



TRANE™

RE THERMO KING

The Future of Refrigerants

Steve Kujak

Director

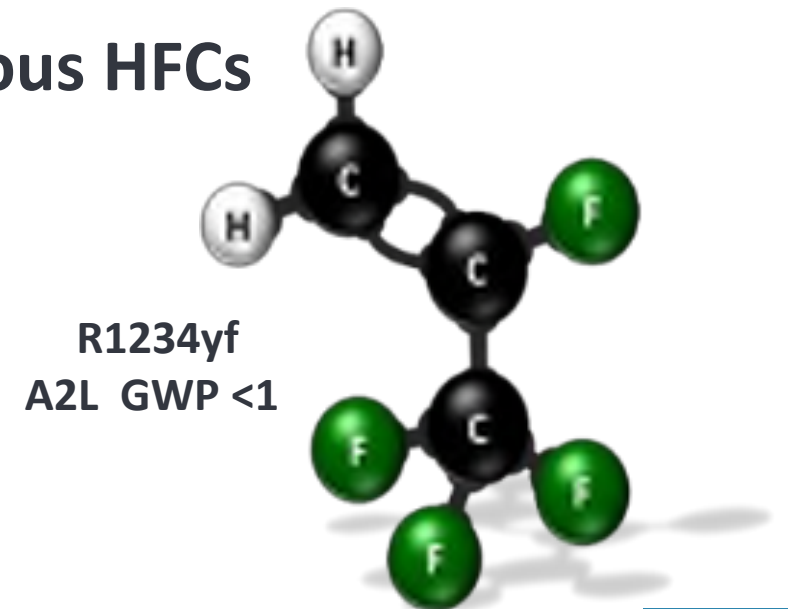
Next Generation Refrigerant Research

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. and Canada to phase out HFCs by the year 2030. This phase-out is being implemented through a series of regulatory actions, including the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Energy (DOE) issuing rules to phase out HFCs in new equipment. The EPA's new rules are being implemented in a series of steps, with the first step being the phase-out of HFCs in new equipment by 2020. The DOE's rules are being implemented in a series of steps, with the first step being the phase-out of HFCs in new equipment by 2020. The EPA's new rules are being implemented in a series of steps, with the first step being the phase-out of HFCs in new equipment by 2020. The DOE's rules are being implemented in a series of steps, with the first step being the phase-out of HFCs in new equipment by 2020.

What Should We Look for in a Refrigerant?

As the industry looks for alternatives to HFCs, it is important to consider the environmental and safety characteristics of the new refrigerants. Key factors to consider include global warming potential (GWP), flammability, and toxicity. The ASHRAE Handbook—HVAC Systems and Equipment, 2017, provides a comprehensive overview of the various refrigerant options available to designers. The handbook is organized into several chapters, each covering a different aspect of refrigerant selection. Chapter 10, "Refrigerants," provides a detailed overview of the various refrigerant options available to designers. Chapter 11, "Refrigerant Selection," provides a detailed overview of the various factors that should be considered when selecting a refrigerant. Chapter 12, "Refrigerant Safety," provides a detailed overview of the various safety considerations that should be taken into account when working with refrigerants. Chapter 13, "Refrigerant Environmental Impact," provides a detailed overview of the various environmental impacts of different refrigerants. Chapter 14, "Refrigerant Regulations," provides a detailed overview of the various regulatory requirements that apply to different refrigerants. Chapter 15, "Refrigerant Alternatives," provides a detailed overview of the various alternative refrigerants that are available to designers. Chapter 16, "Refrigerant Selection Process," provides a detailed overview of the various steps that should be followed when selecting a refrigerant. Chapter 17, "Refrigerant Safety and Environmental Considerations," provides a detailed overview of the various safety and environmental considerations that should be taken into account when working with refrigerants. Chapter 18, "Refrigerant Regulations and Standards," provides a detailed overview of the various regulatory requirements and standards that apply to different refrigerants. Chapter 19, "Refrigerant Alternatives and Future Trends," provides a detailed overview of the various alternative refrigerants and future trends in the refrigerant market.

TECHNICAL FEATURE

Haloolefins Refrigerants

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

ASHRAE Journal
May 2018

What are Haloolefins?

Haloolefins are a class of refrigerants that are highly flammable and have a high global warming potential (GWP). They are composed of hydrocarbons with one or more fluorine atoms. The most common haloolefins are hydrofluoroolefins (HFOs), hydrochlorofluoroolefins (HCFOs), and hydrofluorocarbon (HFC) derivatives. HFOs are the most common type of haloolefin and are used in a variety of applications, including air conditioning, refrigeration, and heat pumps. HCFOs are used in a variety of applications, including air conditioning, refrigeration, and heat pumps. HFC derivatives are used in a variety of applications, including air conditioning, refrigeration, and heat pumps.

Why are Haloolefins being used?

Haloolefins are being used because they have a low global warming potential (GWP) compared to HFCs. This makes them a more environmentally friendly option for HVAC&R systems. Additionally, haloolefins have a high energy efficiency, which makes them a more cost-effective option for HVAC&R systems. Finally, haloolefins are highly stable in HVAC&R equipment, which makes them a more reliable option for HVAC&R systems.

What are the challenges of using Haloolefins?

The main challenge of using haloolefins is their high flammability. This means that they can be highly volatile and can catch fire easily. This is a significant safety concern for HVAC&R systems. Additionally, haloolefins have a high GWP, which means that they can contribute to global warming. This is a significant environmental concern for HVAC&R systems. Finally, haloolefins are highly unstable in the atmosphere, which means that they can break down into other harmful substances. This is a significant health and safety concern for HVAC&R systems.

ROUNDTABLE

Applying Safety Standards for Flammable Refrigerants

ASHRAE Journal
Nov 2022

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 with several industry experts to discuss the challenges of applying safety standards to flammable refrigerants. The roundtable was moderated by [Name], and the participants included [Name], [Name], [Name], and [Name]. The discussion focused on the various safety standards that apply to flammable refrigerants, the challenges of applying these standards, and the various strategies that can be used to address these challenges. The roundtable was a valuable opportunity for industry experts to share their insights and experiences, and it provided a comprehensive overview of the current state of the industry.

Key Takeaways:

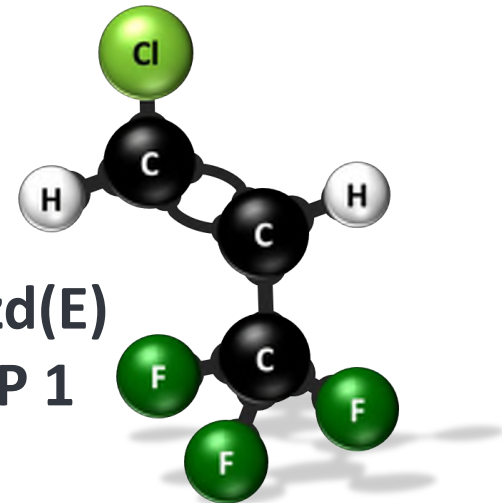
- Flammable refrigerants are being used more widely in HVAC&R systems, but safety standards are still a major barrier to their adoption.
- Industry stakeholders are working to develop new safety standards that are more practical and less restrictive.
- ASHRAE is leading the effort to update its safety standards, and it is working closely with other industry organizations to ensure that the new standards are comprehensive and effective.
- Designers and installers need to be trained on the proper use of flammable refrigerants, and they need to be aware of the various safety risks associated with these refrigerants.
- Building codes need to be updated to allow for the use of flammable refrigerants, and this is a process that is still ongoing.

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

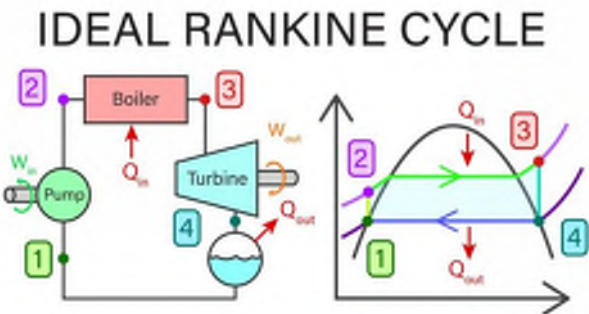
R-1233zd(E)
A1, GWP 1



Four Generational Search for “Perfect” Reverse Rankine Refrigerants



William Rankine
Theory of Heat Engines
“Rankine Cycles”



