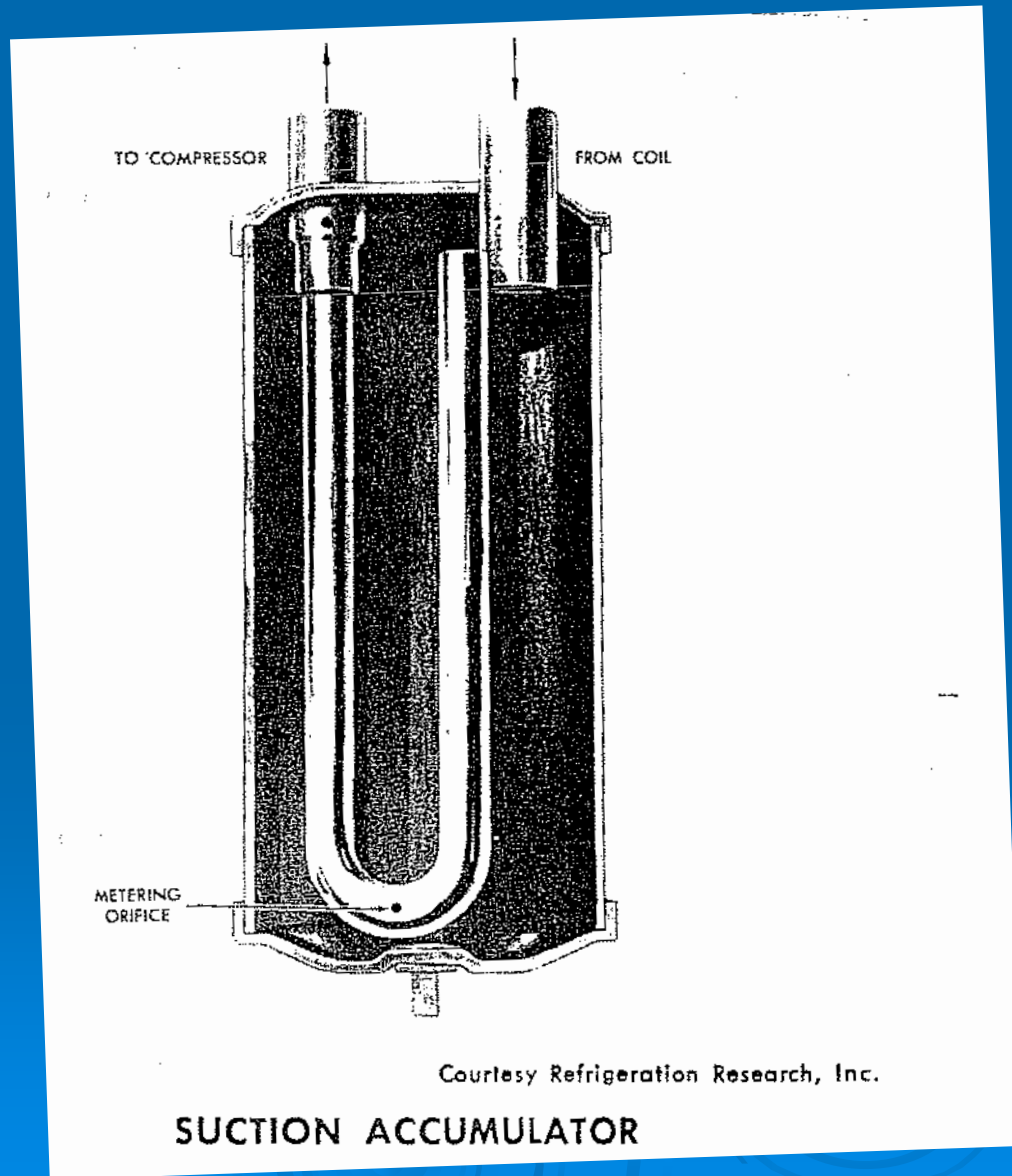
Filter-Drier



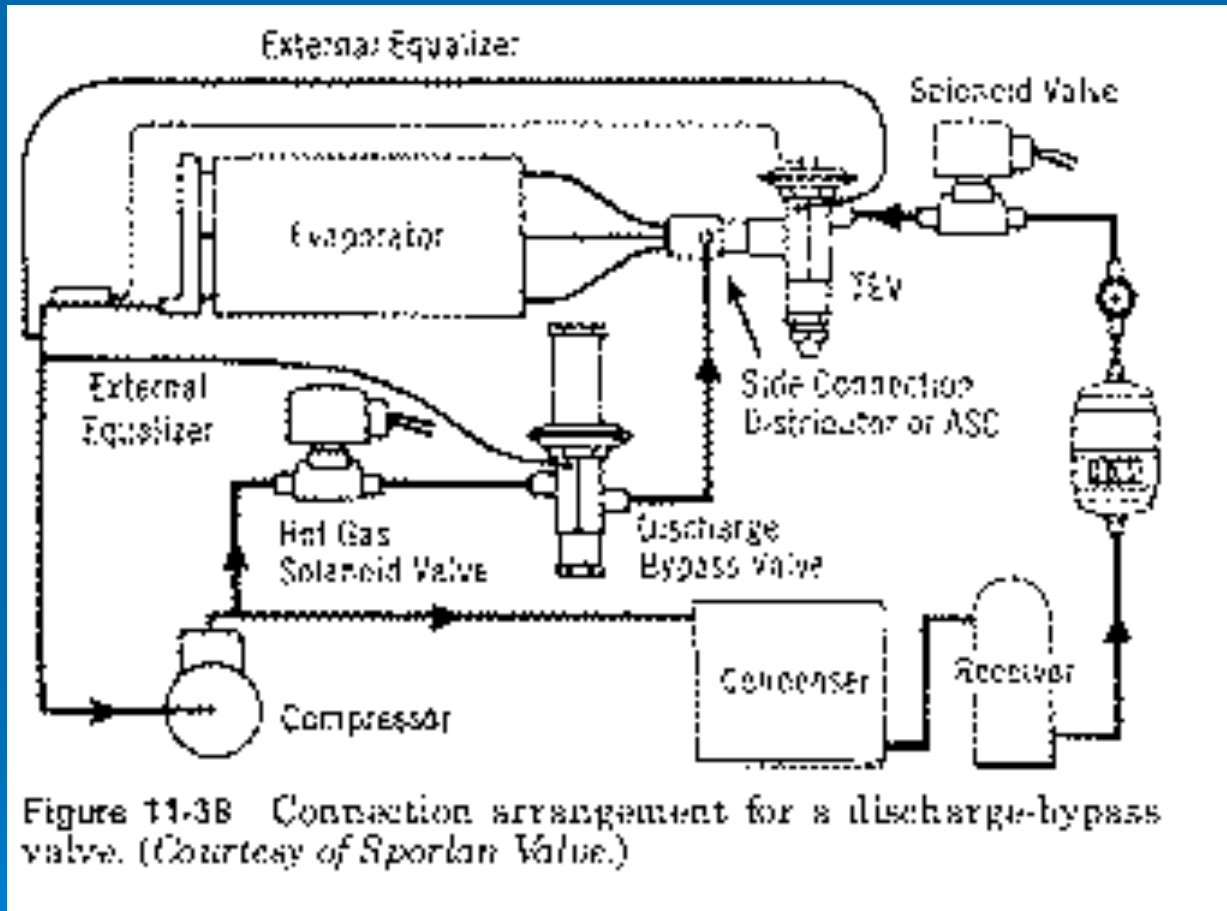
Courtesy Sporlan Valve Co.

TYPICAL FILTER-DRIER

Suction Accumulator



Hot Gas Bypass



Refrigerant Distributor

REFRIGERANT DISTRIBUTOR

What is it?

The refrigerant distributor is a device connected to the outlet of a thermostatic expansion valve (TEV). The outlet of the distributor is machined to accept tubing which connects the distributor to each evaporator coil circuit.

What is its function?

The refrigerant distributor equally distributes refrigerant flow from the thermostatic expansion valve (TEV) into each circuit of a multi-circuit evaporator coil.

FINNED COIL



PLATE EVAPORATOR

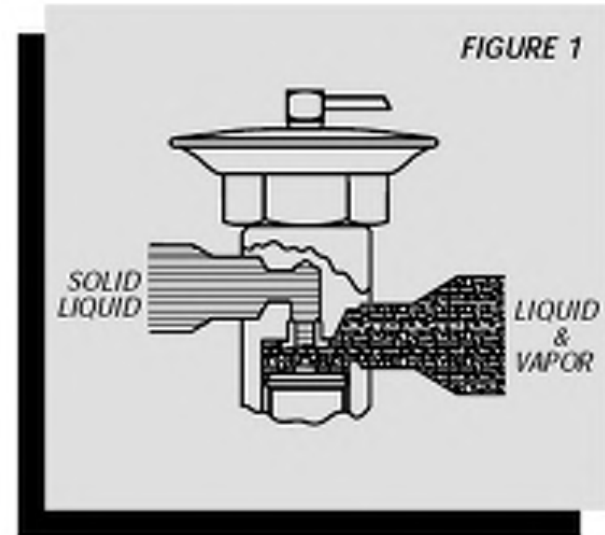
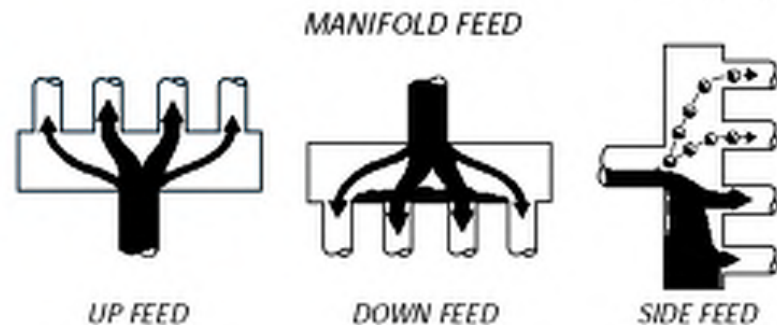


FIGURE 2



UP FEED

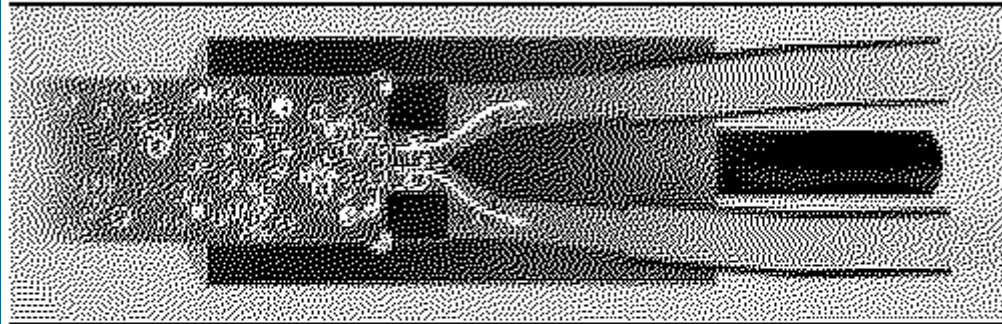
DOWN FEED

SIDE FEED

FLOW WILL BE GREATEST TO PATH OF LEAST RESISTANCE

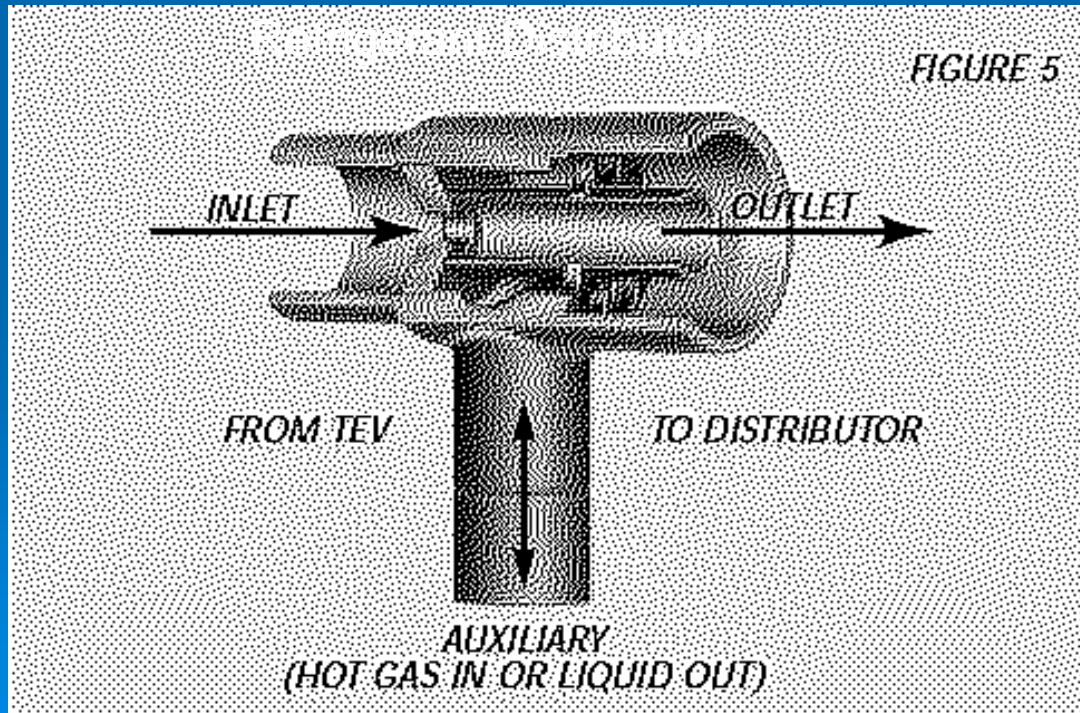
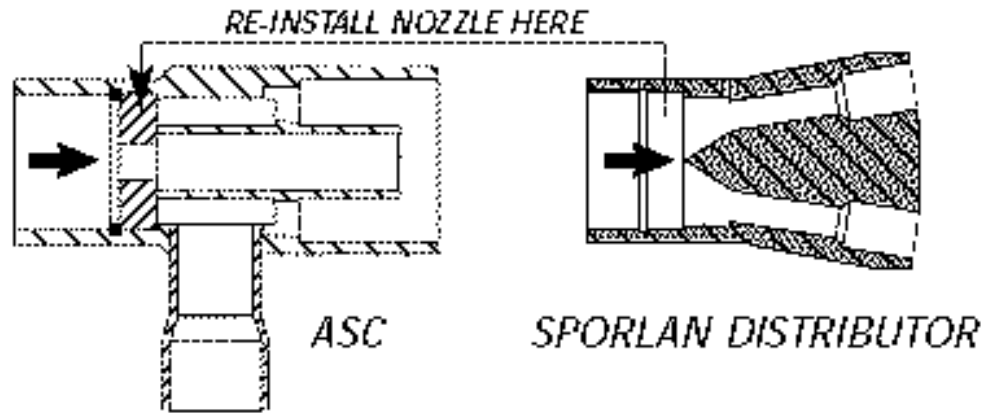
Refrigerant Distributor

