The Future of Refrigerants

Steve Kujak

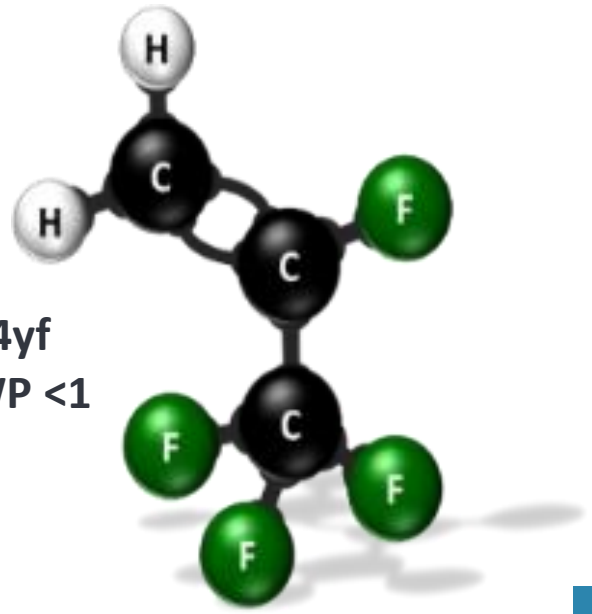
Director

Next Generation Refrigerant Research

Distinguish Lecturer Series
Version 02102022

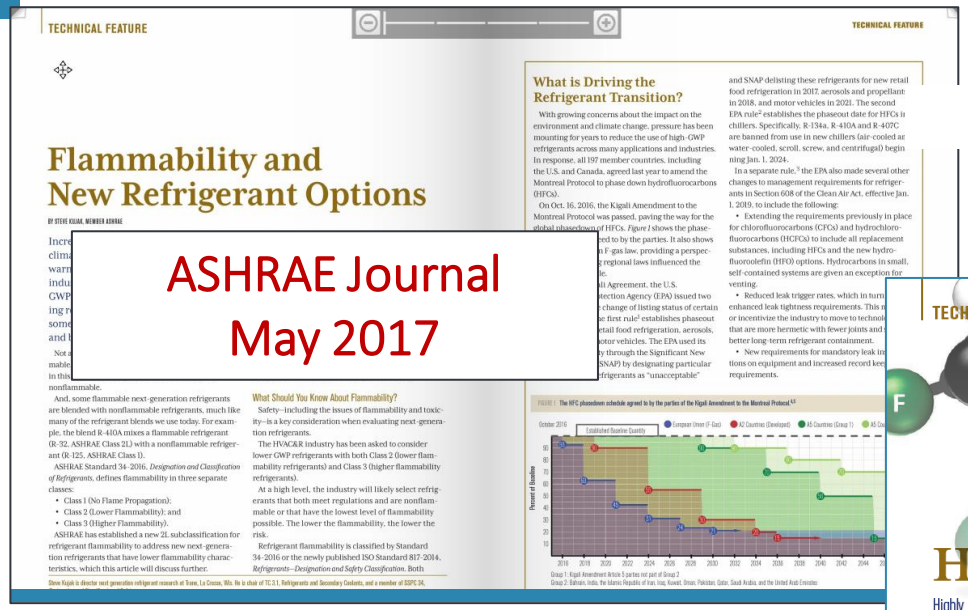
Agenda - Outline

- Brief History of Refrigerant
- Review of HFC Refrigerant Regulations & Regulatory Mechanisms
- Sustainable Refrigerant Selection & Challenges
- Review of Lower GWP Refrigerant Options For Various HFCs
- Q&A



R1234yf
A2L GWP <1

Background – Articles on Regulatory, Basics & Flammability



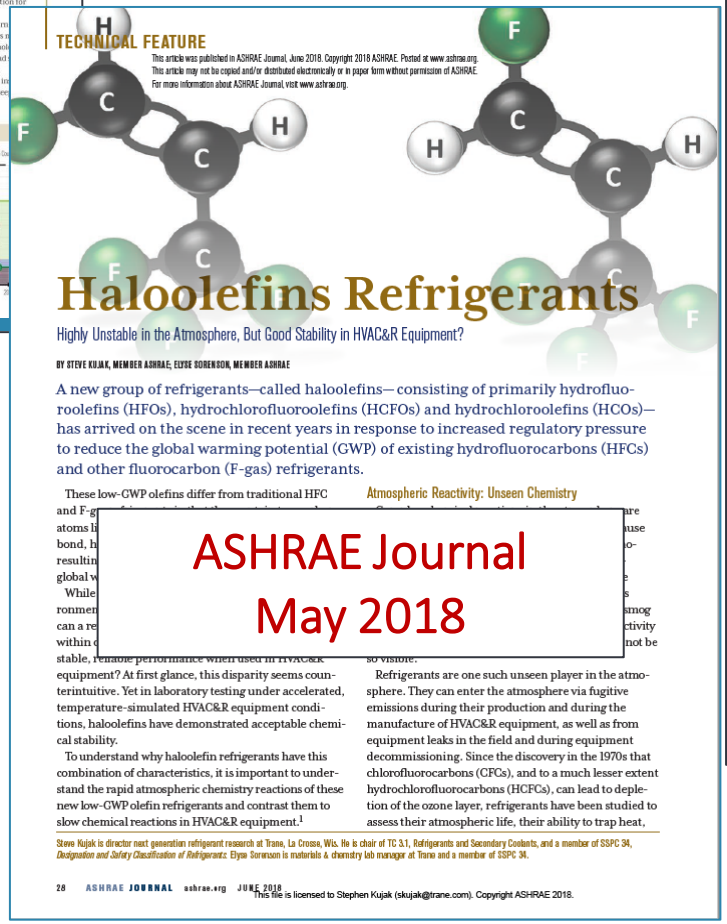
TECHNICAL FEATURE

Flammability and New Refrigerant Options

ASHRAE Journal
May 2017

What is Driving the Refrigerant Transition?

What Should You Know About Flammability?



TECHNICAL FEATURE

Haloolefins Refrigerants

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

BY STEVE KUJAK, MEMBER ASHRAE; ELYSE SORENSON, MEMBER ASHRAE

A new group of refrigerants—called haloolefins—consisting of primarily hydrofluoroolefins (HFOs), hydrochlorofluoroolefins (HCFOs) and hydrochloroolefins (HCOs)—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.