Thomas Midgley Albert Henne



<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



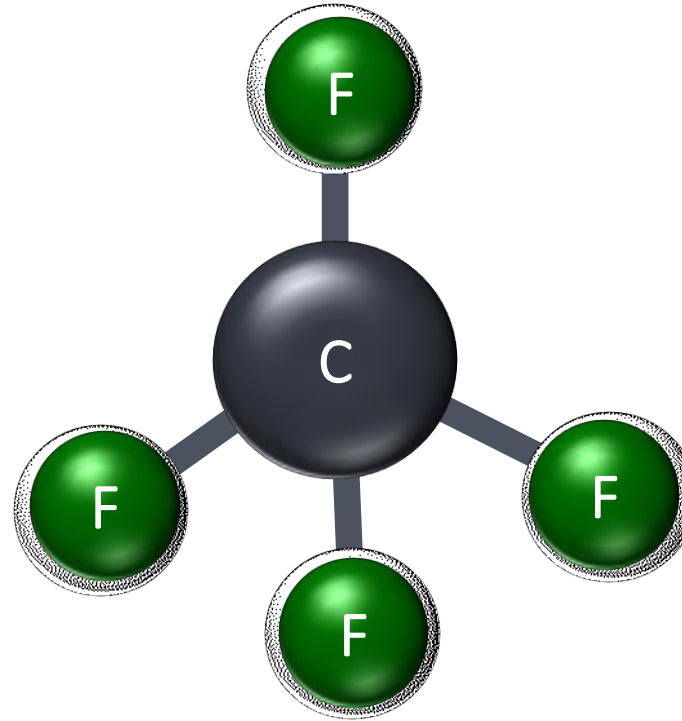
Albert Henne

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

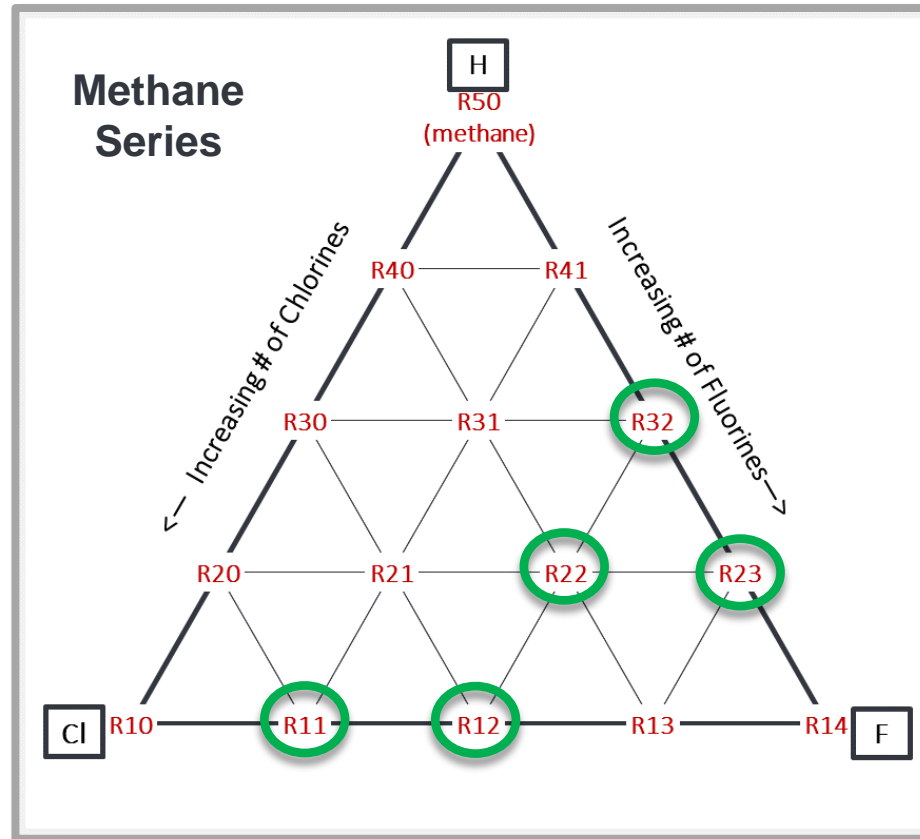
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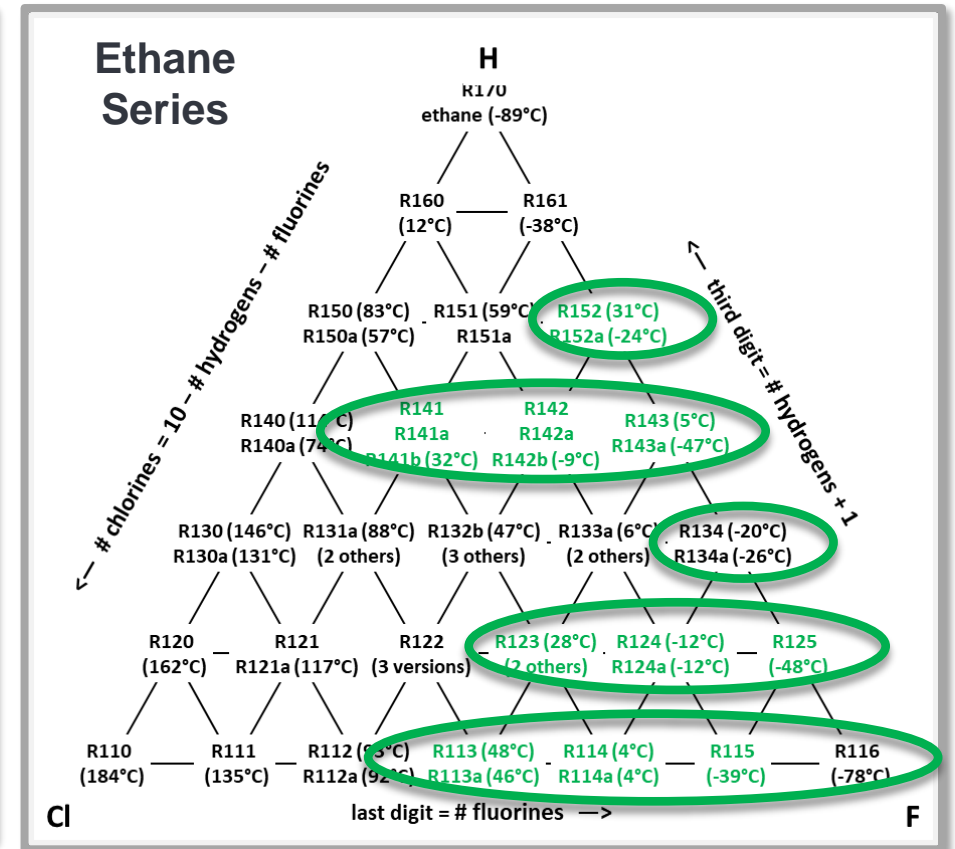
- Innovation enabled exponential societal improvements

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

CFCs, HCFCs, HFCs



14 New Molecules from 1 Methane



55 New Molecules from 1 Ethane

Designing Synthetic Refrigerants for Low GWP?

Optimizing for Safety – Efficiency - Design – Applications



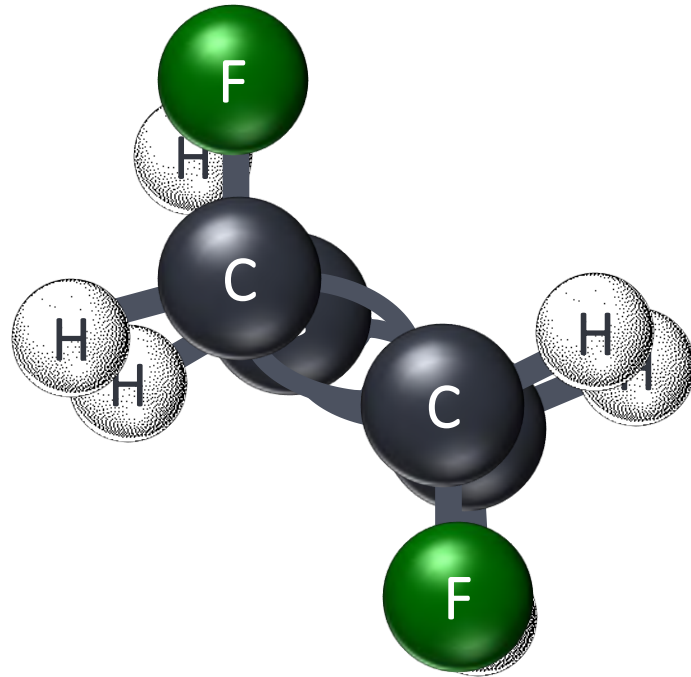
4th Generation
"Global Warming"