OPERATION OF SPORLAN PRESSURE DROP TYPE DISTRIBUTORS

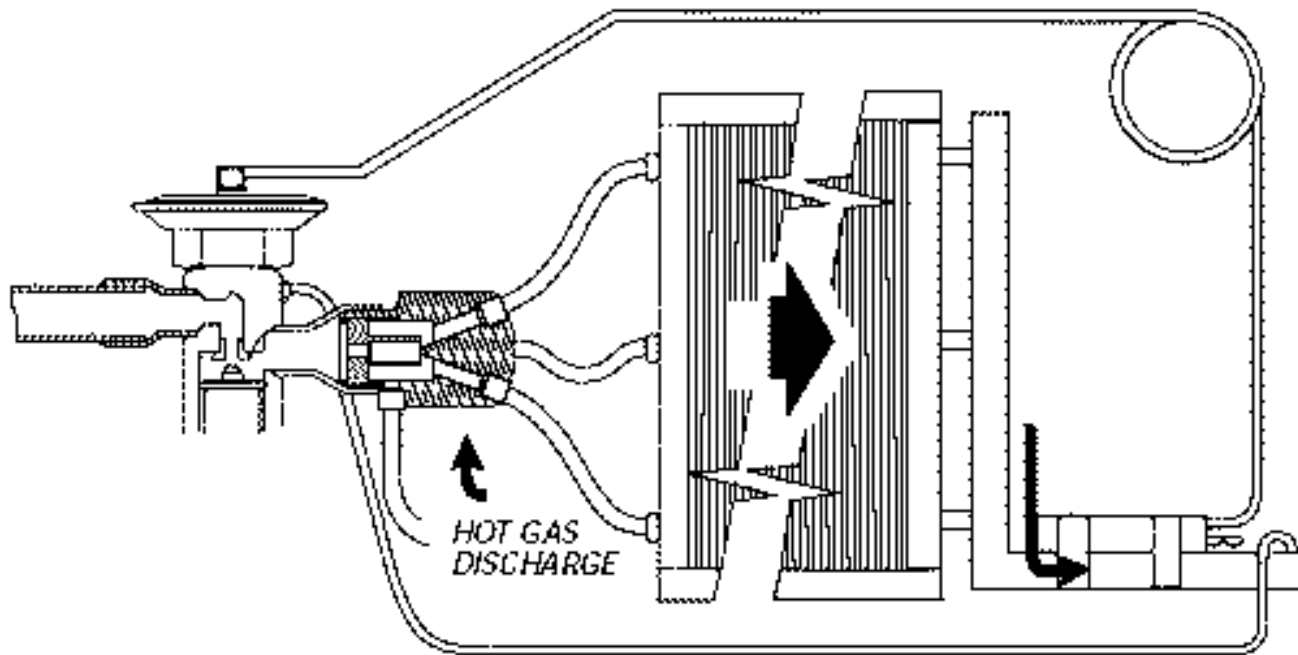


- 1 - Velocity of refrigerant LIQUID-VAPOR MIXTURE increased by flow through nozzle orifice*
- 2 - Orifice provides homogeneous MIXING through turbulence created by pressure drop*
- 3 - Refrigerant MIXTURE divided by conical button while still at high velocity*
- 4 - MIXTURE fed equally to circuits*