ASHRAE Journal
May 2018

ROUNDTABLE

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
Nov 2022

Brief History of HVAC&R Refrigerants

Thomas Midgley

Albert Henne

1st Generation *"What Ever Worked"*	2nd Generation *"Safety and Stability"*	3rd Generation *"Ozone Protection"*	4th Generation *"Global Warming"*
1830's – 1930's	1930's – 1990's	1990's – 2030	2010 - 2050
• Limited applications mainly industrial • "Poor safety & cost"	• Innovation enabled exponential societal improvements	Preserved 2nd gen innovations, safety, stability and efficiency	• Fewer choices • Safety and design challenges
• NH_3 • CO_2 • Various Hydrocarbons • H_2O • Sulfur Dioxide • Methyl Chloride (R40)	• NH_3 • CFCs and HCFCs o R11 o R12 o R22 o R502	• NH_3 • HCFCs & HFCs o R22 o R123 o R134a o R410A o R404A o Many Blends	• NH_3 • Low GWP HFCs & HFOs o R1233zd(E) o R1234yf & R1234ze(E) o HFC/HFO blends • Renewed "Natural" Interest o CO_2 o Hydrocarbons

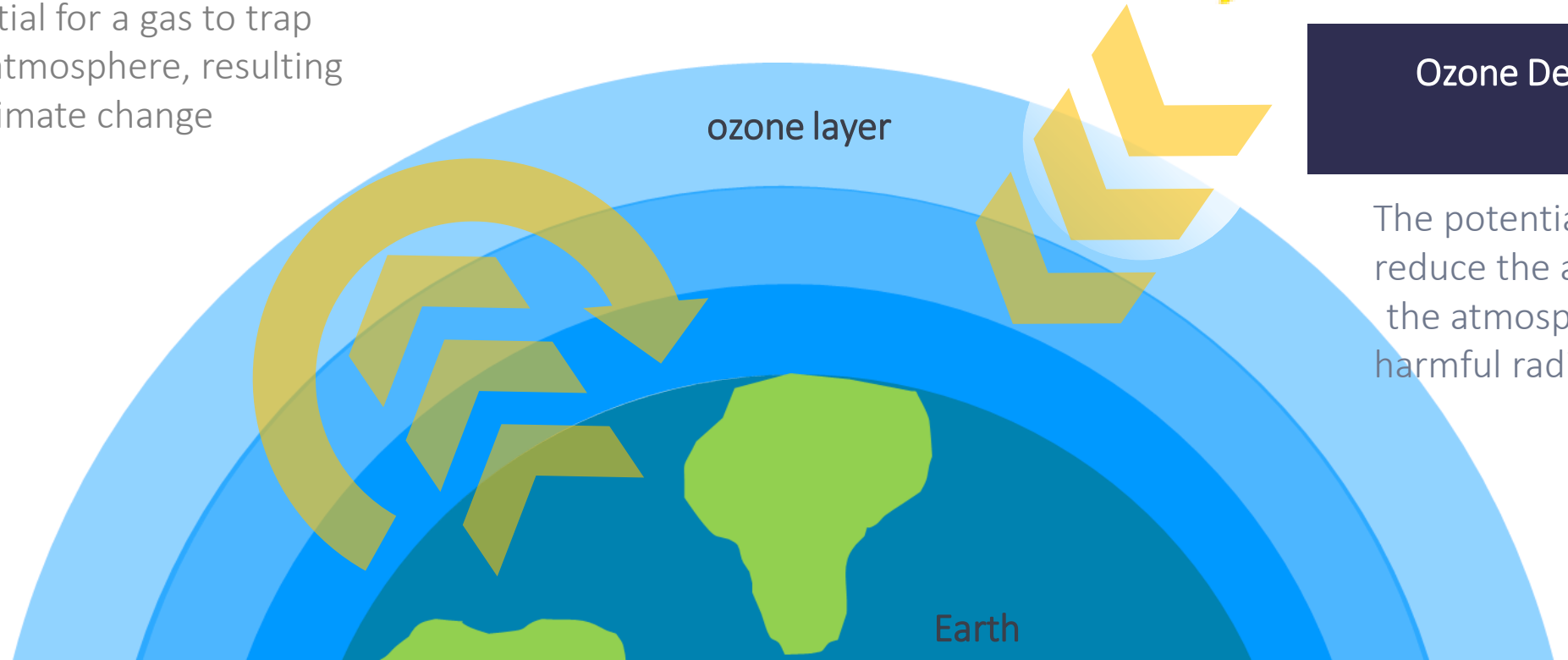
Societal Demands for Lower Climate Impacts of Refrigerants Continues to Drive Innovations

Review of HFC Regulation & Regulatory Mechanisms

Why Are Refrigerants Transitioning?

Global Warming Potential (GWP)

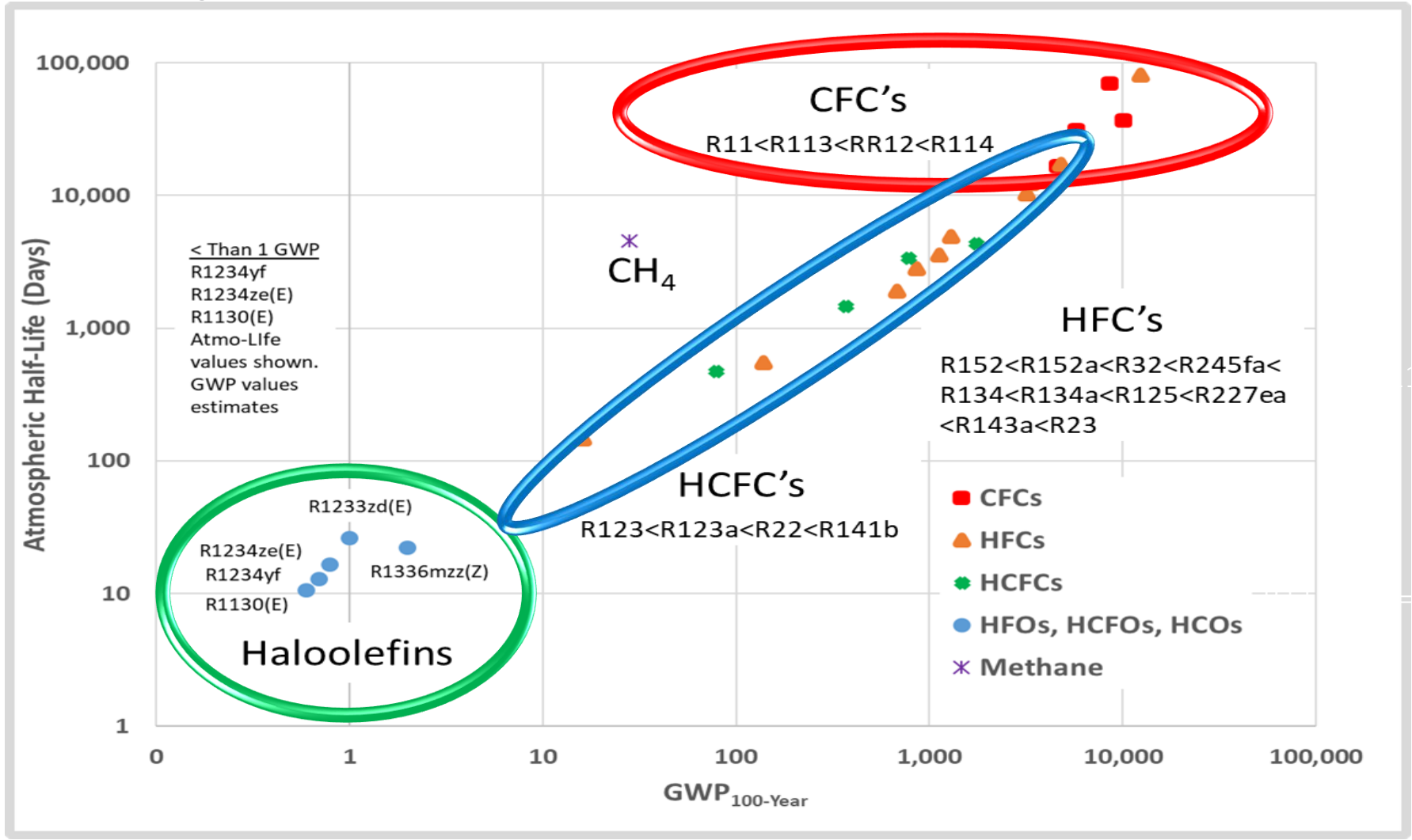
The potential for a gas to trap heat in the atmosphere, resulting in climate change