2010's – 2050's

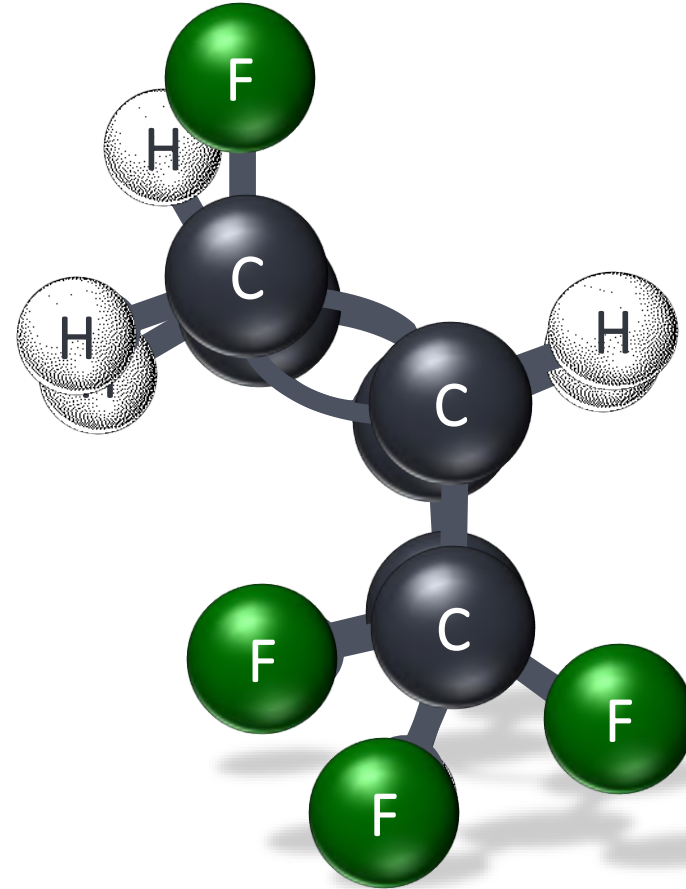


- Fewer choices
- Safety and design challenges

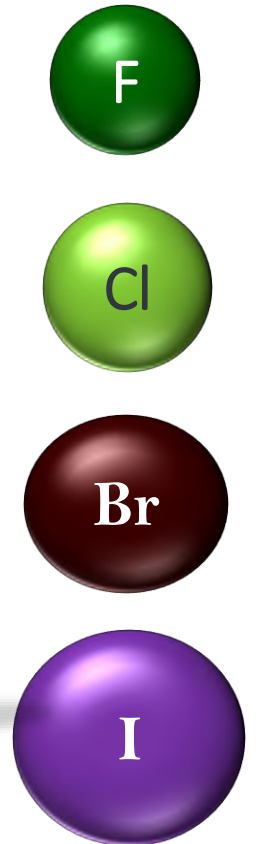
- NH₃
- Low GWP HFCs & HFOs
 - R1233zd(E)
 - R1234yf & R1234ze(E)
 - HFC/HFO blends
- Renewed "Natural" interest
 - CO₂
 - Hydrocarbons



Ethane (R150)
ASHRAE Class A3
GWP - 210



Propane (R270)
ASHRAE Class A3
GWP - 3



Halogens

Global Warming Potential of Refrigerants and Their Impacts



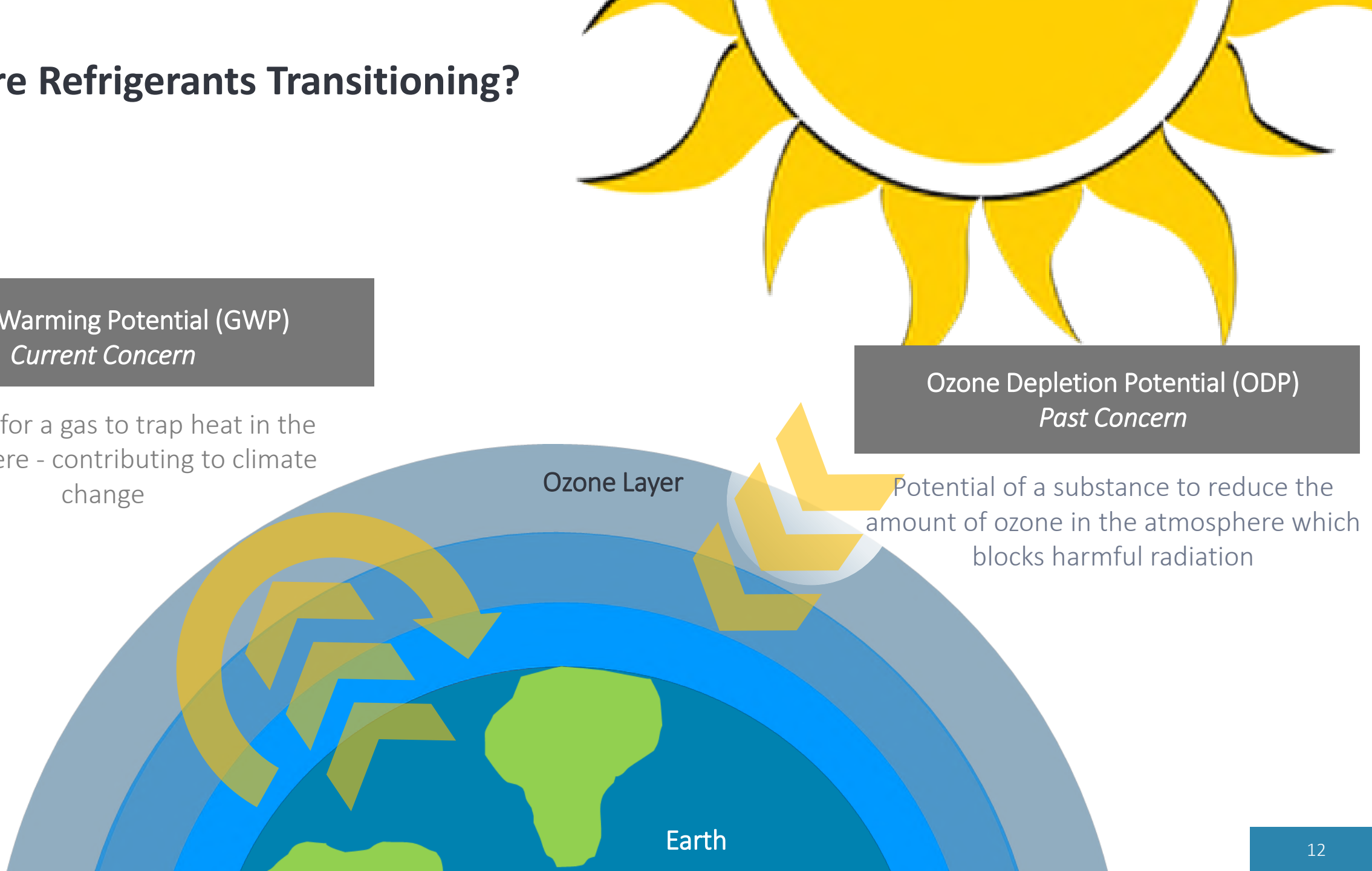
Why Are Refrigerants Transitioning?

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?

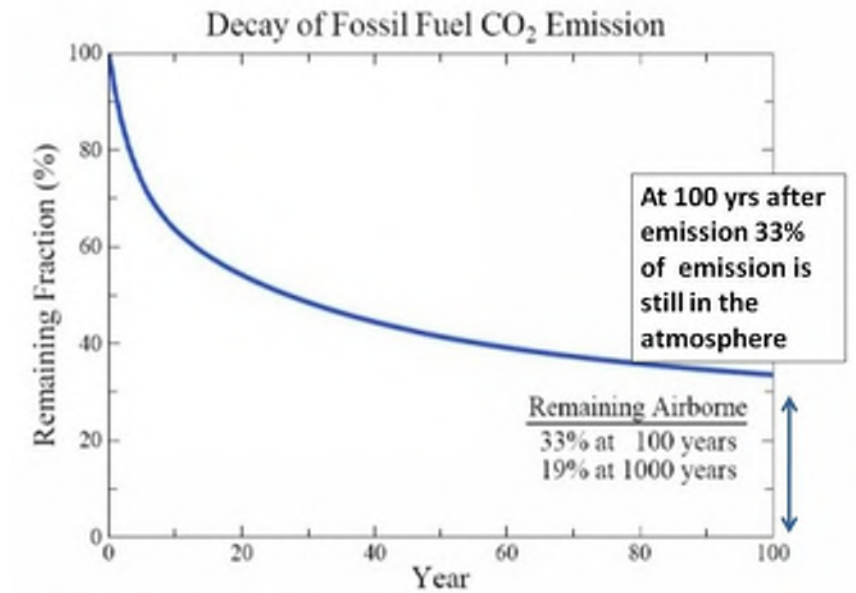
Global warming potential (GWP) is the heat absorbed by any gas in the atmosphere, as a multiple of the heat that would be absorbed by the same mass of CO₂ over a specified time, e.g., 20 or 100 years. All effects beyond 20 or 100 years are disregarded. The GWP value depends on how the gas concentration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