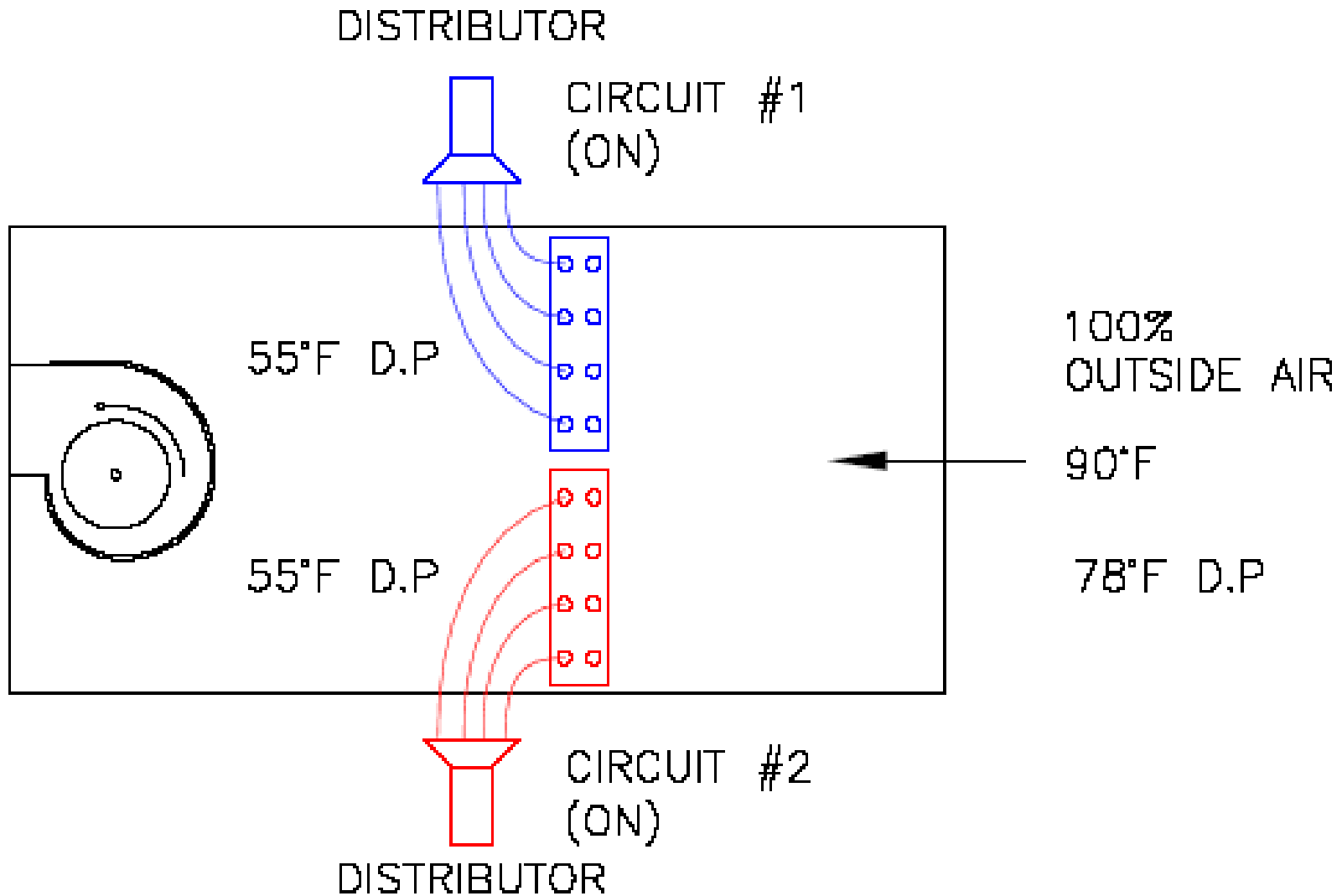
Refrigerant Distributor



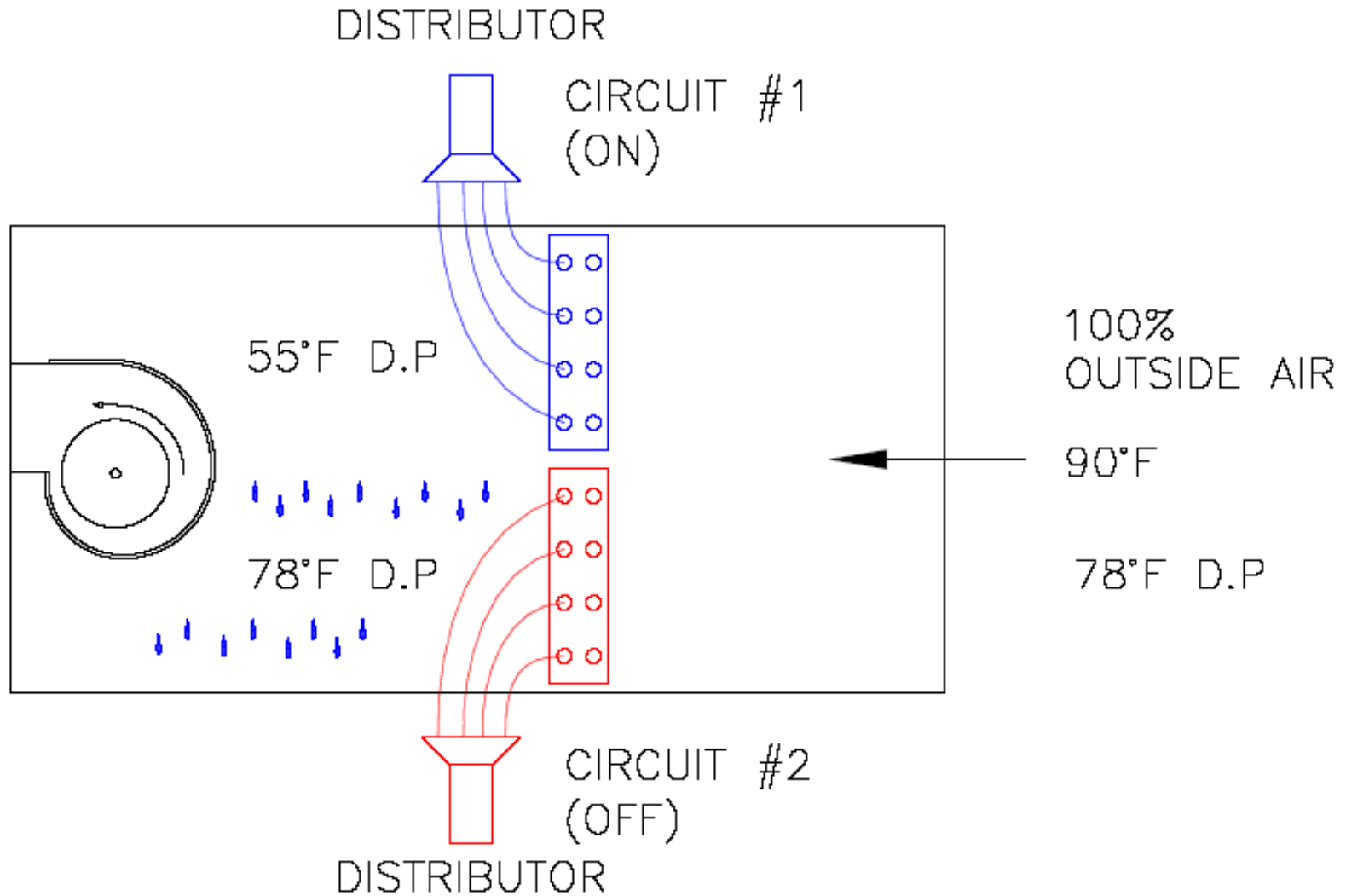
Refrigerant Distributor



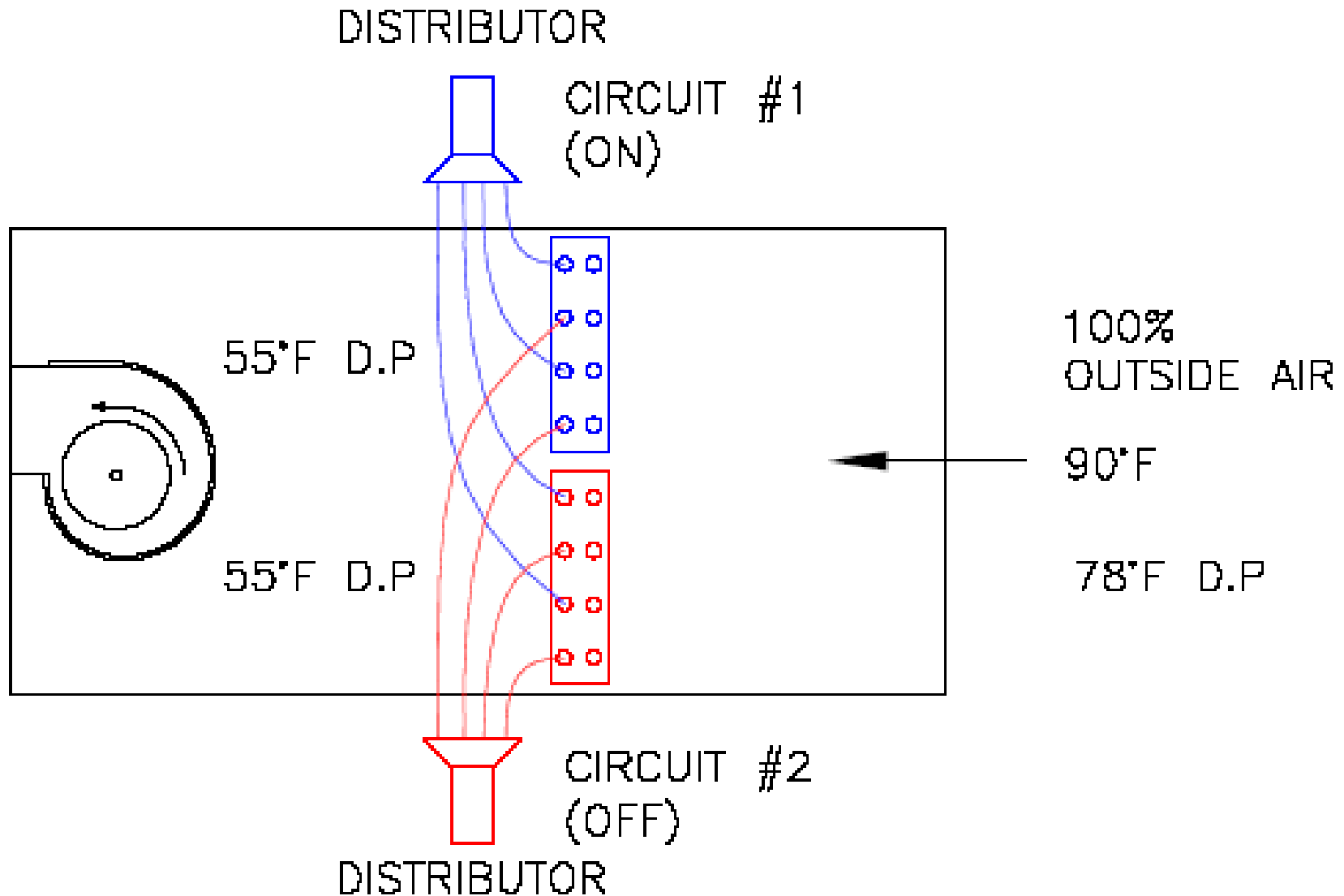
Split Faced Evaporator Coils



Split Faced Evaporator Coils



Interlaced Evaporator Coils



THE END





TRANE

RE THERMO KING

The Future of Refrigerants

Steve Kujak

Director

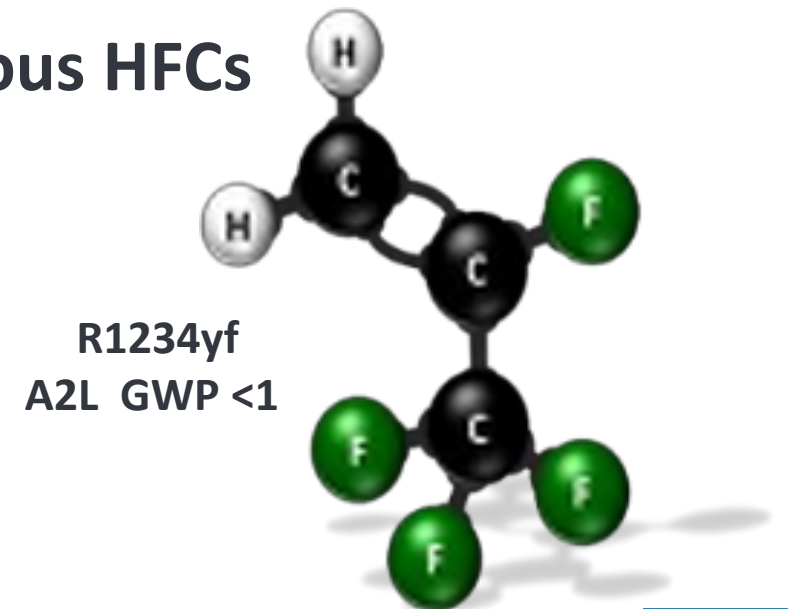
Next Generation Refrigerant Research

TRANE
TECHNOLOGIES

Distinguish Lecturer Series
Version 091223

Agenda - Outline

- Brief History of Refrigerant
- Global Warming Potential of Refrigerants and Their Impacts
- Review of HFC Refrigerant Regulations & Regulatory Mechanisms
- Sustainable Refrigerant Selection & Challenges
- Review of Lower GWP Refrigerant Options For Various HFCs
- Summary & Conclusions
- Q&A



Background – Articles on Regulatory, Basics & Flammability

TECHNICAL FEATURE

Flammability and New Refrigerant Options

ASHRAE Journal
May 2017

What is Driving the Refrigerant Transition?

With growing concerns about the impact on the environment and climate change, pressure has been mounting for years to reduce the use of high-GWP refrigerants across many applications and markets. In response, ASHRAE has been working to address the U.S. and Canada's agreed-upon phase-out of HFCs. On July 16, 2016, the final amendment to the Montreal Protocol was passed, paving the way for the U.S. to phase out HFCs by the year 2030. This document provides a primer on the regulatory changes that are driving the transition to low-GWP refrigerants.

What Should We Know About Flammability?

Safety is a key consideration when evaluating new refrigerant options. The ASHRAE Safety Classification System (ASHRAE Class 1, 2, and 3) provides a framework for evaluating refrigerant safety. Class 1 refrigerants are non-flammable, Class 2 refrigerants are mildly flammable, and Class 3 refrigerants are highly flammable. The ASHRAE Safety Classification System is a key consideration when evaluating new refrigerant options.

TECHNICAL FEATURE

Haloolefins Refrigerants

Highly Unstable in the Atmosphere, But Good Stability in HVAC&R Equipment?

ASHRAE Journal
May 2018

These low-GWP olefins differ from traditional HFC and F-gas refrigerants. Atmospheric Reactivity: Unseen Chemistry

A new group of refrigerants—called haloolefins—consisting of primarily hydrofluoroolefins (HFOs), hydrochlorofluoroolefins (HCFOs) and hydrochloroolefins (HCOOs)—has arrived on the scene in recent years in response to increased regulatory pressure to reduce the global warming potential (GWP) of existing hydrofluorocarbons (HFCs) and other fluorocarbon (F-gas) refrigerants.

Refrigerants are one such unseen player in the atmosphere. They can enter the atmosphere via fugitive emissions during their production and during the manufacture of HVAC&R equipment, as well as from equipment leaks in the field and during equipment decommissioning. Since the discovery in the 1970s that chlorofluorocarbons (CFCs), and to a much lesser extent hydrochlorofluorocarbons (HCFCs), can lead to depletion of the ozone layer, refrigerants have been studied to assess their atmospheric life, their ability to trap heat, and their potential to contribute to global warming.

ROUNDTABLE

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Applying Safety Standards for Flammable Refrigerants

Refrigerant safety standards and resulting building codes have been very restrictive in the use of flammable refrigerants for HVAC&R products. But as societal demands to control climate change are forcing HVAC designers to consider new lower global warming potential (GWP) refrigerants that are flammable, stakeholders have been working to develop the understanding and practice on how to apply these refrigerants. After more than 10 years, product safety standards and ASHRAE application safety standards are in their final stages of being updated to allow the use of flammable refrigerants.

ASHRAE Journal conducted a roundtable discussion on some of the codes and standards that are being modified, we will update standards for flammable refrigerants (see next page). Moderator: Scott M. ...

**ASHRAE Journal
Nov 2022**

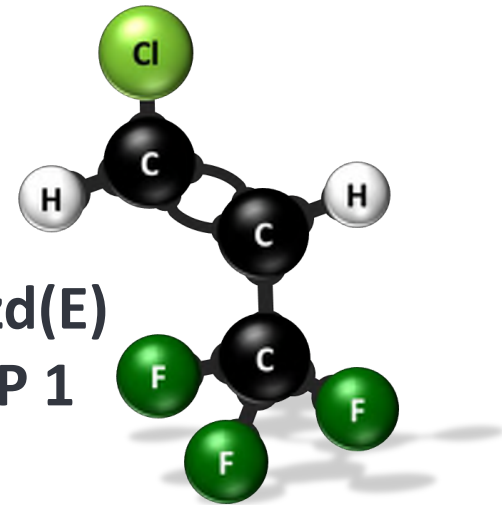
Rusty Tharp: Many of the same practices we use for 60335-2-40 [Standard for Household And Similar Electrical Appliances—Safety—Part 2-40: Particular Requirements for Electrical Heat Pumps, Air-Conditioners and Dehumidifiers] will also apply to flammable A2L, A2 and A3 refrigerants. For example, with A2, these refrigerants can be used in ...

Learning Objectives

1. Describe HFC regulations, regulatory mechanisms and timelines.
2. Explain the challenges when selecting new refrigerants.
3. Provide an update on new lower GWP alternatives and highlight some important considerations, particularly flammability, that engineers, designers, and building owners should keep in mind regarding next-generation refrigerants.

Putting the focus on the “R” in ASHRAE

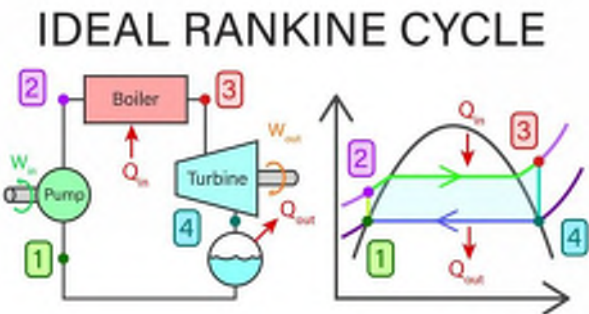
R-1233zd(E)
A1, GWP 1



Four Generational Search for “Perfect” Reverse Rankine Refrigerants



William Rankine
Theory of Heat Engines
“Rankine Cycles”



Thomas Midgley Albert Henne



1830’s – 1930’s

1930’s – 1990’s

1990’s – 2030

2010 - 2050

<ul style="list-style-type: none"> Limited applications mainly industrial “Poor safety & cost” 	<ul style="list-style-type: none"> Innovation enabled exponential societal improvements 	<p>Preserved 2nd gen. innovations, safety, stability and efficiency</p>	<ul style="list-style-type: none"> Fewer choices Safety and design challenges
<ul style="list-style-type: none"> NH₃ CO₂ Various Hydrocarbons H₂O Sulfur Dioxide Methyl Chloride (R40) 	<ul style="list-style-type: none"> NH₃ CFCs and HCFCs <ul style="list-style-type: none"> o R11 o R12 o R22 o R502 	<ul style="list-style-type: none"> NH₃ HCFCs & HFCs <ul style="list-style-type: none"> o R22 o R123 o R134a o R410A o R404A o Many Blends 	<ul style="list-style-type: none"> NH₃ Low GWP HFCs & HFOs <ul style="list-style-type: none"> o R1233zd(E) o R1234yf & R1234ze(E) o HFC/HFO blends Renewed “Natural” interest <ul style="list-style-type: none"> o CO₂ o Hydrocarbons

Societal Demands for Higher Standard of Living Drove Refrigerant Innovations

Why Synthetic Refrigerants?

Optimizing for Safety – Efficiency - Design – Applications



Thomas Midgley



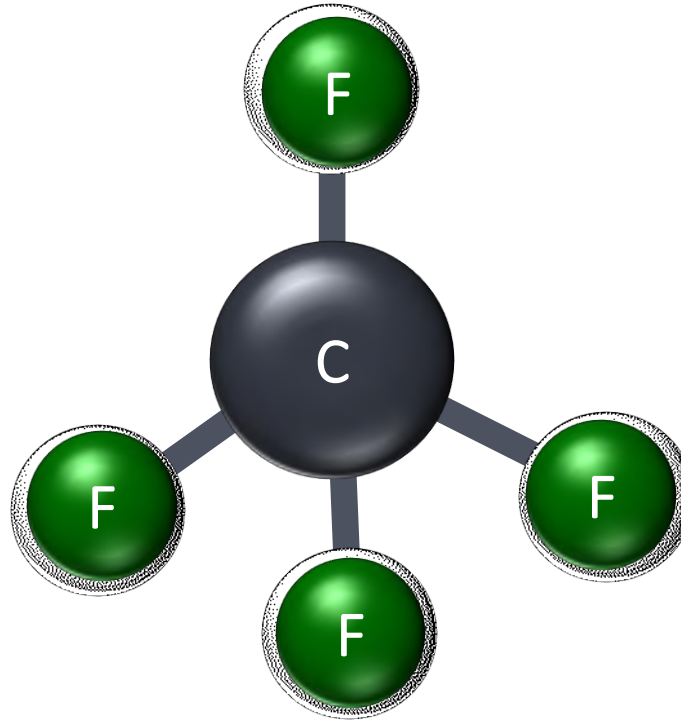
Albert Henne

2nd Generation
"Safety and Stability"

1930's – 1990's

- Innovation enabled exponential societal improvements

- NH₃
- CFCs and HCFCs
 - R11
 - R12
 - R22
 - R502



R-14

ASHRAE Flammability Class 1

GWP - 6630



Halogens

Why Synthetic Refrigerants?