Ozone Depletion Potential (ODP)

The potential of a substance to reduce the amount of ozone in the atmosphere which blocks harmful radiation from the sun

F-Gases Atmospheric Life vs GWP



Two Choices

Possible Actions: Reduce Emissions Or Shorter Atmospheric Life or Both

United Nations Environment Program (UNEP)

Waste Byproduct Emissions

126 / 196 Country Ratifications as of 10/15/2021

Engineered Fluorocarbons

Kyoto Protocol (1997)

Paris Agreement (2016)

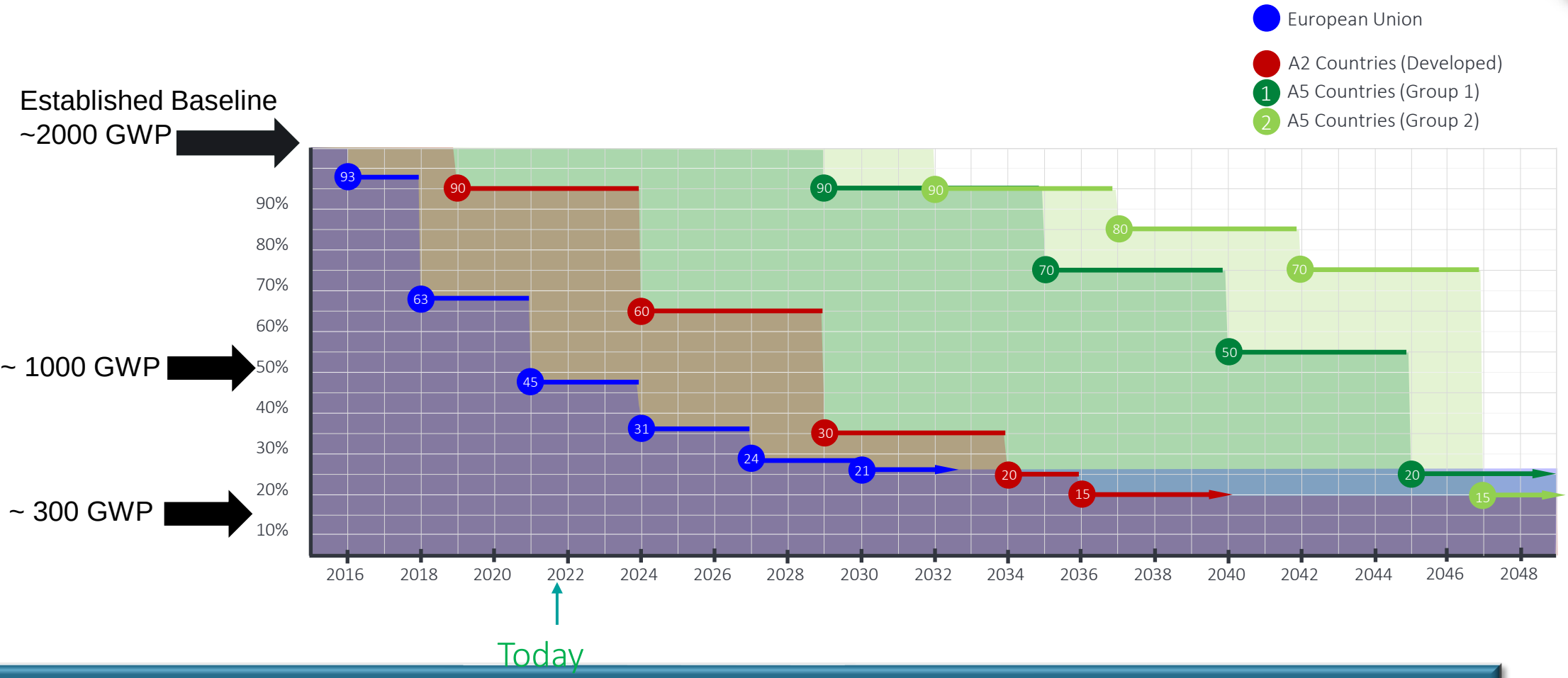
Montreal Protocol (1987 – CFCs -ODP)

Kigali Amendment (2016 – HFCs - GWP)

Each Country Independently Needs to Comply with Montreal Protocol

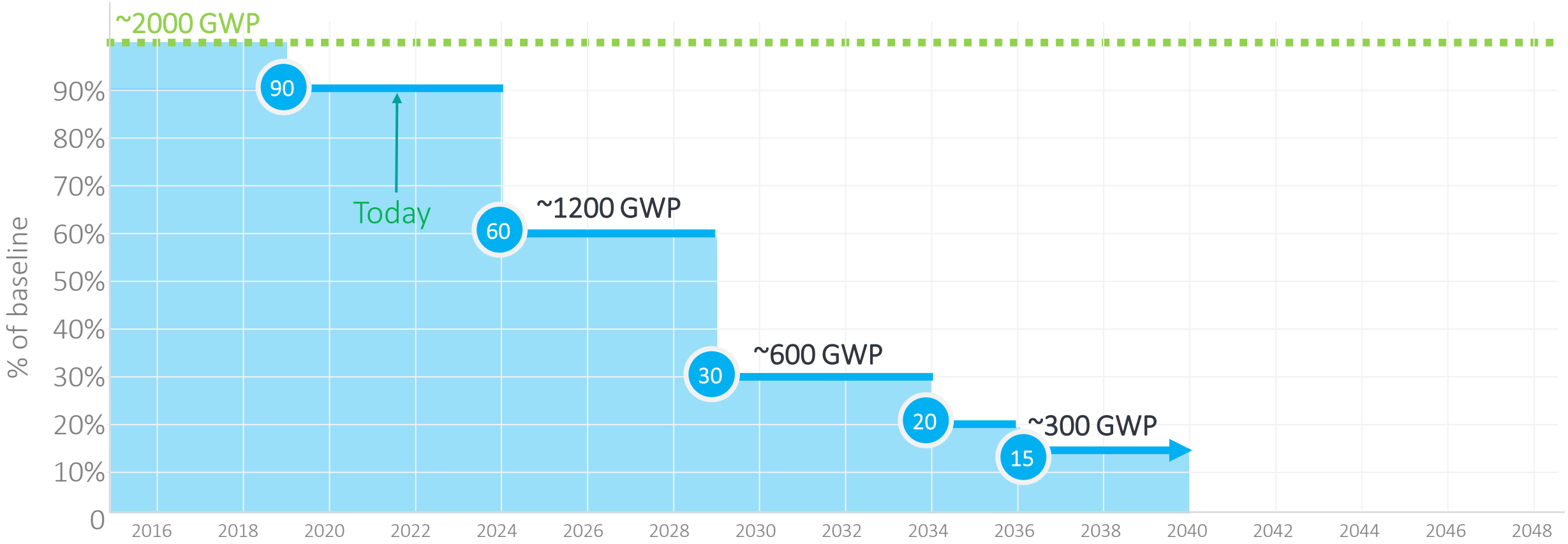
2016 Montreal Protocol HFC Amendment Agreement