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

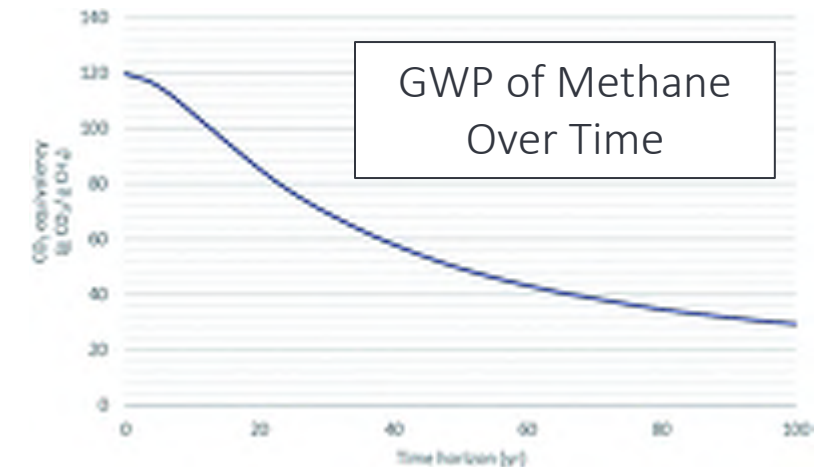
Time Horizon →

Radiative Efficiency →
*Not necessarily Linear over time

Concentration Decay Rate →

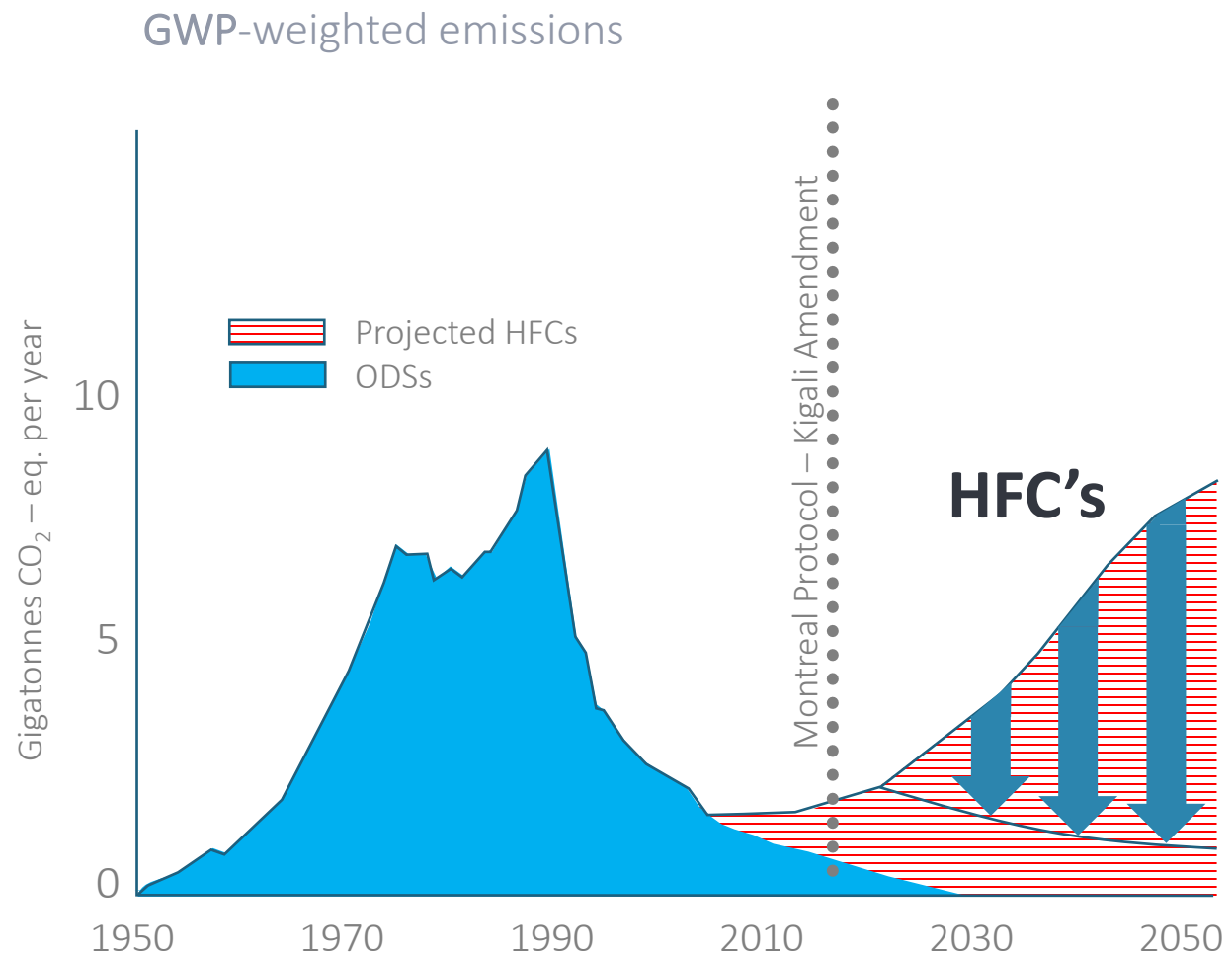
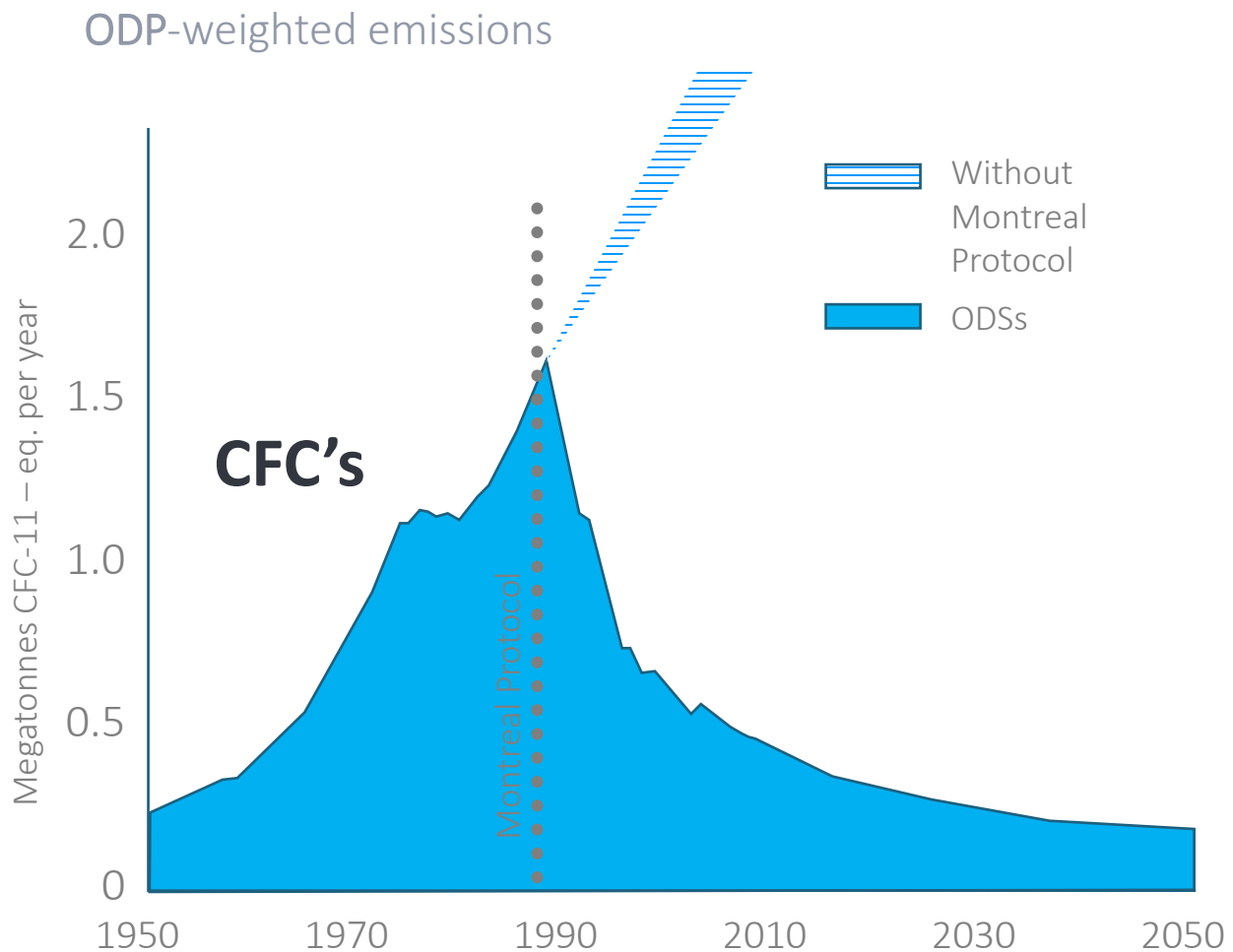