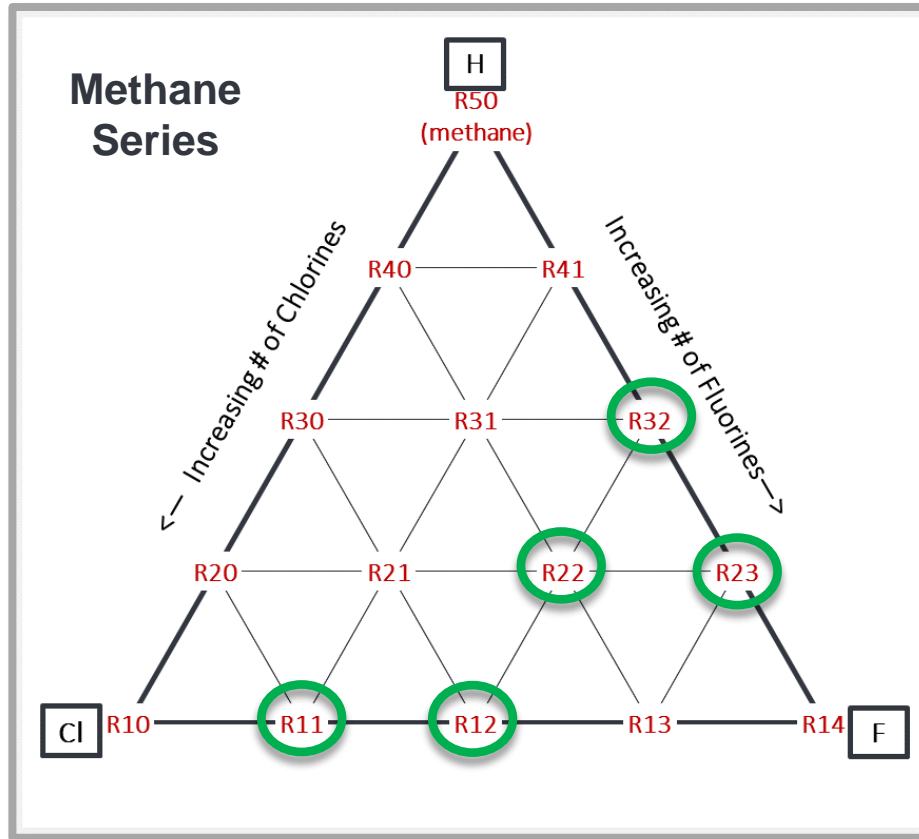
More Potential Rankine Fluid Options



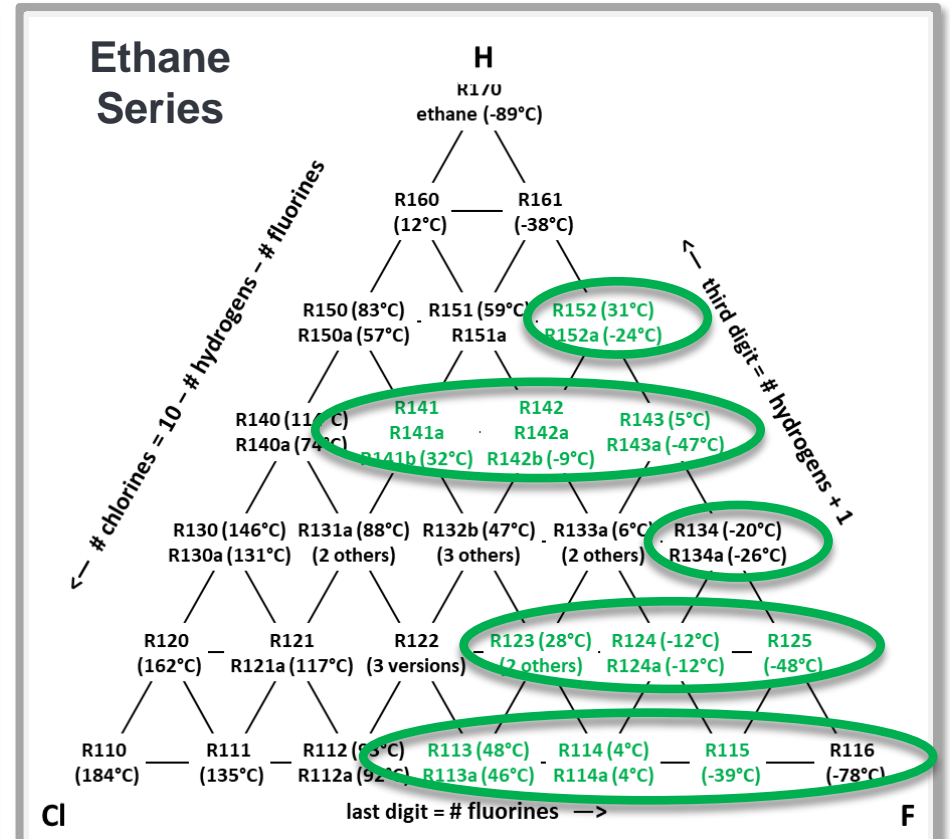
Thomas Midgley

Albert Henne

CFCs, HCFCs, HFCs



14 New Molecules from 1 Methane



55 New Molecules from 1 Ethane

2nd Generation
"Safety and Stability"

1930's – 1990's

- Innovation enabled exponential societal improvements

- NH₃
- CFCs and HCFCs
 - R11
 - R12
 - R22
 - R502

Designing Synthetic Refrigerants for Low GWP?

Optimizing for Safety – Efficiency - Design – Applications



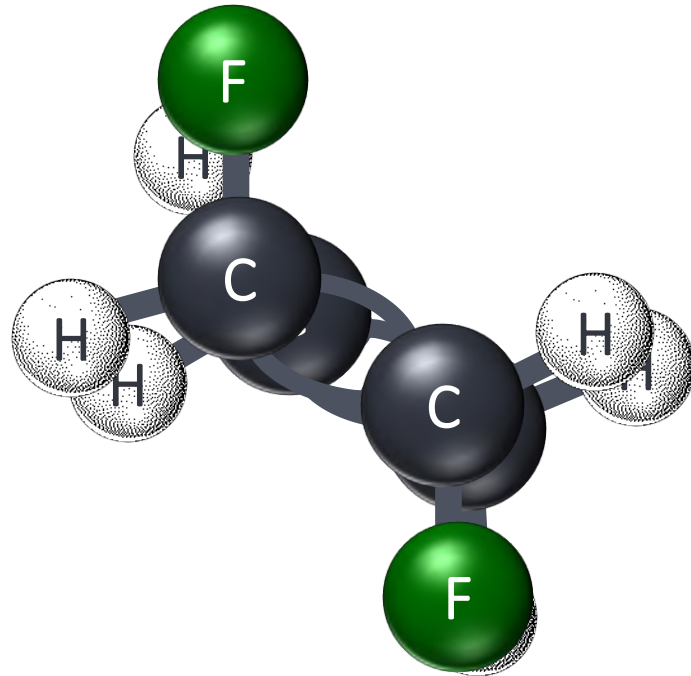
4th Generation
"Global Warming"

2010's – 2050's

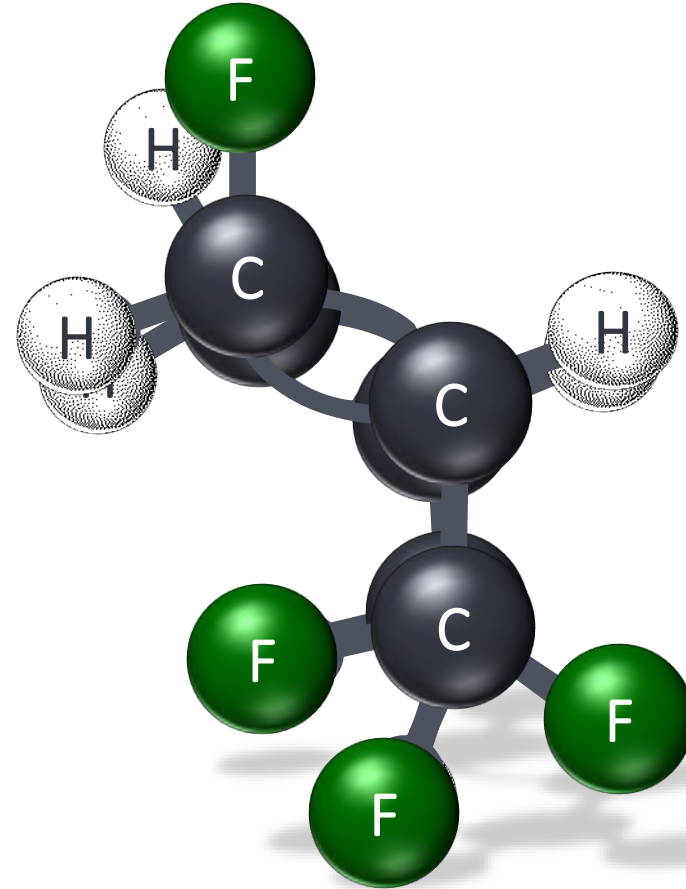


- Fewer choices
- Safety and design challenges

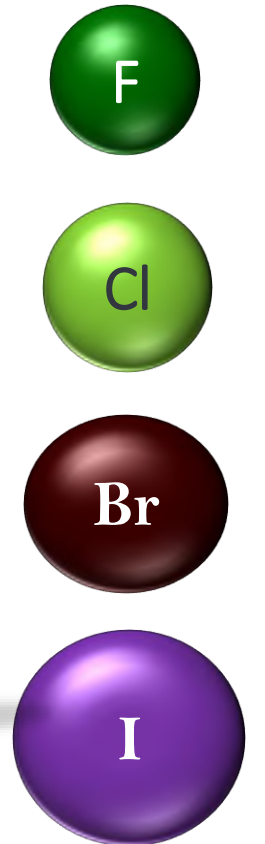
- NH₃
- Low GWP HFCs & HFOs
 - R1233zd(E)
 - R1234yf & R1234ze(E)
 - HFC/HFO blends
- Renewed "Natural" interest
 - CO₂
 - Hydrocarbons



Ethane (R150)
ASHRAE Class A3
GWP - 210



Propane (R270)
ASHRAE Class A3
GWP - 3



Halogens

Global Warming Potential of Refrigerants and Their Impacts



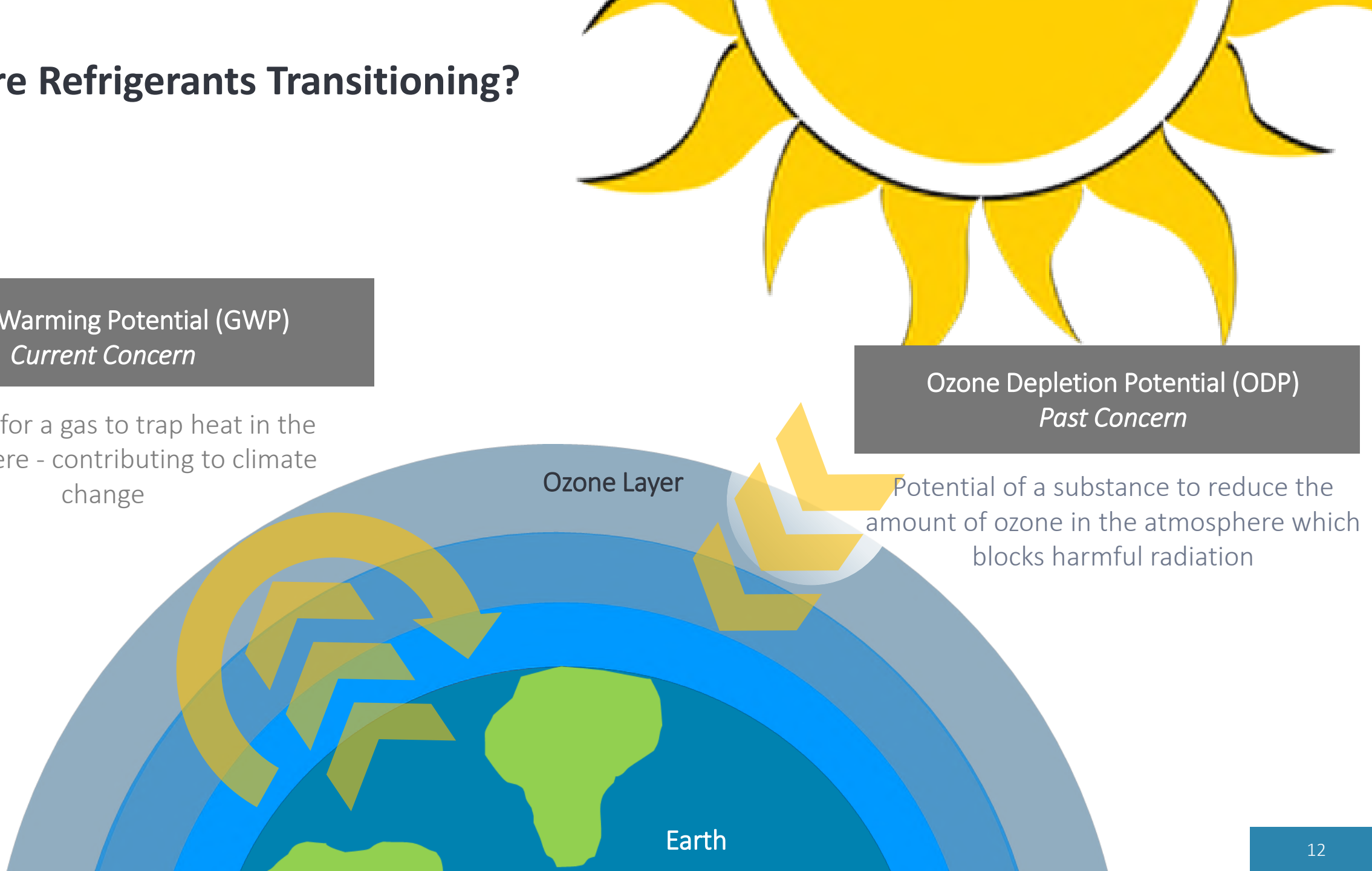
Why Are Refrigerants Transitioning?

Global Warming Potential (GWP)
Current Concern

Potential for a gas to trap heat in the atmosphere - contributing to climate change

Ozone Depletion Potential (ODP)
Past Concern

Potential of a substance to reduce the amount of ozone in the atmosphere which blocks harmful radiation



How is GWP of a Gas Calculated?

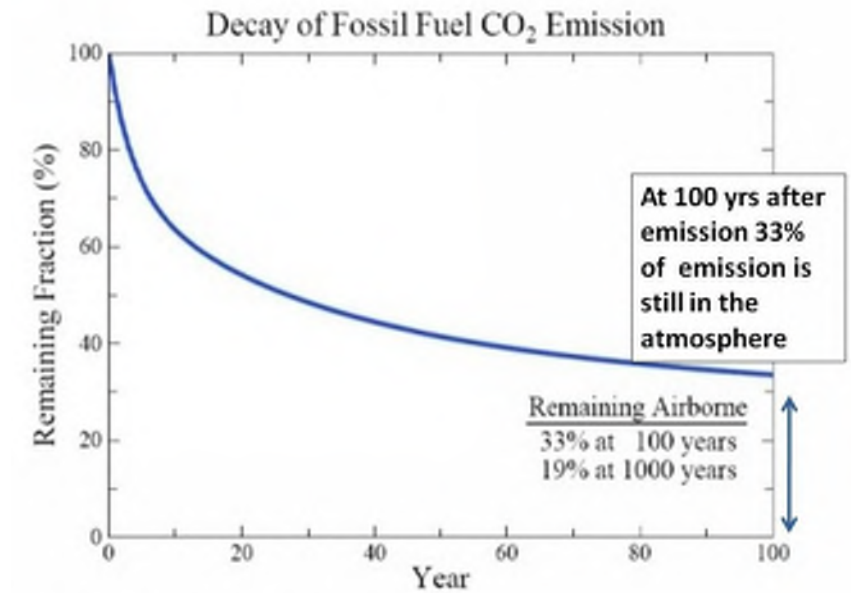
Global warming potential (GWP) is the heat absorbed by any gas in the atmosphere, as a multiple of the heat that would be absorbed by the same mass of CO₂ over a specified time, e.g., 20 or 100 years. All effects beyond 20 or 100 years are disregarded. The GWP value depends on how the gas concentration and CO₂ concentration decays over time in the atmosphere.

$$GWP(x) = \frac{a_x \int_0^{TH} [x](t) dt}{a_r \int_0^{TH} [r](t) dt} \frac{\text{Gas}}{\text{CO}_2}$$