Kigali Amendment - Global Transitions Based on GWP



More Complex Than ODP Phase Out (Banned Chemicals)
This is a Phase Down (All Refrigerants Available for Use)

Closer Look - Developed Nations – GWP Cap and Phase Down Details



Kigali Phase-Down of HFCs starting in 2019 for Developed Nations
USA (AIM Act) – Starting ↓10% 2022 then ↓40% by 2024

AIM (American Innovation and Manufacturing) Act – Enacted Dec 2020

How and When on United States HFC Phasedown Timing

- On April 30 in accordance with the AIM legislation, the USEPA issued a proposed rule to reduce HFC production and consumption https://www.epa.gov/newsreleases/epa-moves-forward-phase-down-climate-damaging-hydrofluorocarbons
- On Oct 1 & Oct 5 - HFC allocation final rule issued in accordance with AIM
  - 10% reduction for 2022 and 2023 (expect 40% reduction rule next year)
  - HFC baseline set using 3 highest production years between 2011-2019
  - Ban of non-refillable cylinders by 2027
  - Required tracking of refrigerants and use (QR codes)
- On Oct 7 – Grants petitions in support of HFC phasedown for rule making
  - AHRI, AHAM, EIA, NRD..etc means EPA granting or partial granting requests made in future rule making

EPA Rules and SNAP Notices
https://www.epa.gov/climate-hfcs-reduction
https://www.epa.gov/snap/snap-regulations#rule23supplemental

EPA will Release Draft HFC Rule Up To 40% Phasedown in 2022/Final 2023

AHRI & AHAM Petition – Air Conditioning, Chillers, Commercial Refrigeration

AHRI
AIR-CONDITIONING, HEATING, & REFRIGERATION INSTITUTE
we make life better®

AHAM
ASSOCIATION OF HOME APPLIANCE MANUFACTURERS

April 21, 2021

1111 19th Street NW • Suite 402 • Washington, DC 20036
t 202.872.5955 f 202.872.9354 www.aham.org

The Honorable Michael S. Regan
Administrator
Environmental Protection Agency
1200 Pennsylvania Avenue, N.W.
Washington, DC 20460

Re: AHRI Petition for Technology Transition under The American Innovation and Manufacturing Act of 2020 (Air Conditioning)

Refrigeration

AC

RACs & Others

AC Chiller Equipment

Jan 1, 2024

Unitary and VRF Equipment

Unitary: Jan 1, 2025
VRF: Jan 1, 2026

Jan 1, 2023 – No Electric Heat
Jan 1, 2024-Electric Heat
Dehumidifier-2 yrs after R-32
SNAP Approved

AC - <750 GWP For All Products

TABLE 1

Product Category (New Equipment[1])	AR4 GWP Limit	Transition Date
Standalone/Self-contained Refrigeration Systems	SNAP Rules 20/21 Prohibitions	January 1, 2022
Remote Refrigeration Systems (> 50 lbs refrigerant charge)	1500	January 1, 2022
Remote Refrigeration Systems (<= 50 lbs refrigerant charge)	2200	January 1, 2022
Industrial and Processing Refrigeration (w/o chillers)	1500	January 1, 2022
ACIM (> 50 lbs refrigerant charge)	2200	January 1, 2022
Transport Refrigeration	2200	January 1 2023
Exceptions: ACIM < 50lbs charge, Medical, Scientific and Research Applications		

[4] SNAP Rules 20 and 21 https://www.govinfo.gov/content/pkg/FR-2015-07-20/pdf/2015-17066.pdf and https://www.govinfo.gov/content/pkg/FR-2016-12-01/pdf/2016-25167.pdf

TABLE 2

Chillers[5]	AR4 GWP Limit	Transition Date
Chillers (designed for chilled fluid leaving temperature > +35° F)	750	January 1, 2024
Chillers (designed for chilled fluid leaving temperature ≤+35° and > -10° F)	1500	January 1, 2024
Chillers (designed for chilled fluid leaving temperature ≤-10° to -50° F)	2200	January 1, 2024
Chillers (< 20lbs charge) (designed for chilled fluid leaving temperature <+35° F)	2200	January 1, 2024
Exceptions: Chillers <-50 F, Medical, Scientific and Research Applications		

Refrig -More Complex Based On Available Technology by App

Canada Regulatory Details

The baseline HFC consumption quantity for Canada is 19,118,651 tons of CO2 equivalent. The reduction regulation is as follows:

90% in 2019
60% in 2024
30% in 2029
20% in 2034
15% in 2036

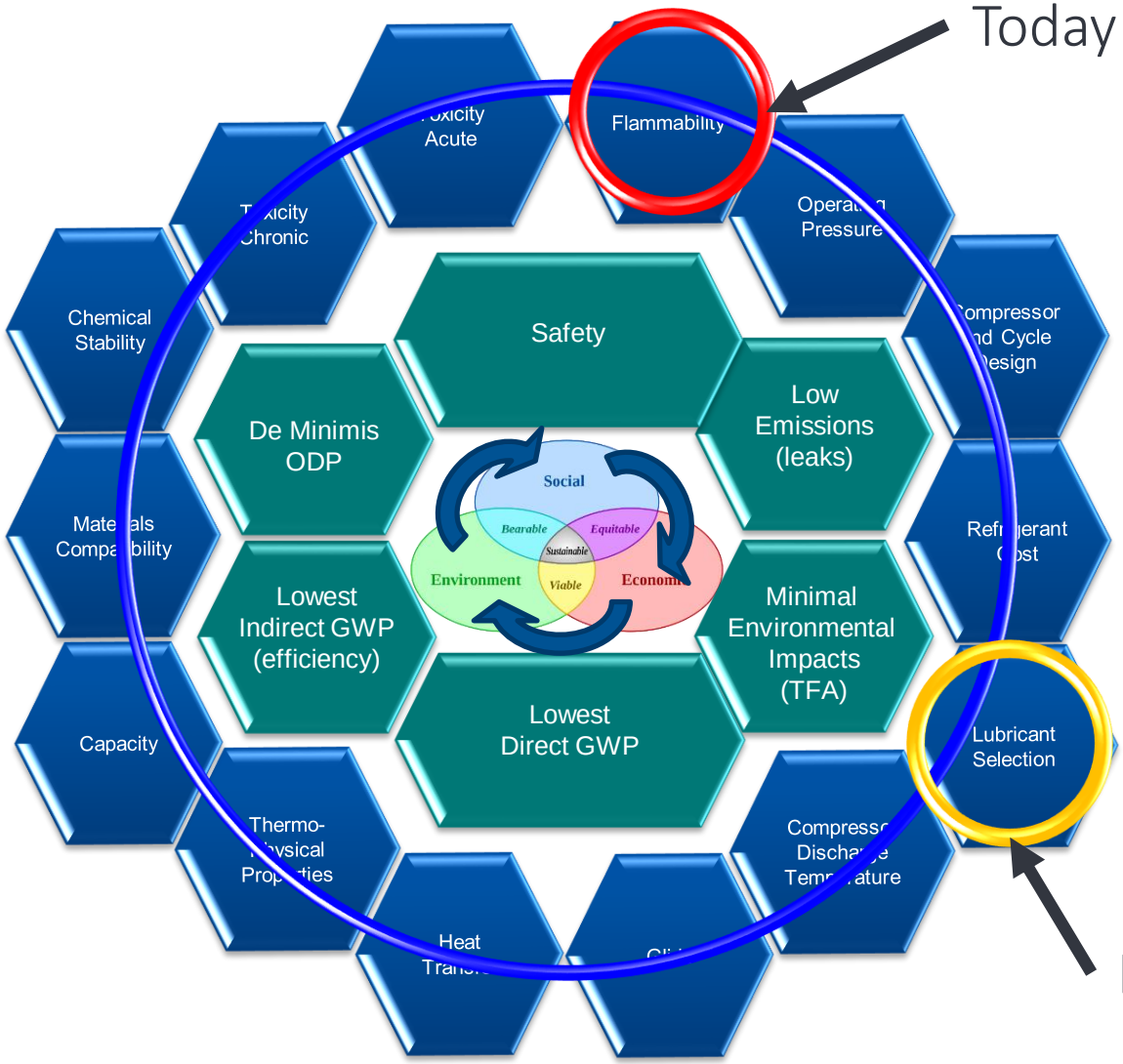
The second part of the regulation establishes limits on global warming potential (GWP) of refrigerants that can be used with industry systems and compliance dates for these limits. The limits and compliance dates are as follows: (Note compliance dates either import or manufacturing)