IPCC 2007 Science Technical



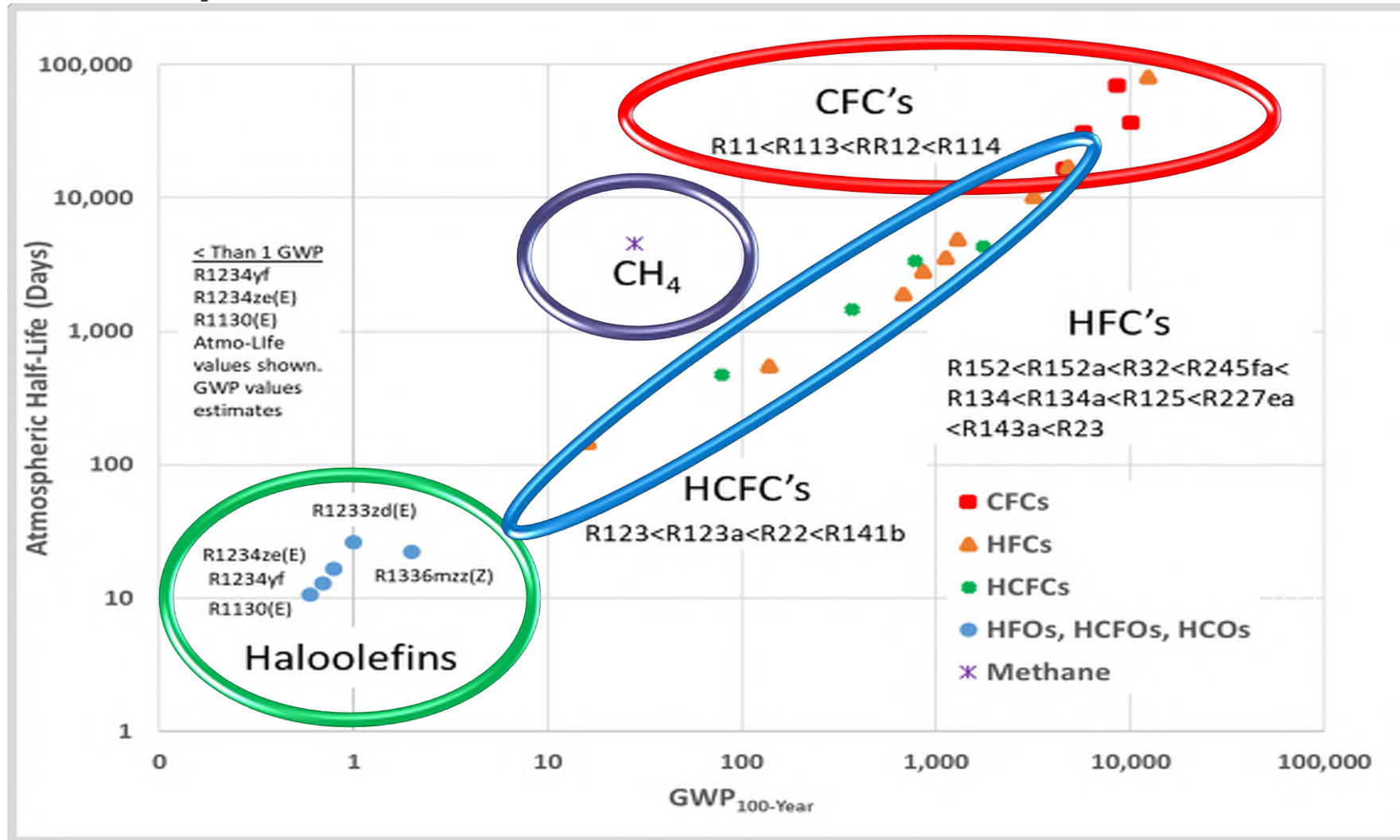
**UNEP Climate Assessment Reports Determine and Publish GWP Values (AR1-AR6)
Regulators Using AR4 100 Year Time Horizon for Gases**

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

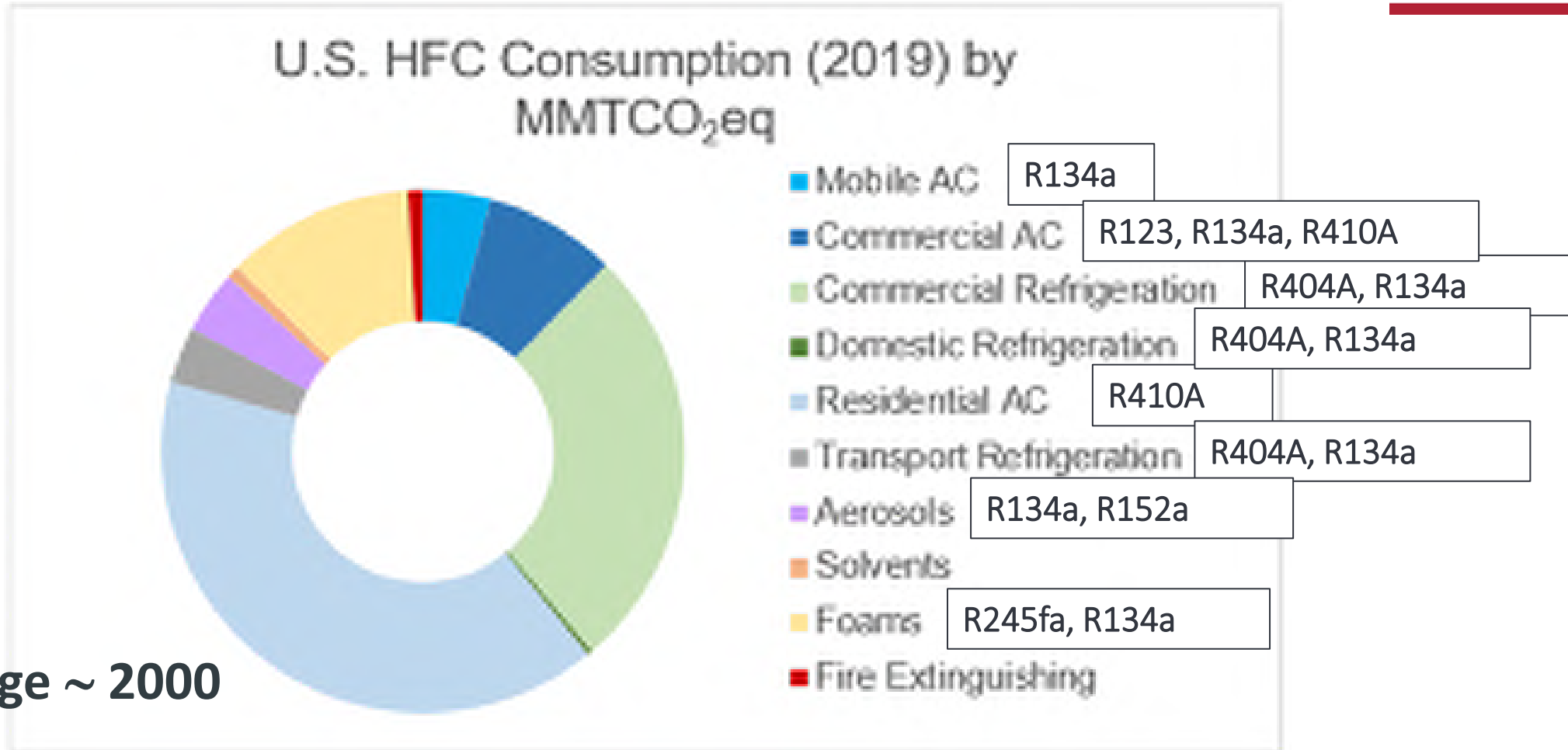
A pair of hands is shown holding a small, red, textured globe. The globe is the color of a hot planet and has the words "Global Warming" written on it in white, bold, sans-serif font. The hands are positioned as if they are carefully holding the globe. The background is a blurred green field of tall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

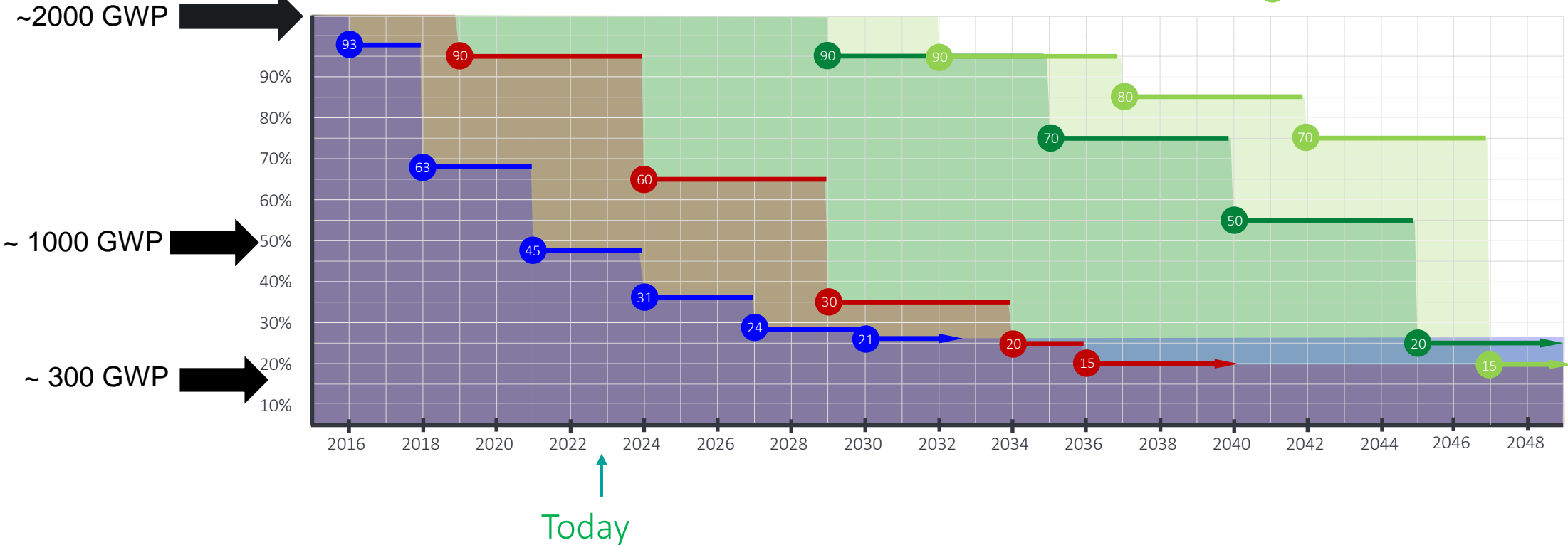
>60% HFC GHG Consumption Used for Commercial Refrigeration (R404A) & Residential ACs (R410A)