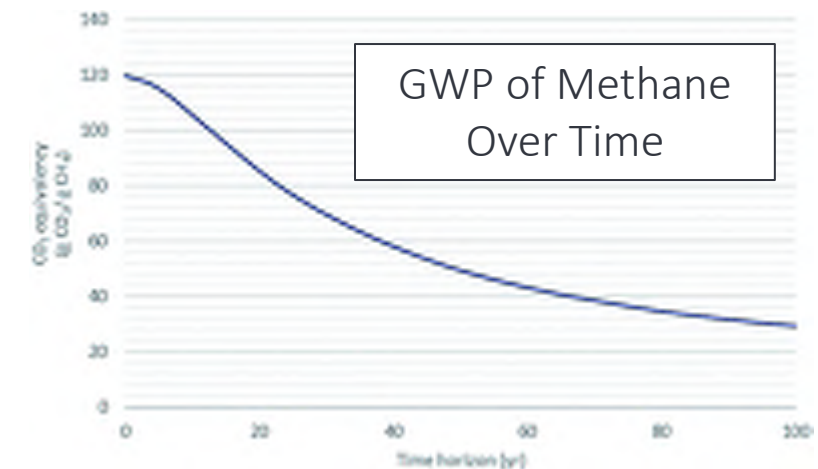
Time Horizon →

Radiative Efficiency →
*Not necessarily Linear over time

Concentration Decay Rate →

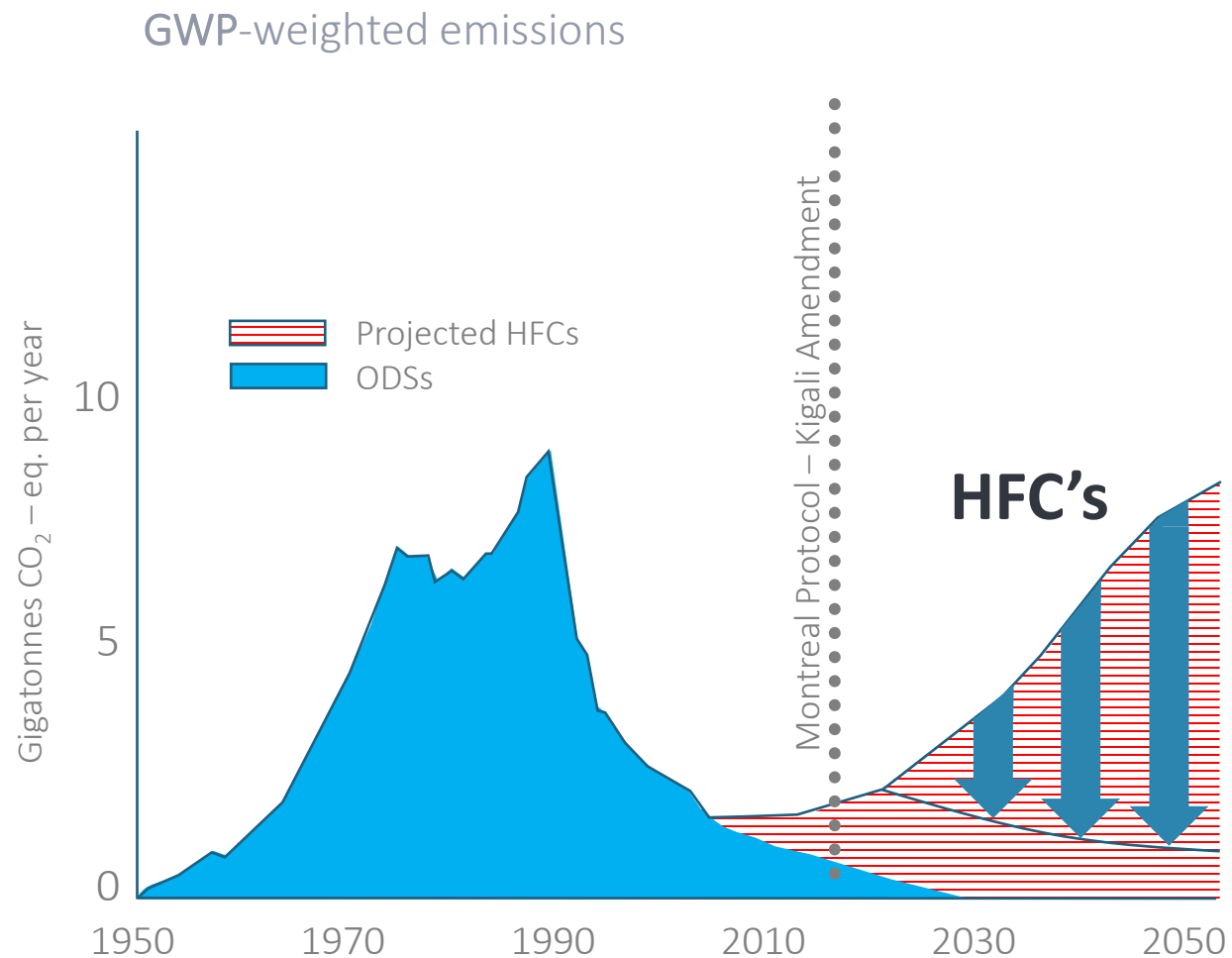
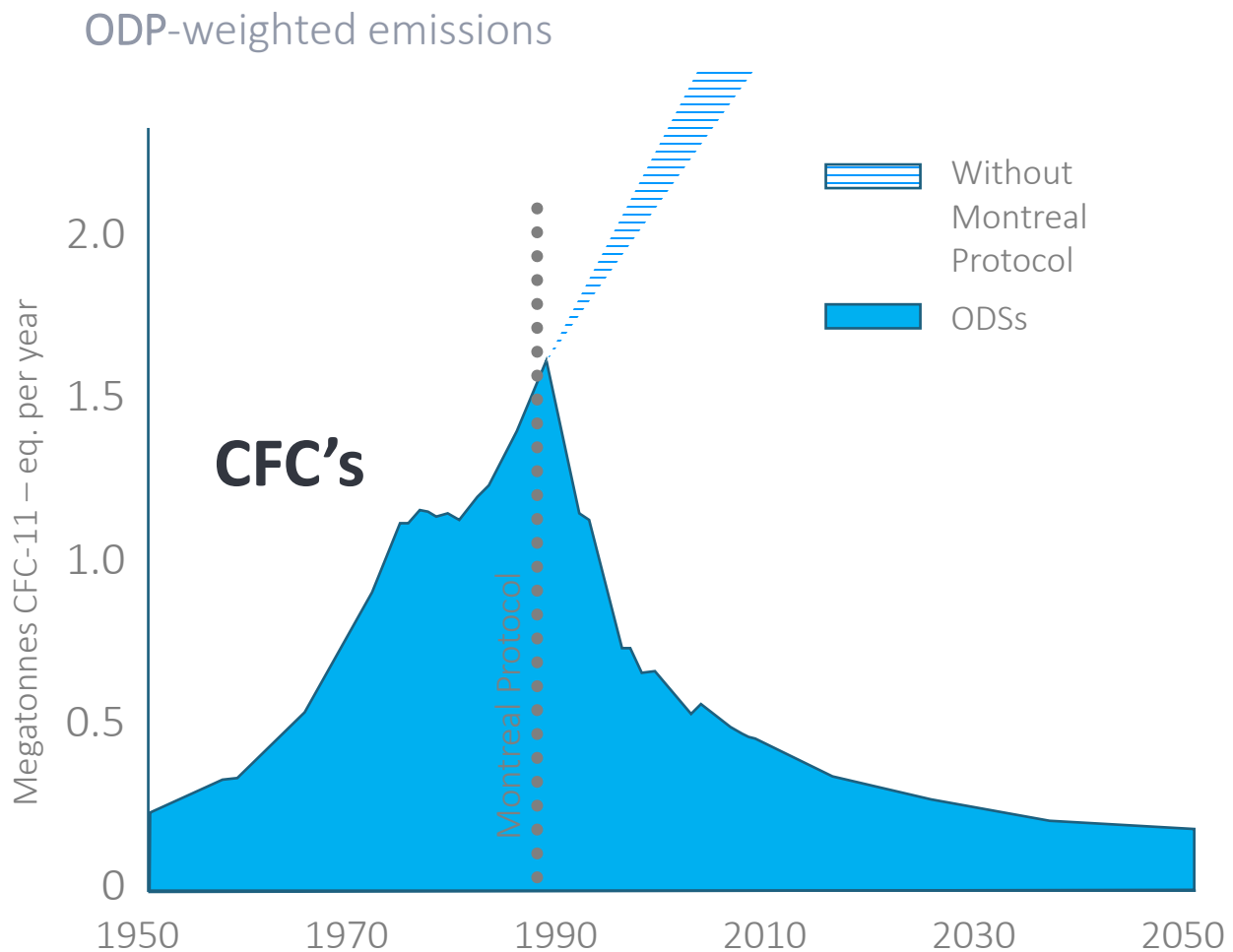


IPCC 2007 Science Technical



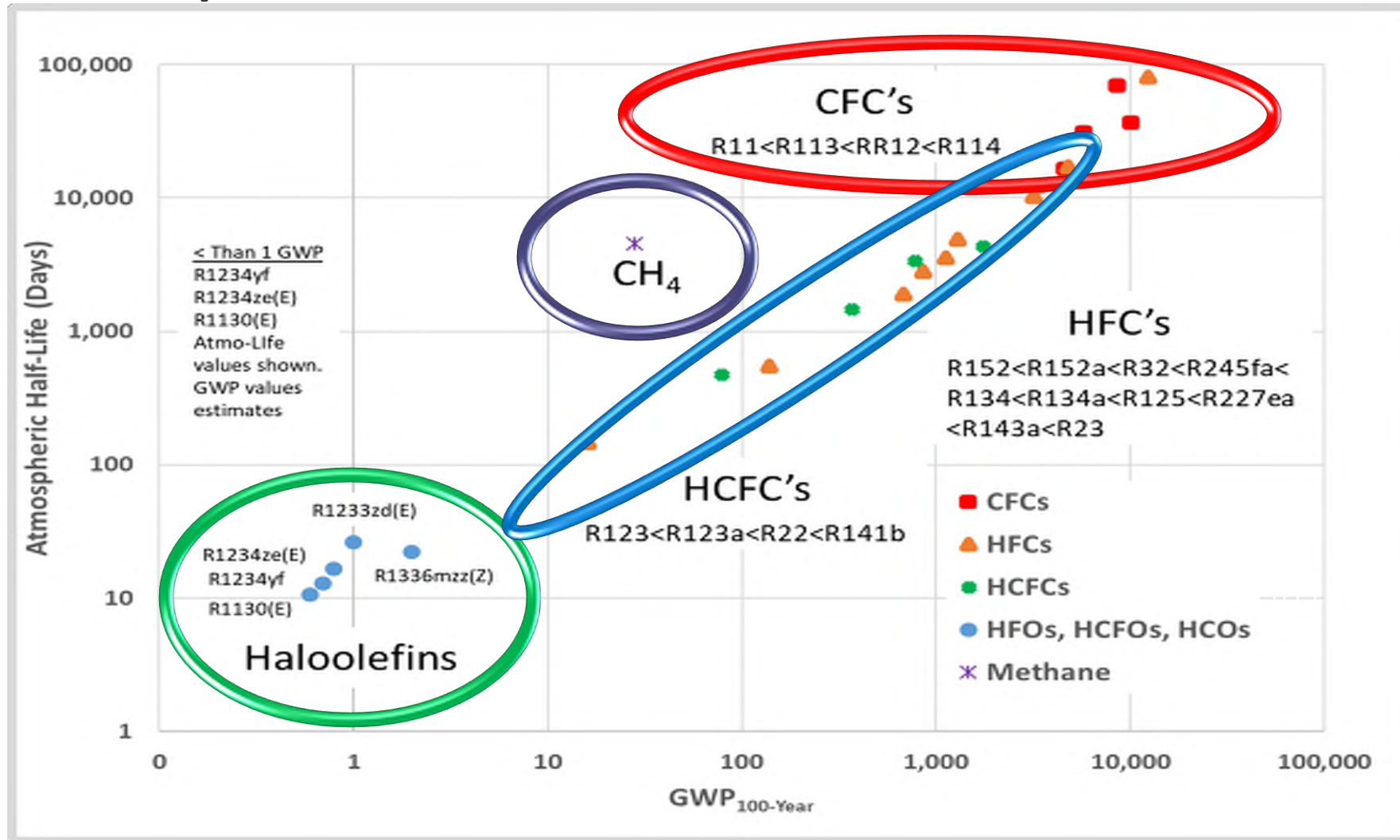
**UNEP Climate Assessment Reports Determine and Publish GWP Values (AR1-AR6)
Regulators Using AR4 100 Year Time Horizon for Gases**

Refrigerant Global Warming Impacts



Source: Velders et al., PNAS (2009)