1. Stand-alone medium temp refrigeration systems	1400 (January 1, 2020)
2. Stand-alone low temp refrigeration systems	1500 (January 1, 2020)
3. Centralized refrigeration systems	2200 (January 1, 2020)
4. Condensing Units	2200 (January 1, 2020)
5. Chillers	750 (January 1, 2025)
6. Mobile refrigeration systems	2200 (January 1, 2025)

ECCC - USEPA to Align Regulations as Much as Possible

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

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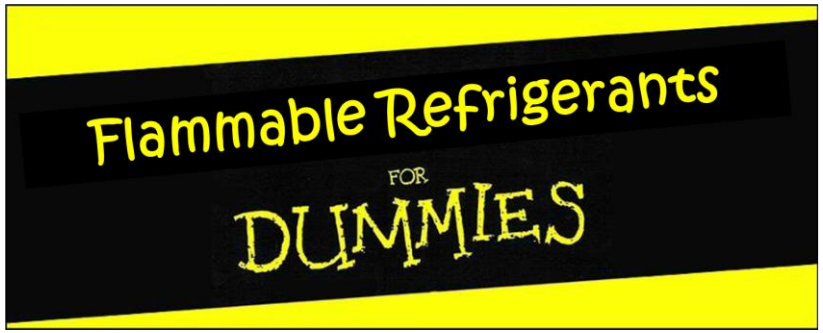
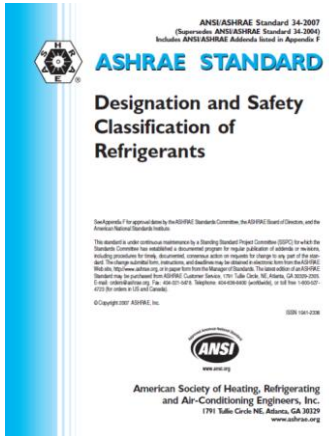
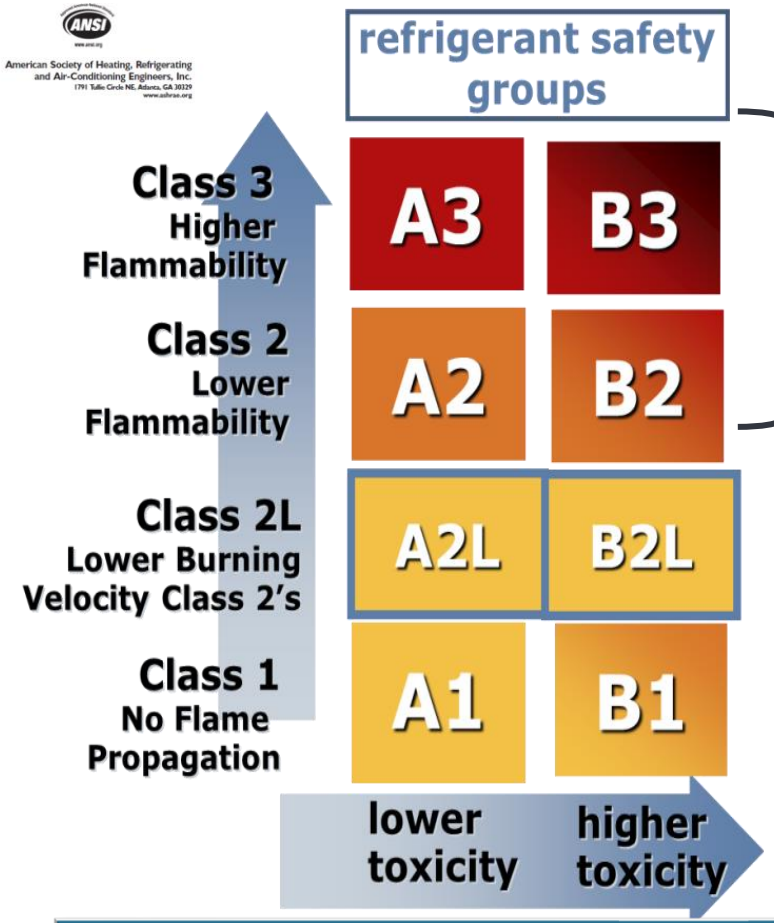


Challenge: Selecting Refrigerants with Best Balance (Sustainability)
Flammability Greatest Challenge for this Transition – Not in All Cases