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

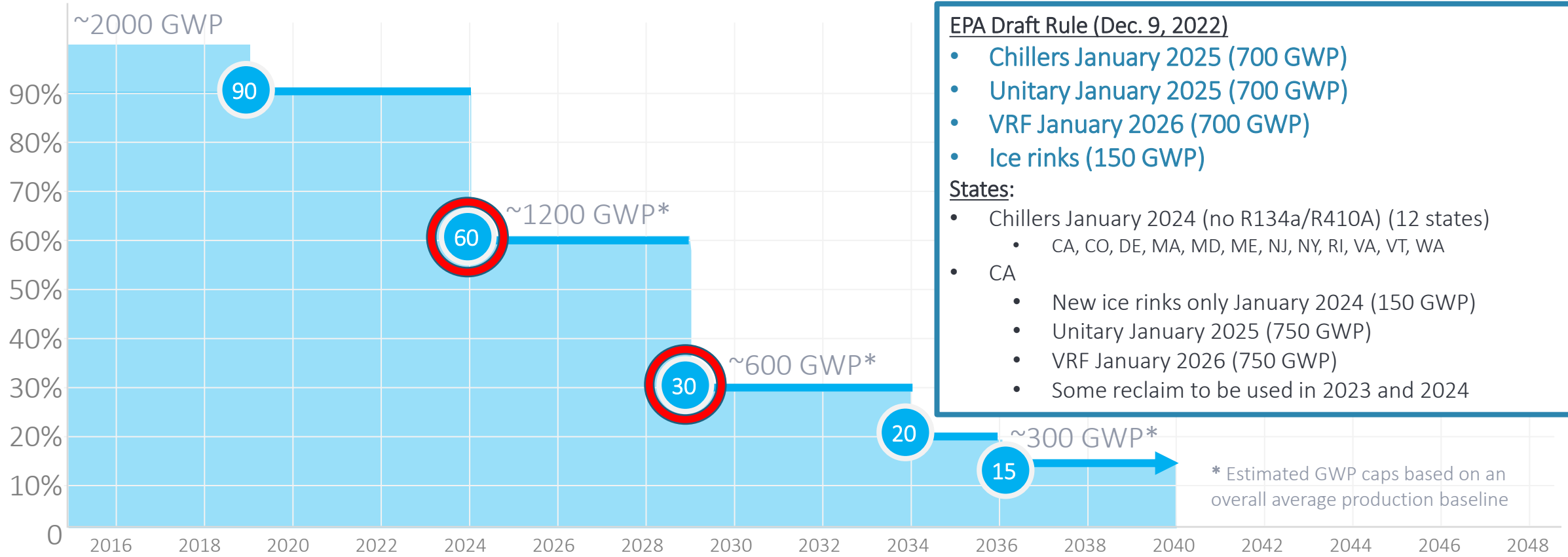
- U.S. AIM Act requires EPA to regulate HFC phase down in the same time frame as the Kigali Amendment (Senate Ratified Oct 22)
- EPA allocation regulation (Sept. 2021) reduces refrigerant supply by 10 percent (GWP) in 2022 to align with legislation
- EPA sets equipment sector bans with GWP limits by **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



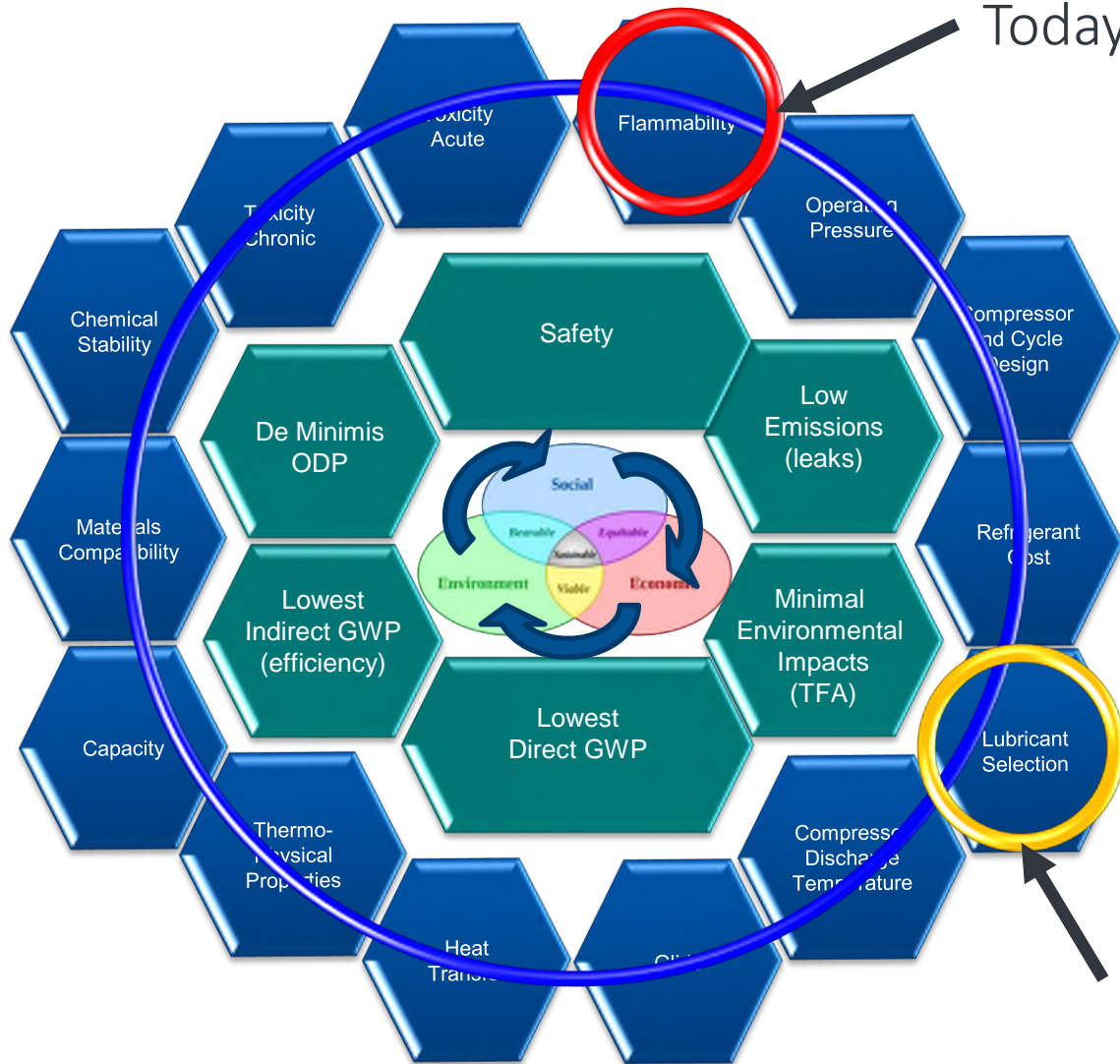
	Refrigeration Equipment (Proposed Compliance Date 1/1/25)	GWP
Industrial Process Refrigeration	Systems with refrigerant charge capacities of 200 pounds or greater	150
	Systems with refrigerant charge capacities less than 200 pounds	300
	High temperature side of cascade systems	300
	Chillers	700
Retail 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