F-Gases Atmospheric Life vs GWP



Two Choices

Possible Actions: Reduce Emissions Or Shorter Atmospheric Life or Both

HFC Regulations & Regulatory Mechanisms

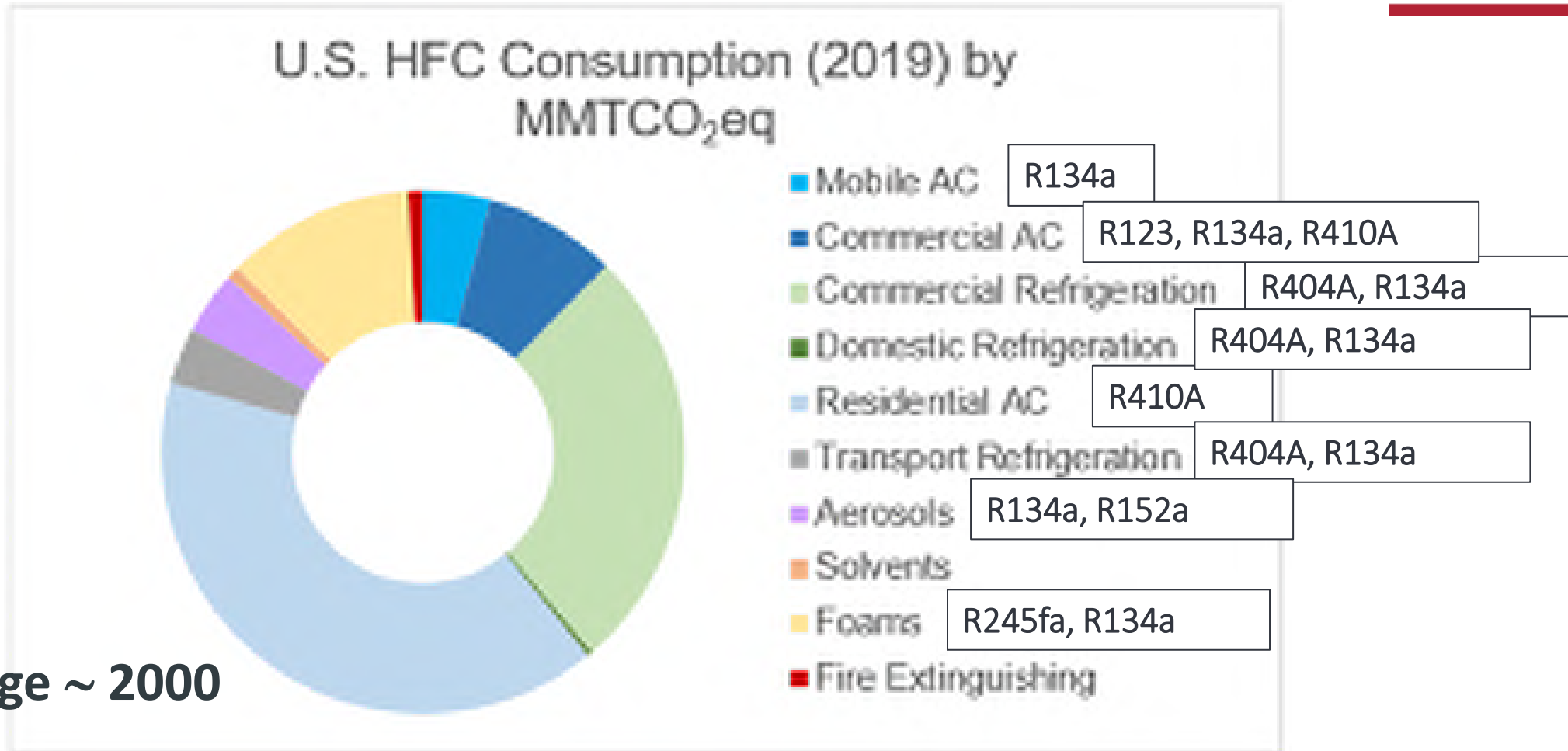
A pair of hands is shown holding a small, red, textured globe. The globe is the color of a tomato and has the words "Global Warming" written on it in white, bold, sans-serif font. The hands are positioned as if they are carefully holding the globe. The background is a blurred green field of tall grass.

**Global
Warming**



Today - HFCs Used by Category (GWP Based Consumption)

GWP Average ~ 2000



Source: U.S. EPA, April 2016. EPA Report EPA-430-R-16-002.

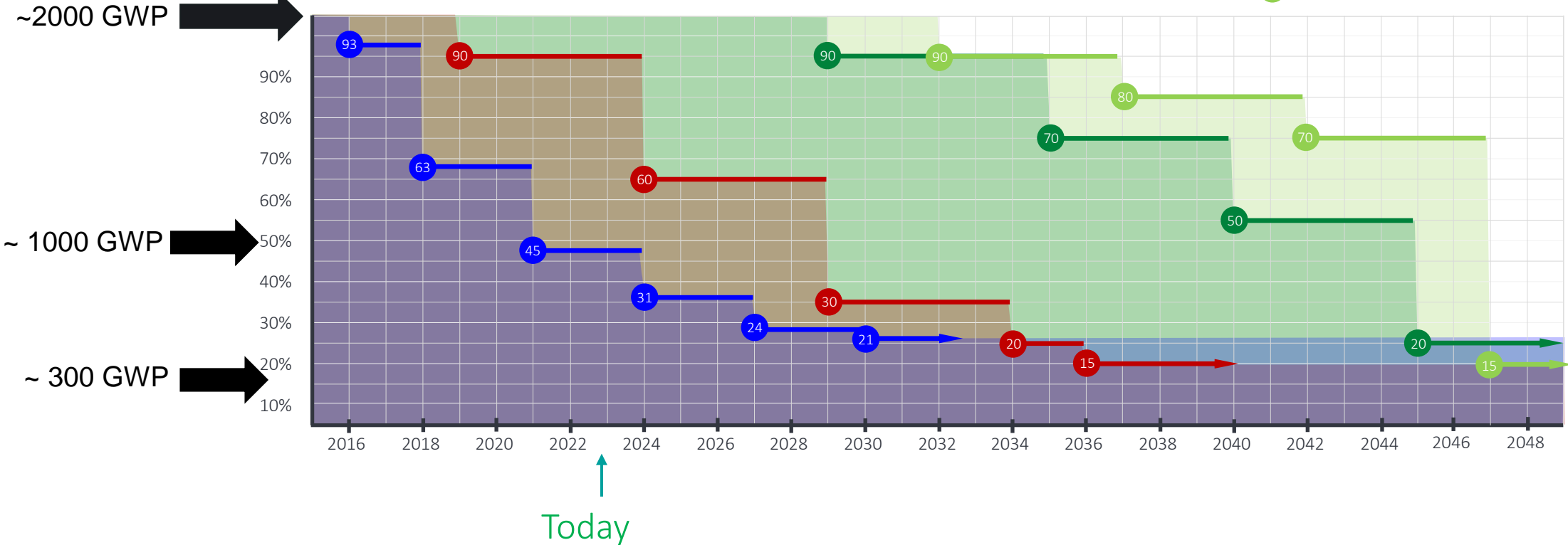
>60% HFC GHG Consumption Used for Commercial Refrigeration (R404A) & Residential ACs (R410A)

Summary of Global HFC Phase Downs Agreement

Kigali Amendment + EU F-Gas
Global Transitions Based on GWP

- European Union
- A2 Countries (Developed)
- A5 Countries (Group 1)
- A5 Countries (Group 2)

Established Baseline (Average GWP of all HFC Produced)



This is a Phase Down, Not Phase Out (All Refrigerants Available for Use)
Kigali Phase-Down of HFCs Started in 2019 for Developed Nations

The U.S. is Regulating the HFC Transition Now



Comprehensive Federal U.S. HFC phase down

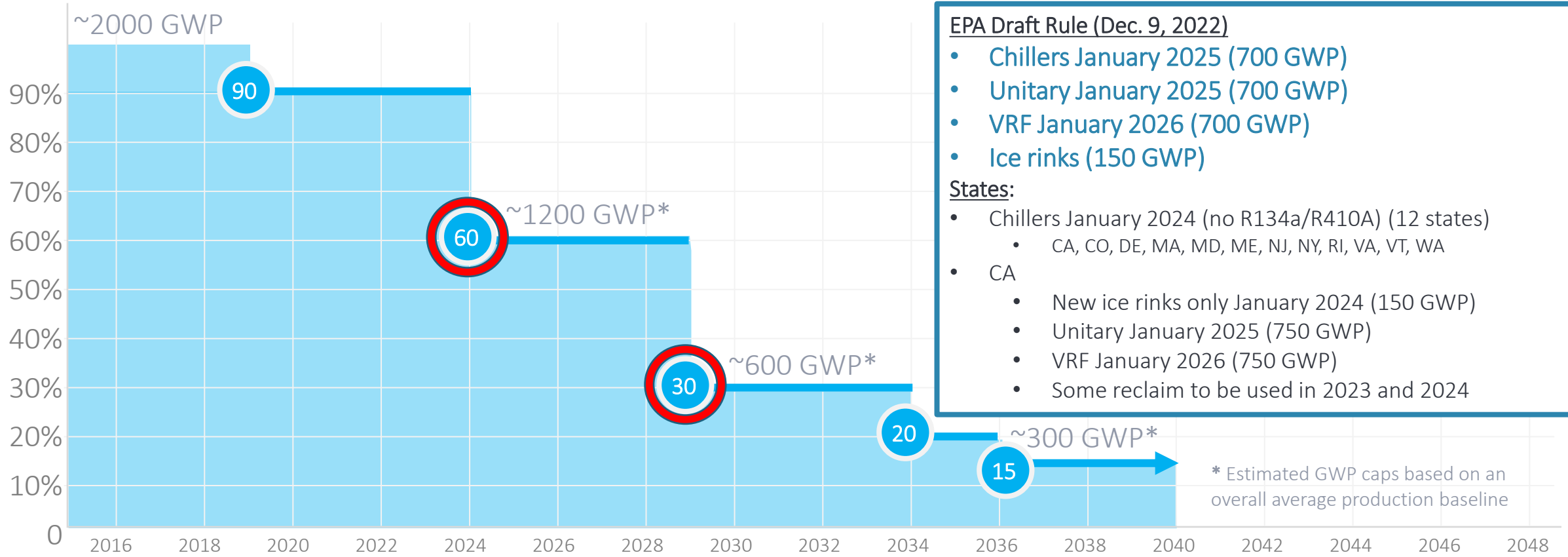
- U.S. AIM Act requires EPA to regulate HFC phase down in the same time frame as the Kigali Amendment (Senate Ratified Oct 22)
- EPA allocation regulation (Sept. 2021) reduces refrigerant supply by 10 percent (GWP) in 2022 to align with legislation
- EPA sets equipment sector bans with GWP limits by **Oct 2023** per AIM Act – Draft rule out Dec. 9, 2022
- EPA to add HFCs to refrigerant management regulation (CAA 608)
- Federal regulation reduces refrigerant supply by 40 percent (GWP) in 2024

The Future is Known... the How and When is becoming Clearer
Final Technology Transition Rule – Due Oct 6, 2023



The U.S. HFC Transition

AIM Act Requires Production/Consumption Reductions through Allocations Following the Montreal Protocol Kigali Schedule for Developed Countries



EPA Draft Rule (Dec. 9, 2022)

- Chillers January 2025 (700 GWP)
- Unitary January 2025 (700 GWP)
- VRF January 2026 (700 GWP)
- Ice rinks (150 GWP)

States:

- Chillers January 2024 (no R134a/R410A) (12 states)
 - CA, CO, DE, MA, MD, ME, NJ, NY, RI, VA, VT, WA
- CA
 - New ice rinks only January 2024 (150 GWP)
 - Unitary January 2025 (750 GWP)
 - VRF January 2026 (750 GWP)
 - Some reclaim to be used in 2023 and 2024

* Estimated GWP caps based on an overall average production baseline

Transition Date: Date of manufacture - The date the label is put on equipment unless it is field assembled then it is the date the system is filled with refrigerant for startup.

New Equipment - Does not include modifications, servicing, or repairs to equipment in existence prior to December 27, 2020. (Beyond EPA's regulatory authority)

Significant GWP Reductions in 2024 and 2029 and Overlapping Product Bans
GWP Target: <700 GWP by 2024 to 2026

The U.S. HFC Transition – Refrigeration



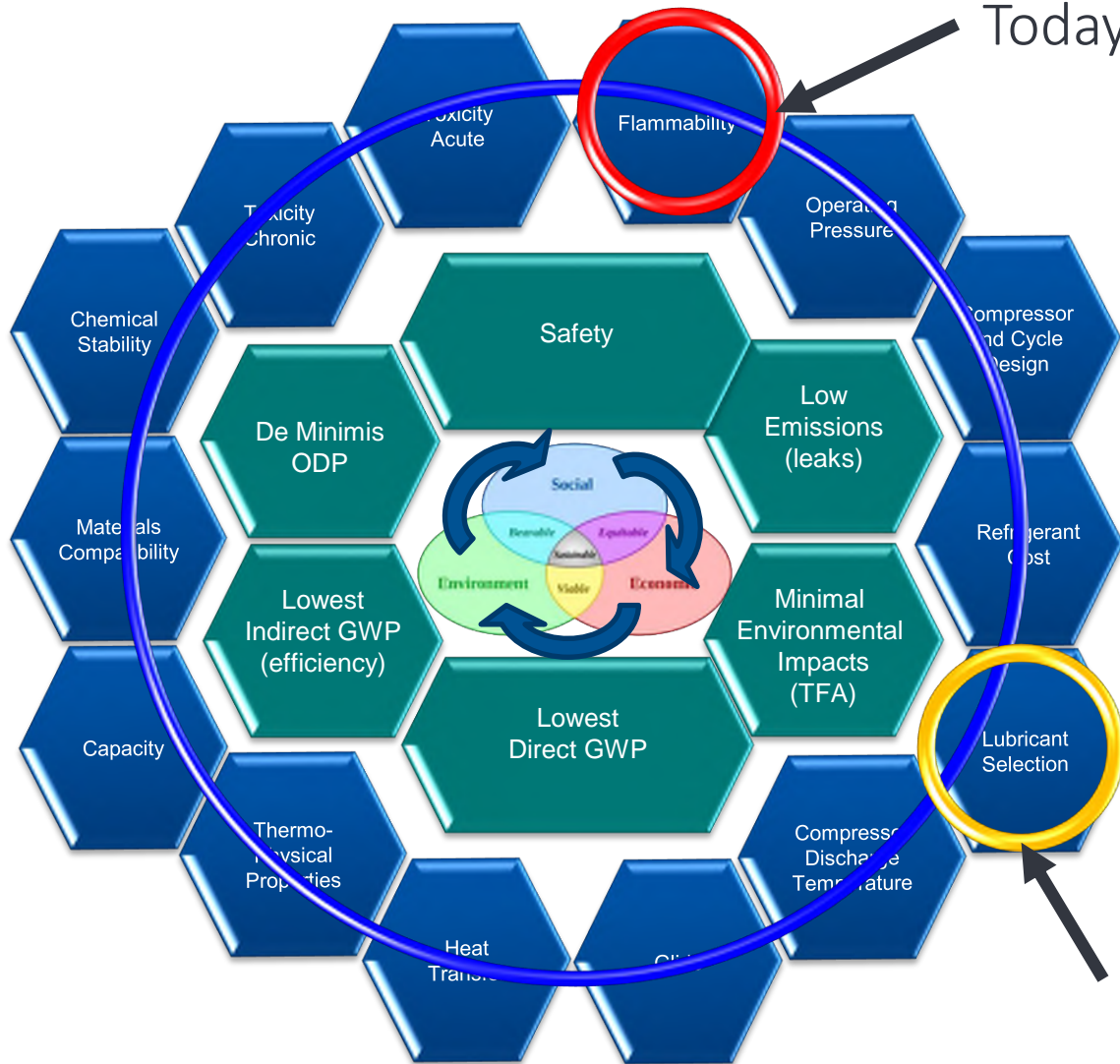
	Refrigeration Equipment (Proposed Compliance Date 1/1/25)	GWP
Industrial Process Refrigeration	Systems with refrigerant charge capacities of 200 pounds or greater	150
	Systems with refrigerant charge capacities less than 200 pounds	300
	High temperature side of cascade systems	300
	Chillers	700
Retail Food Refrigeration	Stand-alone units	150
	Refrigerated food processing and dispensing equipment	150
	Supermarket systems with refrigerant charge capacities of 200 pounds or greater	150
	Supermarket systems with refrigerant charge capacities less than 200 pounds charge	300
	Supermarket systems, high temperature side of cascade system	300
	Remote condensing units with refrigerant charge capacities of 200 pounds or greater	150
	Remote condensing units with refrigerant charge capacities less than 200 pounds	300
	Remote condensing units, high temperature side of cascade system	300
	Vending machines	150
Cold Storage Warehouse	Systems with refrigerant charge capacities of 200 pounds or greater	150
	Systems with refrigerant charge capacities less than 200 pounds	300
	High temperature side of cascade system	300
	Ice rinks	150
	Automatic commercial ice machines – selfcontained with refrigerant charge capacities of 500 grams or lower (Note: Does not align with petition)	150
	Transport refrigeration – intermodal containers	700
	Residential refrigeration	150