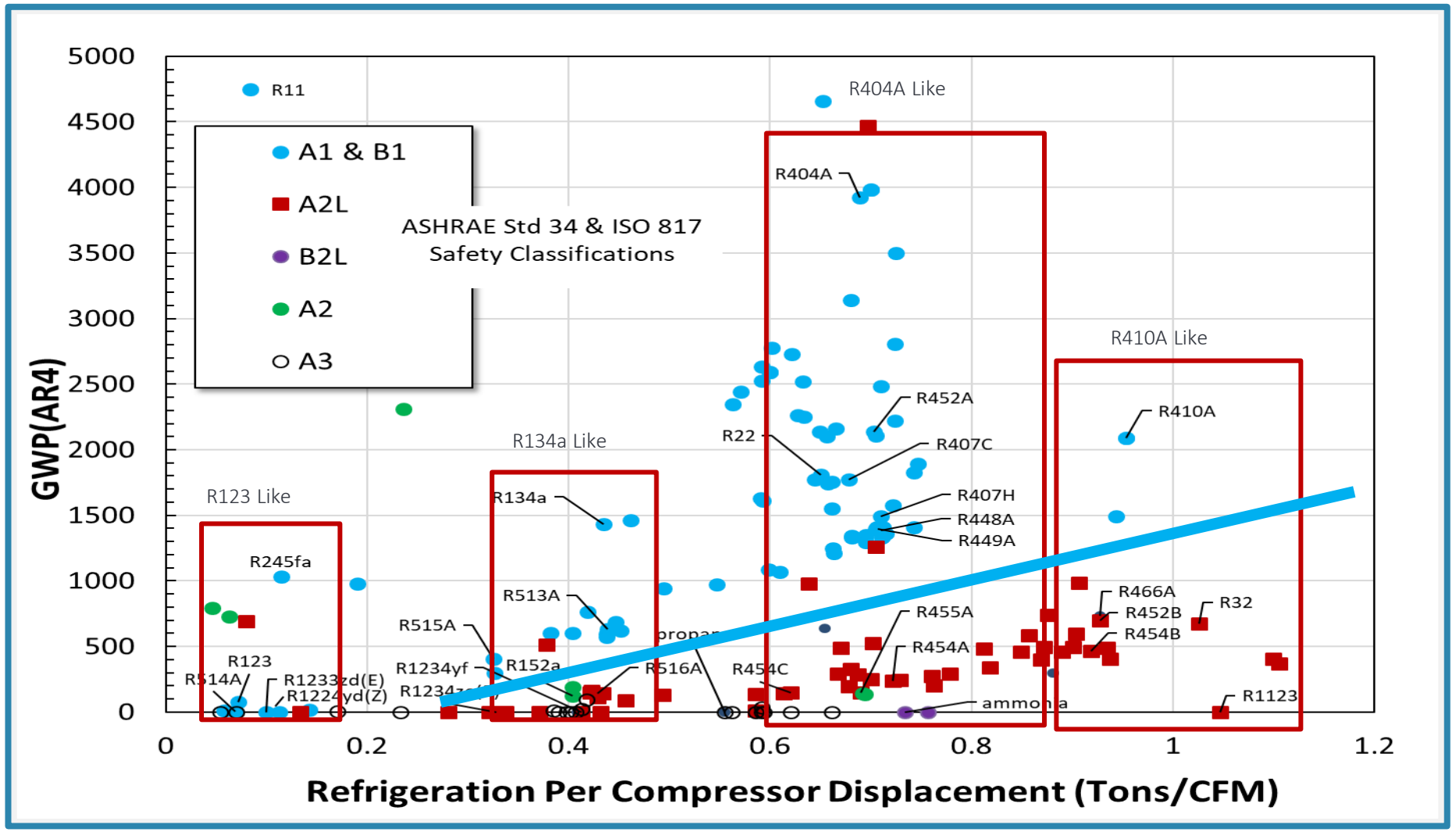
ASHRAE Standard 34
Safety Classification of Refrigerants

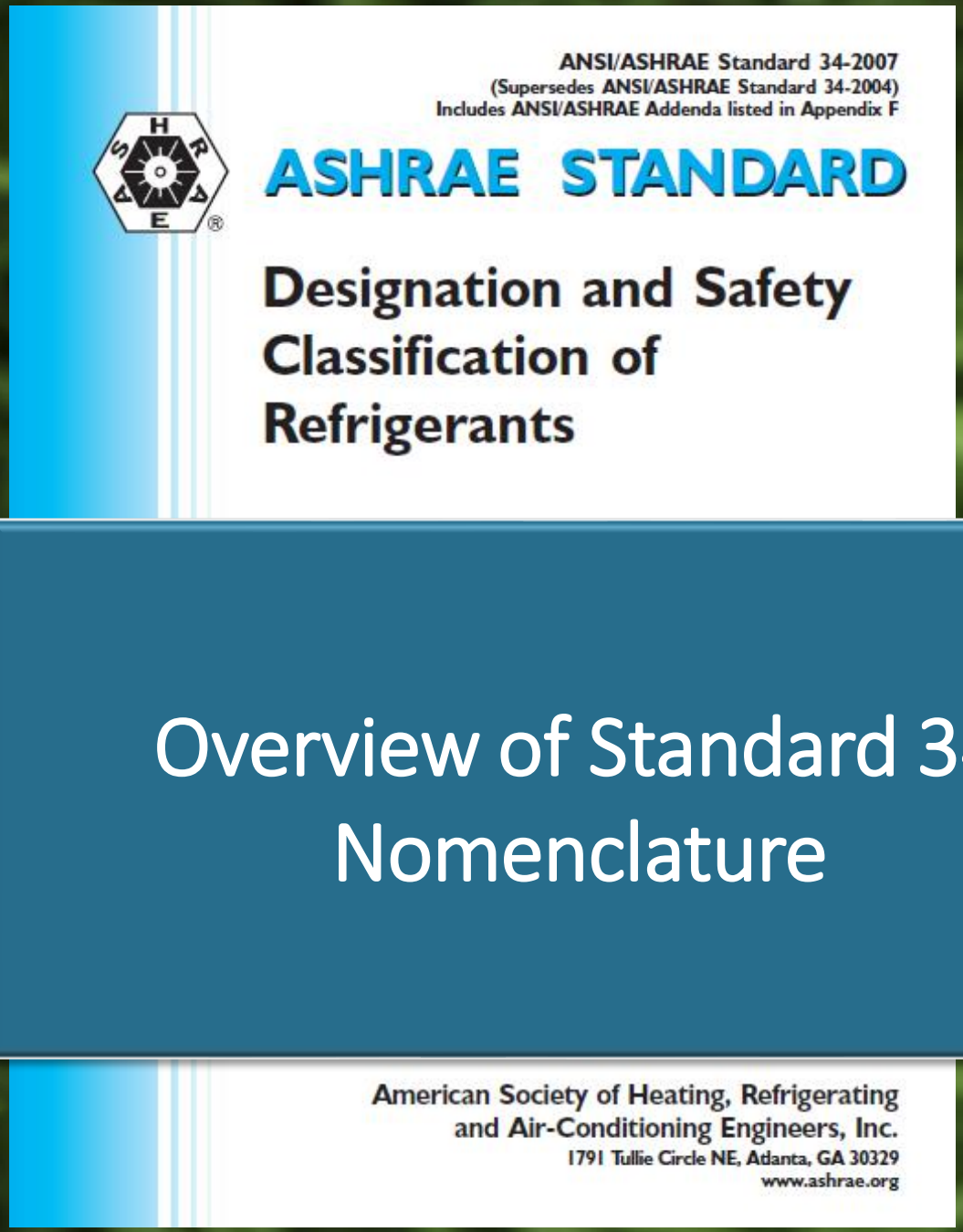


- Toxicity
  - A or B Based > or = to 400 ppm Occupational Exposure Limit (OEL) Dividing Line
  - **Class A**, most refrigerants, like R134a
  - **Class B**, R123 and ammonia are examples
- Flammability
  - **Class 1**, Non-flame propagating most refrigerants used today, like R123, R134a, R404A, R410A, etc., called nonflammable
  - **Class 2L,** Lower Flammable Class 2's <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"