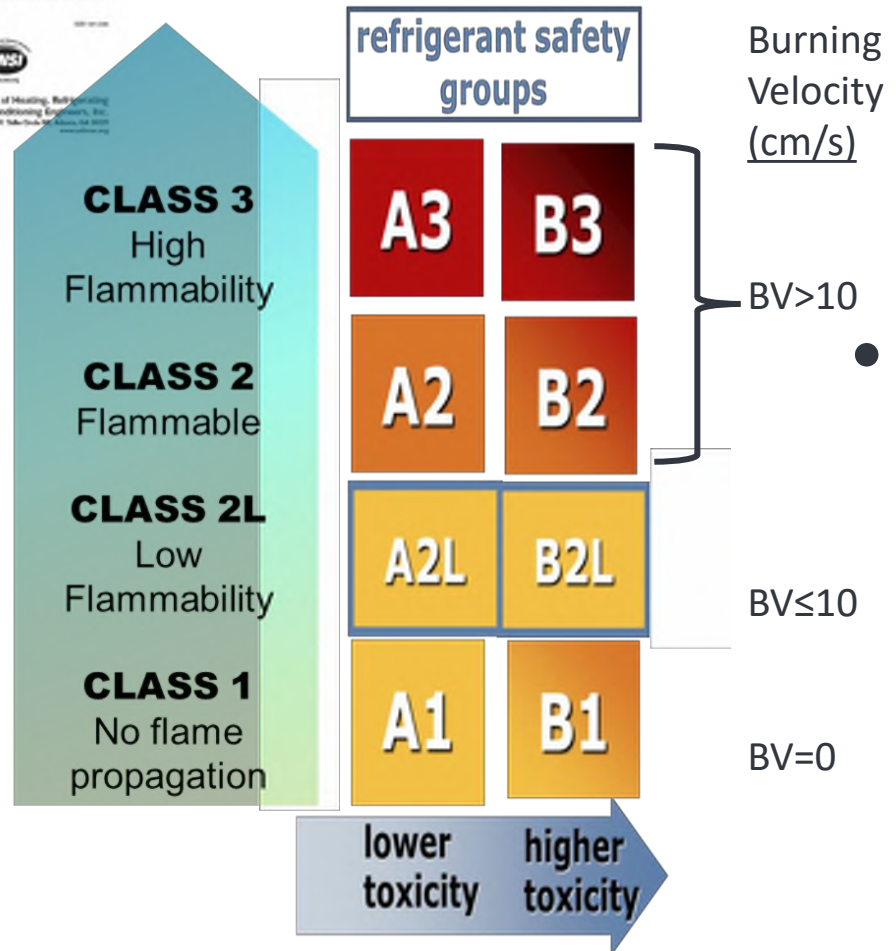


Last Transition

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



ASHRAE Standard 34 Safety Classification of Refrigerants



• Toxicity

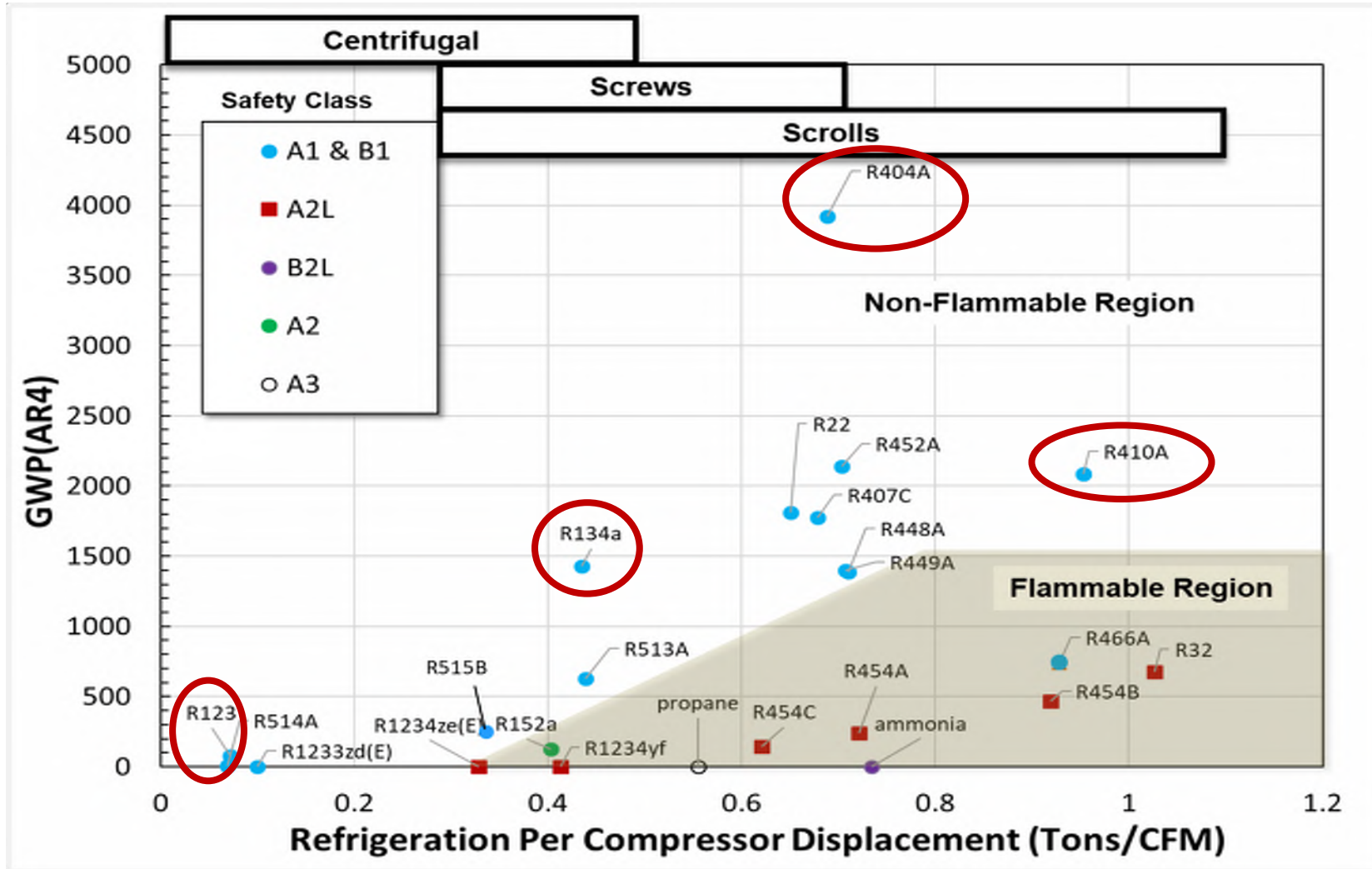
- A or B Based > or = to 400 ppm Occupational Exposure Limit (OEL) Dividing Line
- Class A, most refrigerants, like R134a
- Class B, R123 and ammonia are examples

• 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 <math>< 10</math> 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

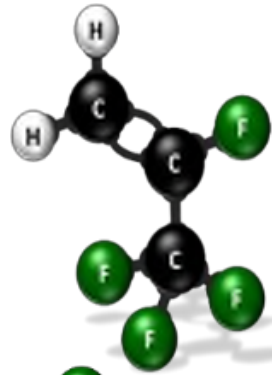


Flammable Refrigerants Required For Some Applications to Achieve a Low GWP Refrigerant Future

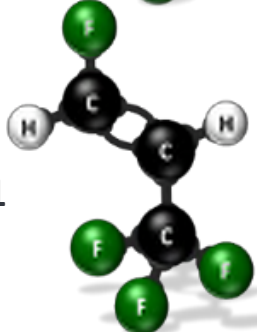
Review of Lower GWP Refrigerant Option for Various HFCs



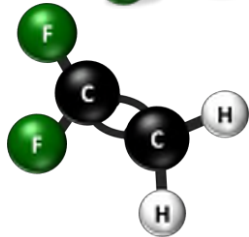
Toolbox of <10 GWP Next Generation Refrigerants



R1234yf
A2L GWP <1

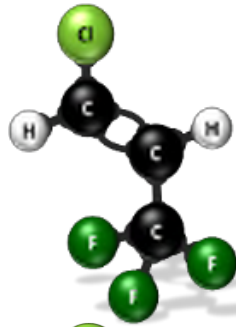


R1234ze(E)
A2L GWP <1

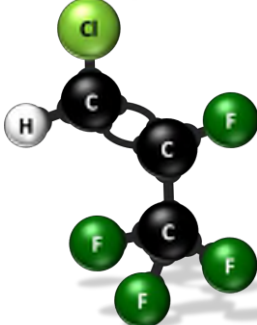


R1132a
A2 GWP <1

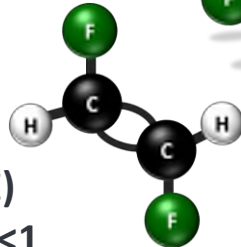
R1233zd(E)
A1 GWP 1



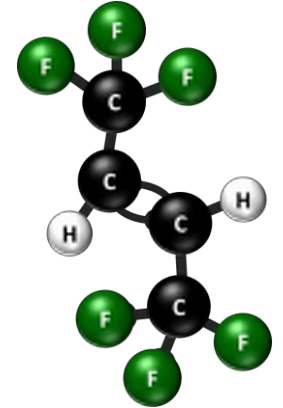
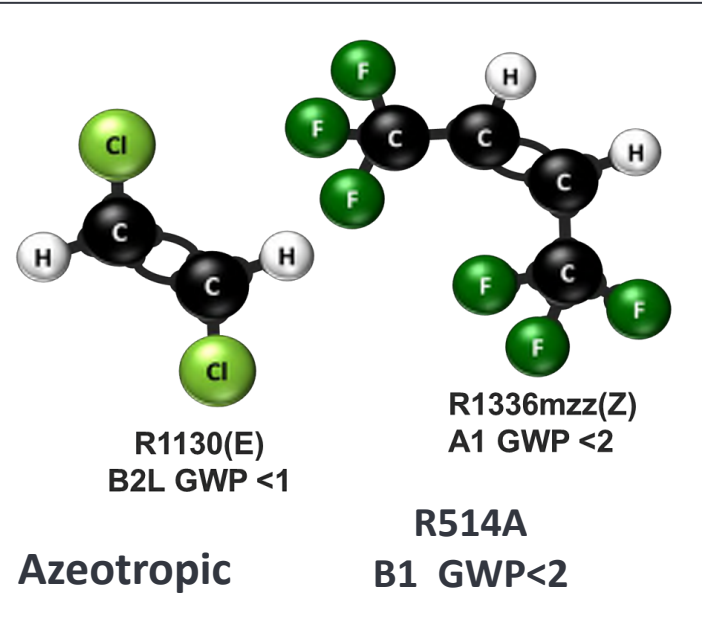
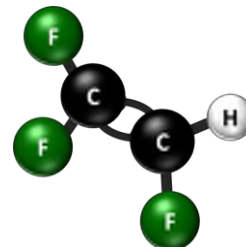
R1224yd(Z)
A1 GWP 1