Refrigeration - More Complex Based On Available Technology by Application

Sustainable Refrigerant Selection & Challenges



Refrigerant Replacement Challenge



Today Primary Challenge

Balancing Key Factors for;

- Direct Refrigerant GWP
- Efficiency (Indirect GWP)
- Safety
- Transition Costs
- Intellectual Property
- Product Sustainability



Last Transition

**Challenge: Selecting Refrigerants with Best Balance (Sustainability)
Flammability Greatest Challenge for this Transition – Not in All Cases**

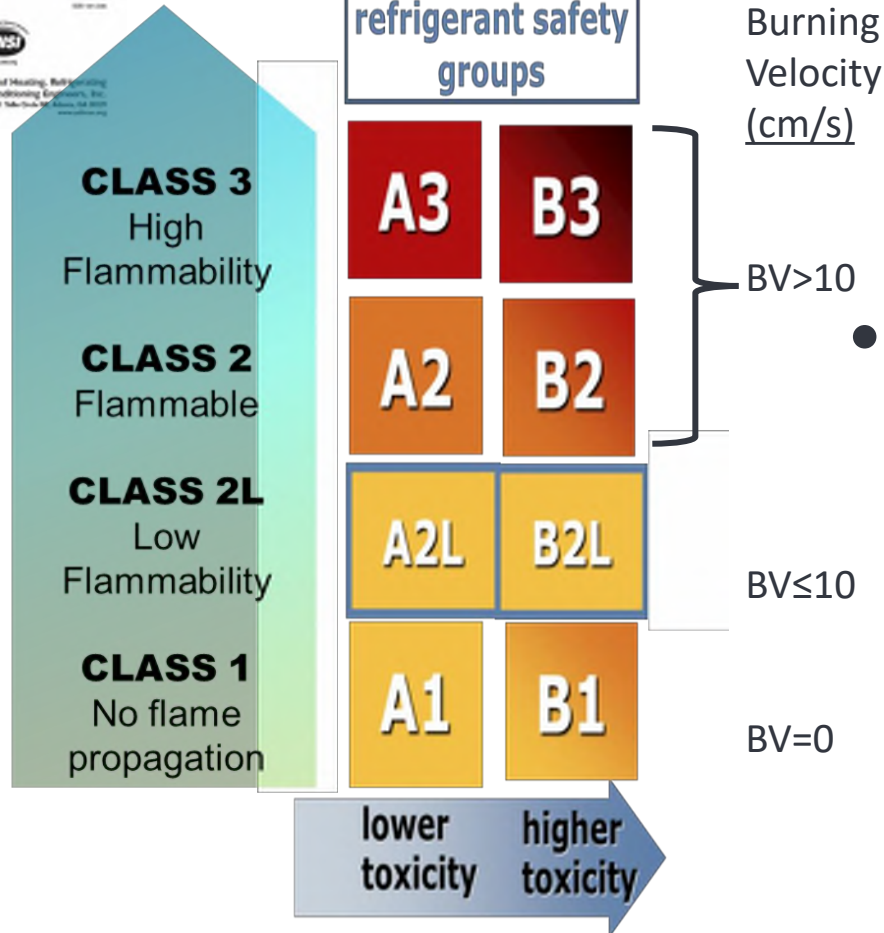


ASHRAE Standard 34 Safety Classification of Refrigerants

ASHRAE Standard 34-2010
Designation and Safety Classification of Refrigerants
Approved for use by the ASHRAE Council on 10/15/10
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• Toxicity

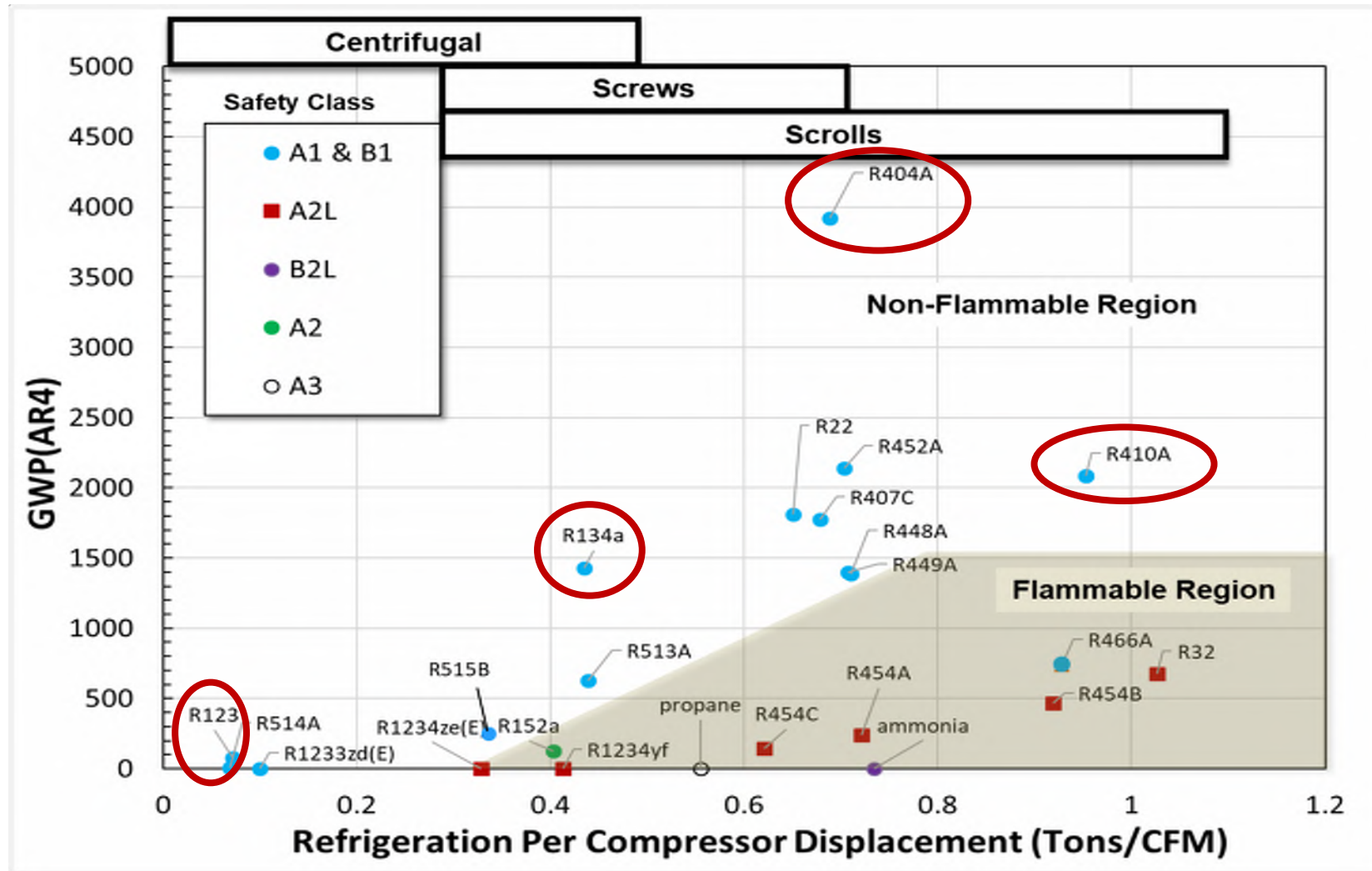
- A or B Based > or = to 400 ppm Occupational Exposure Limit (OEL) Dividing Line
- Class A, most refrigerants, like R134a
- Class B, R123 and ammonia are examples

• Flammability

- Class 1, Non-flame propagating most refrigerants used today, like R123, R134a, R404A, R410A, etc., called nonflammable
- Class 2L, Lower Flammable Class 2's <10 cm/sec burning velocity, most new HFO's, R32, R1234yf
- Class 2, more flammable, R152a
- Class 3, explosive, like propane (R290), Isobutane (R600a)

**Flammability is a Continuum without Specific Limits
"Flammables are Flammable"**

Viability Lower GWP & Ultra Low GWP Alternatives

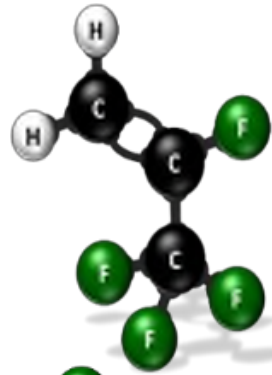


Flammable Refrigerants Required For Some Applications to Achieve a Low GWP Refrigerant Future

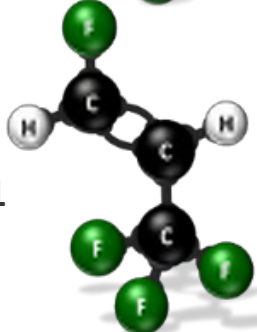
Review of Lower GWP Refrigerant Option for Various HFCs



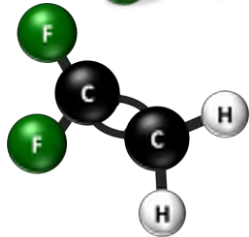
Toolbox of <10 GWP Next Generation Refrigerants



R1234yf
A2L GWP <1

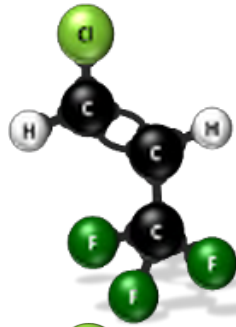


R1234ze(E)
A2L GWP <1

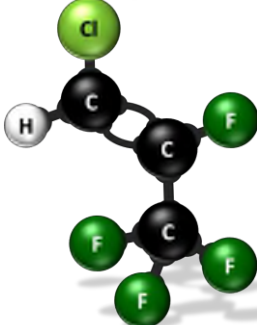


R1132a
A2 GWP <1

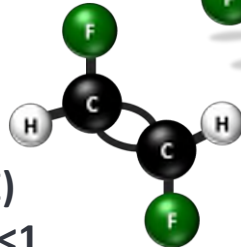
R1233zd(E)
A1 GWP 1



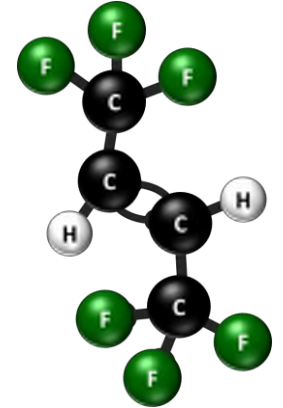
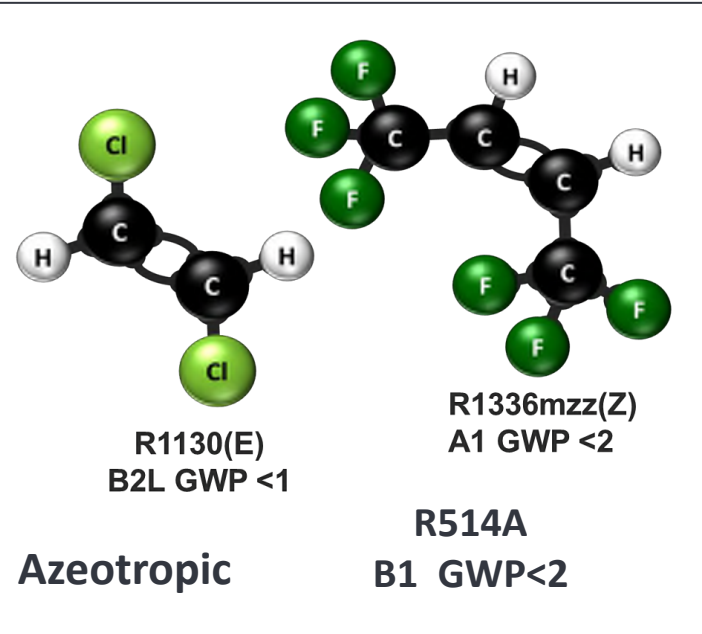
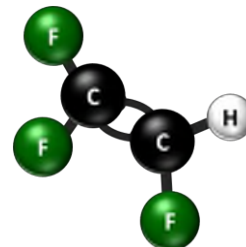
R1224yd(Z)
A1 GWP 1