Refrigerant Alternatives - Flammability vs GWP



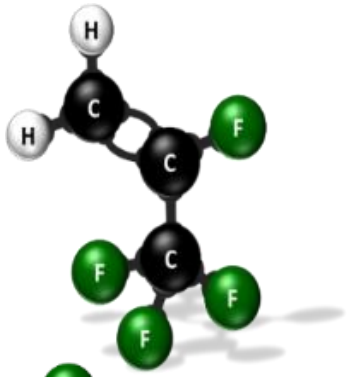


Overview of Standard 34 Nomenclature

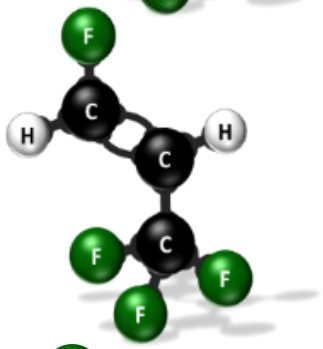
Review of Lower GWP Refrigerant Option for Various HFCs

Toolbox of <10 GWP Next Generation Refrigerants

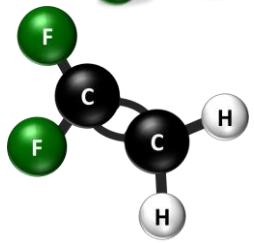
R1234yf
A2L GWP <1



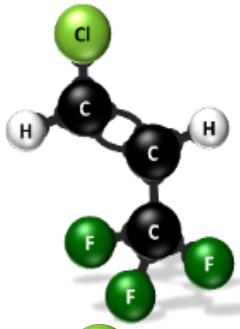
R1234ze(E)
A2L GWP <1



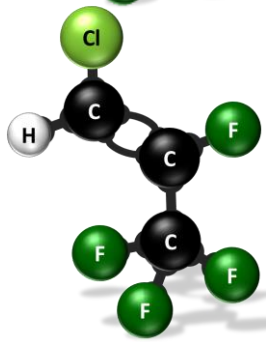
R1132a
A2 GWP <1



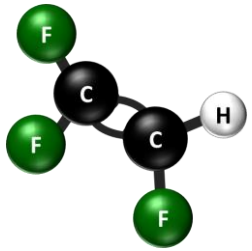
R1233zd(E)
A1 GWP 1



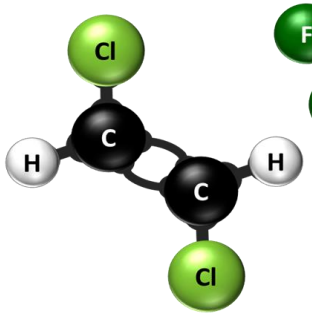
R1224yd(Z)
A1 GWP 1



R1123
A2L GWP <1

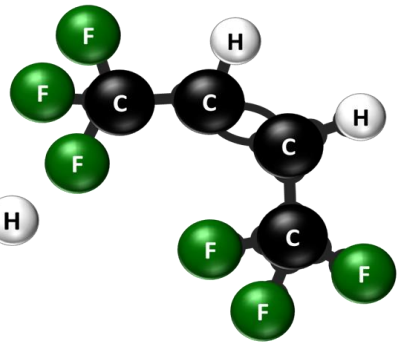


R1130(E)
B2L GWP <1