R1132(E)
B2 GWP <1



R1123
?2L GWP <1

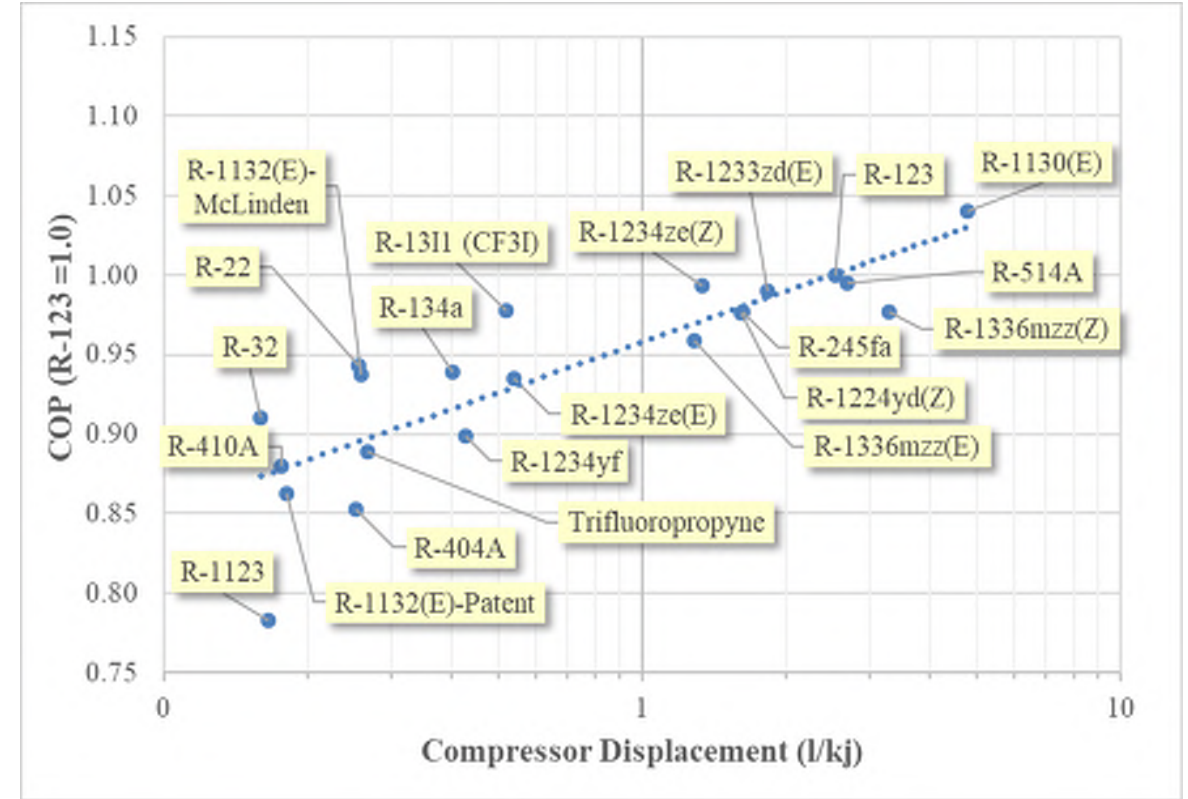
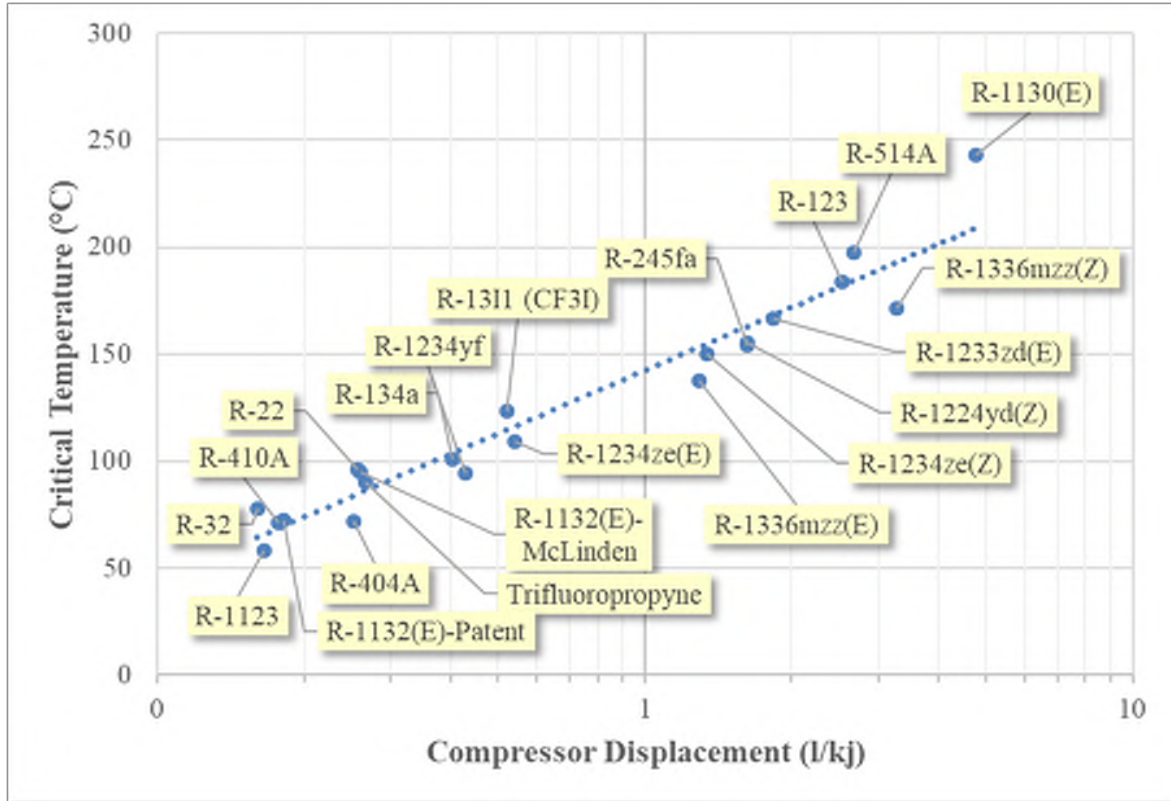


R1336mzz(E)
A1 GWP <6

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

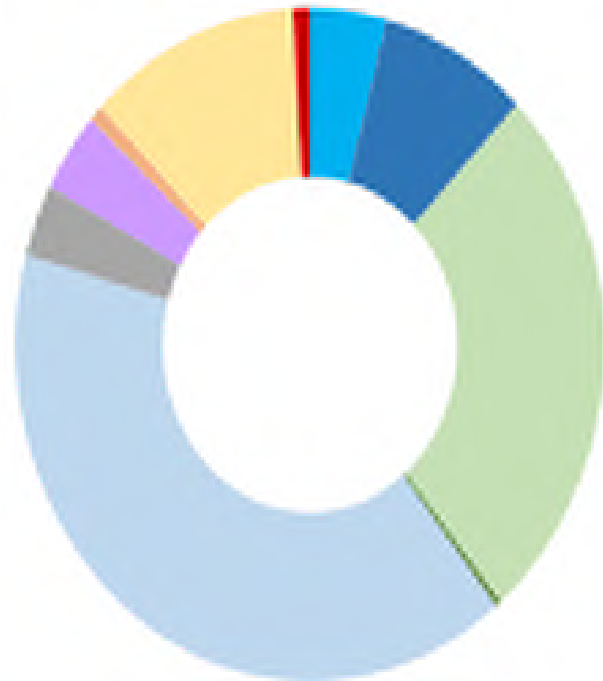
- Single Refrigerants or Blends will not be used from small to large capacity products
- Lack of low glide
- There is no Perfect Refrigerant! A balanced approach is required
 - *Safety, Environmental Impact, Efficiency*
 - *Reaching final GWP goals requires more refrigerant technology innovation (Interim 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