R1132(E)
B2 GWP <1



R1123
?2L GWP <1

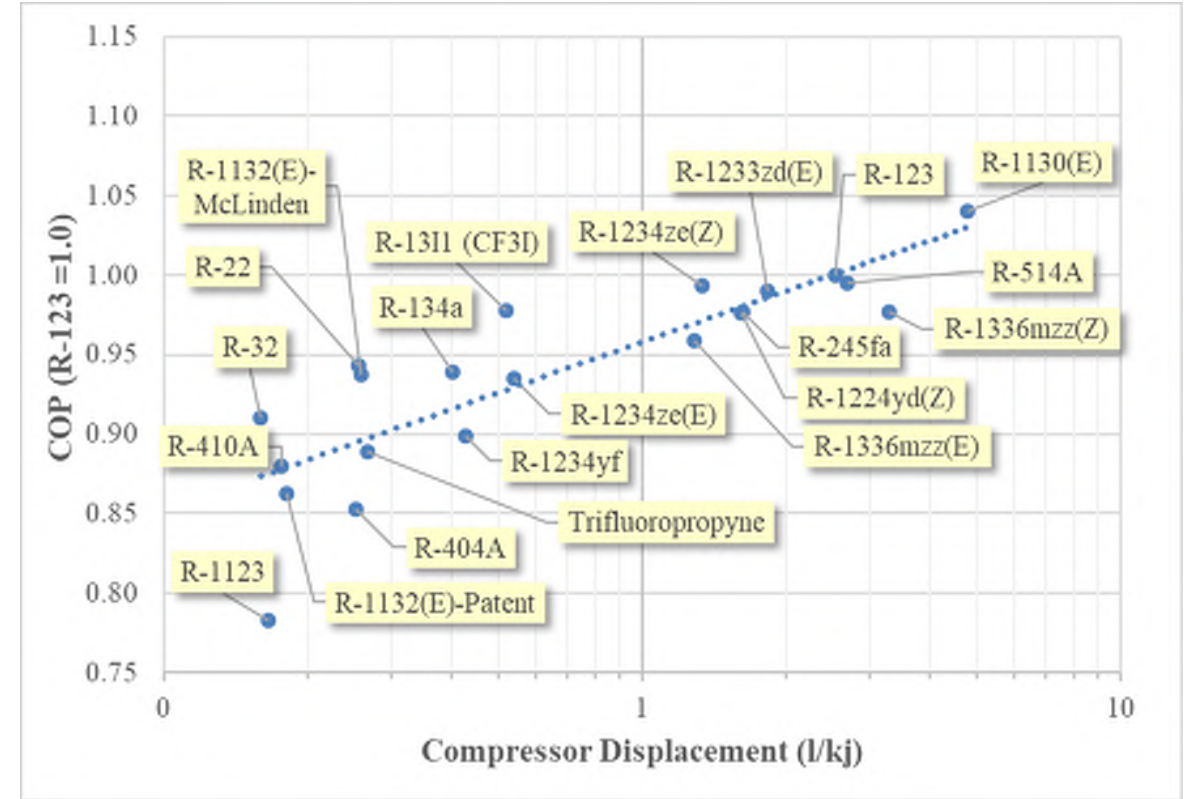
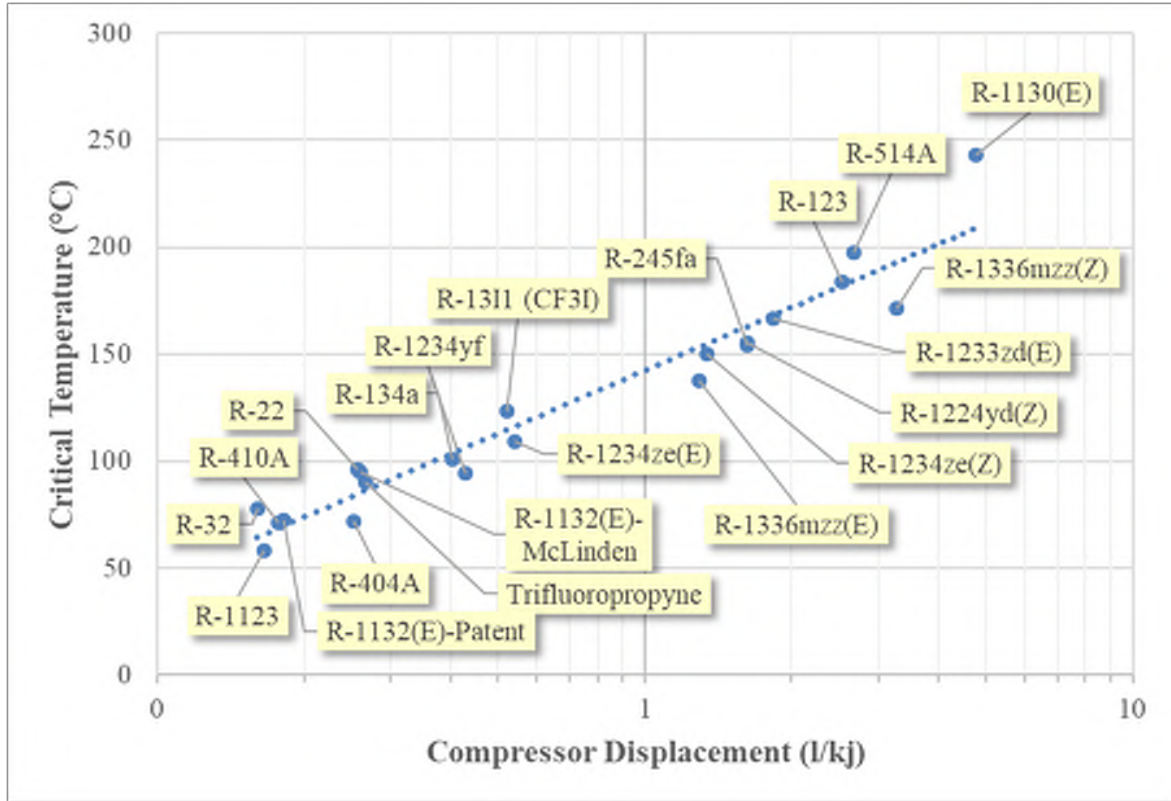


R1336mzz(E)
A1 GWP <6

Along with
Carbon Dioxide (R744) – A1
Ammonia (R717) – B2L
Hydrocarbons (R290, R600, R600a) – A3

8 New Molecules/9 Older Molecules - HFOs, HCFOs, HCOs, IFC, CO2, NH3, HCs
Many of Which are Flammable

Summary of <10 GWP Refrigerants in the Toolbox



The Same or Better Efficiency Over HFCs - Still Less Than CFCs
Many of these are Zeotropic (R-400) Blends to Optimize Properties
Some R-500 Series Refrigerants are Azeotrope – No Change in Blend Composition if Leaked

Low Pressure Alternatives

R123 Replacements

Alternatives Attributes

- Most Low GWP (<10)
- Non-flammable
- Good efficiency
- Near design compatible alternatives available
- Near R123 and R245fa capacities
- All with no glide
- Issues: none

		Baseline	Ultra-Low GWP	
		R-123	R-514A	R-1233zd(E)
Flammability	ASHRAE Class	1	1	1
Toxicity ¹	ASHRAE Class	Higher (B)	Higher (B)	Lower (A)
	OEL (ppm)	50	320	800
Efficiency (COP)		8.95	8.91	8.87
Capacity Change		baseline	~5% loss	~35% gain
GWP ²		77	1.7	1
Atmospheric Life		1.3 years	22 days	26 days



*Modeling Conditions: 100% isentropic compressor efficiency, 95°F/44°F, 0 superheat, 0 subcooling

R1233zd(E) and R514A – Good Choices Nonflammable, GWP <2, High Efficiency
All These Candidates Considered “Long Term Solutions”
R514A & R1233zd(E) Products Available in Market Place

Medium Pressure Alternatives - R134a Replacements

Alternatives Attributes

- Flammability
 - GWP 300-600 nonflammable
 - GWP <150 flammable
- Good to ok efficiency
- All with no glide (azeotropes)
- Near design compatible alternatives available
 - Near R134a capacity (R513A)
 - R1234ze(E) = -25% capacity
- Issues: Lower superheat than R134a

		Baseline	Lower GWP		Ultra-Low GWP	
		R-134a	R-513A	R-515B	R-1234yf	R-1234ze(E)
Flammability	ASHRAE Class	1	1	1	2L 	2L 
Toxicity ¹	ASHRAE Class	Lower (A)	Lower (A)	Lower (A)	Lower (A)	Lower (A)
	OEL (ppm)	1000	650	810	500	800
Efficiency (COP)		8.47	8.27	8.32	8.17	8.45
Capacity Change		baseline	similar	~25% loss	~5% loss	~25% loss
GWP ²		1430	630	298	6	4
Atmospheric Life		13.4 years	5.9 years	3.1 years	11 days	18 days



*Modeling Conditions: 100% isentropic compressor efficiency, 95°F/44°F, 0 superheat, 0 subcooling

*R-513A introduced for ice rinks applications in 2019

R513A & R515B (Nonflammable) and R1234ze(E) Good Choices

R513A & R515B Products Available In Market Place (USA) – ZE & YF in EU

High Pressure Alternatives - R404A Replacements

		R-404A	R448A	R449A	R407H	R454A	R454C
Flammability	ASHRAE Class	1	1	1	1	2L 	2L 
Toxicity ¹	ASHRAE Class	Lower (A)	Lower (A)	Lower (A)	Lower (A)	Lower (A)	Lower (A)
	OEL (ppm)	1000	860	840	1000	690	620
Efficiency (COP)		2.65	2.70	2.70	2.71	2.69	2.72
Capacity Change		baseline	~4% loss	~5% loss	~8% loss	~3% gain	~13% loss
Glide (R) Condenser		0.8	9.7	9.0	10.4	9.9	13.5
GWP _{AR4}		3922	1397	1387	1494	239	148
Atmospheric Life		36 years	11.5 years	11.6 years	13 years	1.84 years	1.14 years

Conditions: 65% Isentropic compressor efficiency, 35% SLHX, -25F Evap, 60F Cond, 5R SC, 10R SH

- Flammability
 - R448A, R449A, R407's (Nonflams)
 - R454A, R454C leading flammables
 - R600a, R290, leading hydrocarbons
- Issues: High glide, high CDT, <150 GWP lower capacity, all flammable
- No low glide blends for low temperature refrigeration flooded evaporator chillers



**R448A, R449A, R452A Good Interim Candidates (Nonflammables)
Innovation Still Needed and Underway <150 GWP Possible - Tradeoffs**

High Pressure Alternatives

R410A Replacements

Alternatives Attributes

- Flammability
 - R454B & R32 leading candidates are both 2L
- Efficiency - equal or greater
- R454B Near design compatible
- Low glide
 - R454B-R410A like with low glide (0 to <2K)
- Issues: No <300 GWP “R410A Like”
- Issues: <300 GWP “R404A Like”, but with high glide/CDT

		Baseline	Lower GWP	
		R-410A	R-454B	R-32
Flammability	ASHRAE Class	1	2L 	2L 
Toxicity ¹	ASHRAE Class	Lower (A)	Lower (A)	Lower (A)
	OEL (ppm)	1000	850	1000
Efficiency (COP)		7.99	8.16	8.22
Capacity Change		baseline	~3% loss	~8% gain
GWP ²		2088	467	675
Atmospheric Life		17 years	3.6 years	5.2 years

*Modeling Conditions: 100% isentropic compressor efficiency, 95°F/44°F, 0 superheat, 0 subcooling

R454B & R32 Primary “Interim” GWP Phasedown Refrigerants
Innovation Still Needed and Underway to Achieve <300 for All Products

Summary & Conclusions



Summary & Conclusions

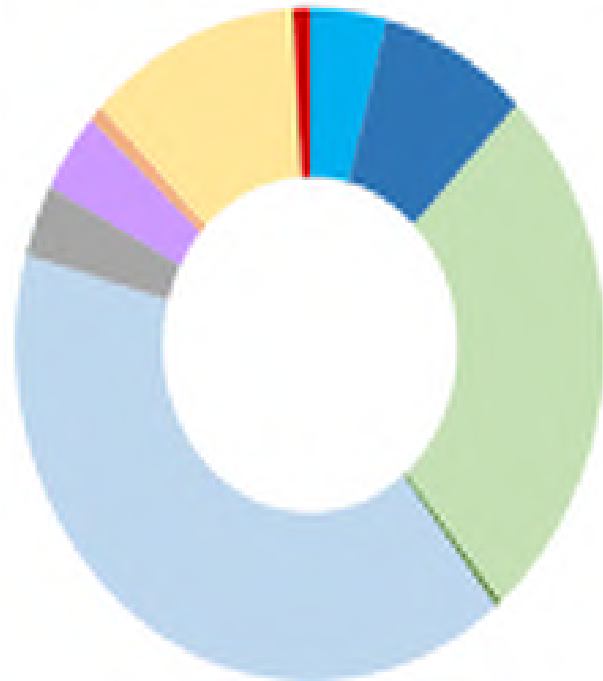
- Single Refrigerants or Blends will not be used from small to large capacity products
- Lack of low glide
- There is no Perfect Refrigerant! A balanced approach is required
 - *Safety, Environmental Impact, Efficiency*
 - *Reaching final GWP goals requires more refrigerant technology innovation (Interim Adoptions)*
 - *Widespread Use of Flammable Refrigerants Required to Achieve Final Phasedown Goals*
 - *Remember – Flammables are Flammable No Matter the ASHRAE Classification (Class 2L, 2 and 3)*
 - *Leak tightness is key!*
- Low or ultra low alternatives are available today/will be shortly for many products
- Use of Natural Refrigerant expanding
 - *Ammonia (R717) continues in US. Carbon dioxide (R744) trials accelerating/maturing in specific applications. Hydrocarbons common in small portable appliances*
- Expect more product fragmentation by refrigerant. A single refrigerant may not be used from small to large capacity products

Use the Facts to Plan for Tomorrow

Tomorrow - HFCs Used by Category



U.S. HFC Consumption (2019) by MMTCO₂eq



- Mobile AC: R1234yf
- Commercial AC: R514A, R1233zd, R513A, R515B, R1234yf, R1234ze, R32, R454B
- Commercial Refrigeration: R600a, R290, CO₂, Ammonia, R454A, R454C, R515B, R1234yf
- Domestic Refrigeration: R600a, R290
- Residential AC: R32, R454B
- Transport Refrigeration: R452A, R454A, R454C, R513A, R1234yf
- Aerosols: HCs, R152a, R1234ze
- Solvents
- Foams: R1233zd, R1234ze, R1336mzz, HCs, Water
- Fire Extinguishing

GWP Average < 300

Low GWP Goals Achievable – But with Increased Market Fragmentation

People Continue to Argue... Nature Acts



Sunrise over the Mississippi River at my House – Brownsville, MN – July 2020