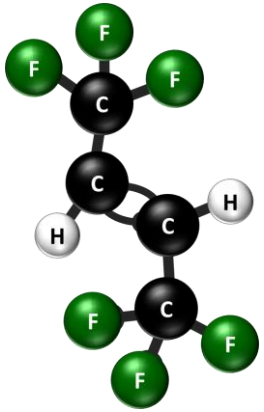


Azeotropic

R514A
B1 GWP<2

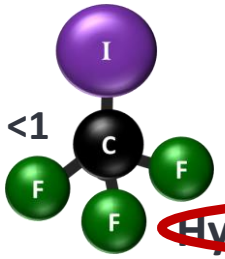


R1336mzz(Z)
A1 GWP <2



R1336mzz(E)
A1 GWP <6

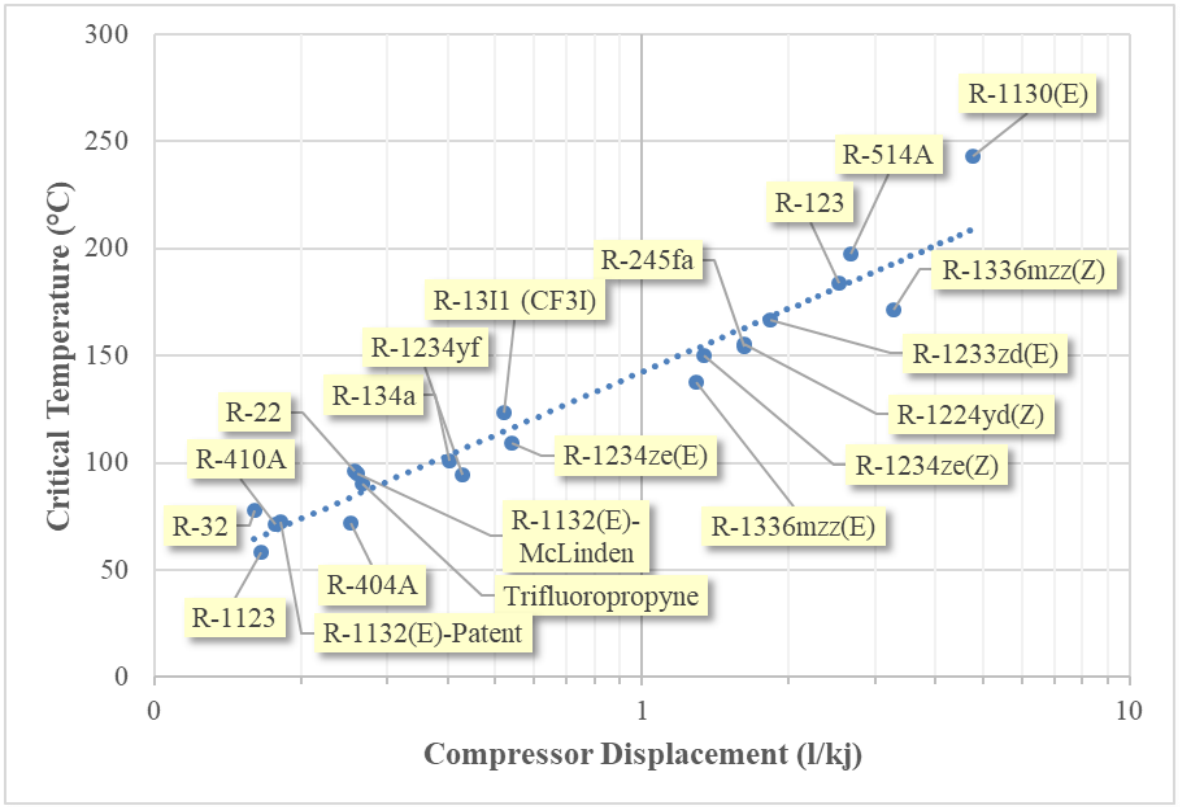
R13I1
A1 GWP <1

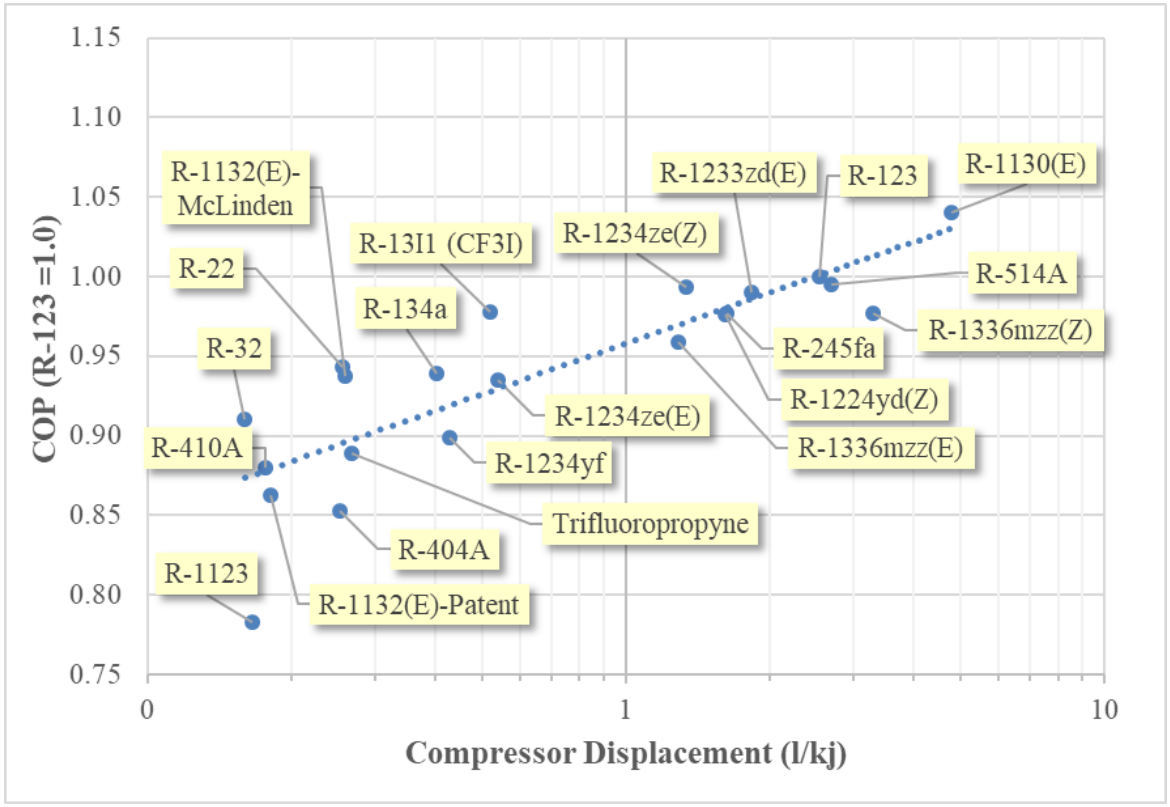


Along with
Carbon Dioxide (R744) – A1
Ammonia (R717) – B2L
Hydrocarbons (R290, R600, R600a) – A3

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

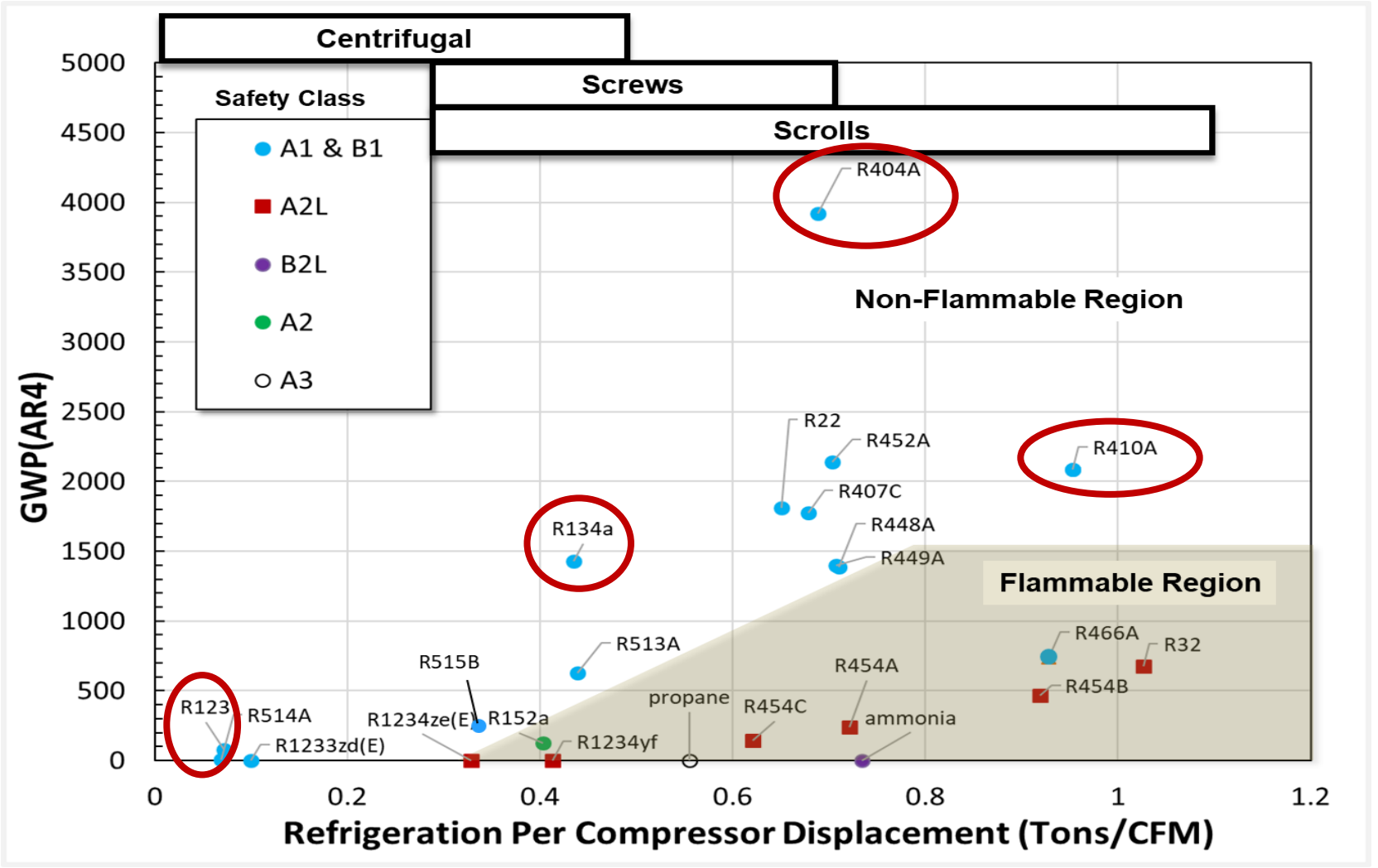
Summary of <10 GWP Refrigerants in the Toolbox





Many of these are Blended to Optimize Properties
R-500 Series Refrigerants are Azeotrope – No Change in Blend Composition if Leaked

Closer Look – Viable Lower & Ultra Low GWP Alternatives

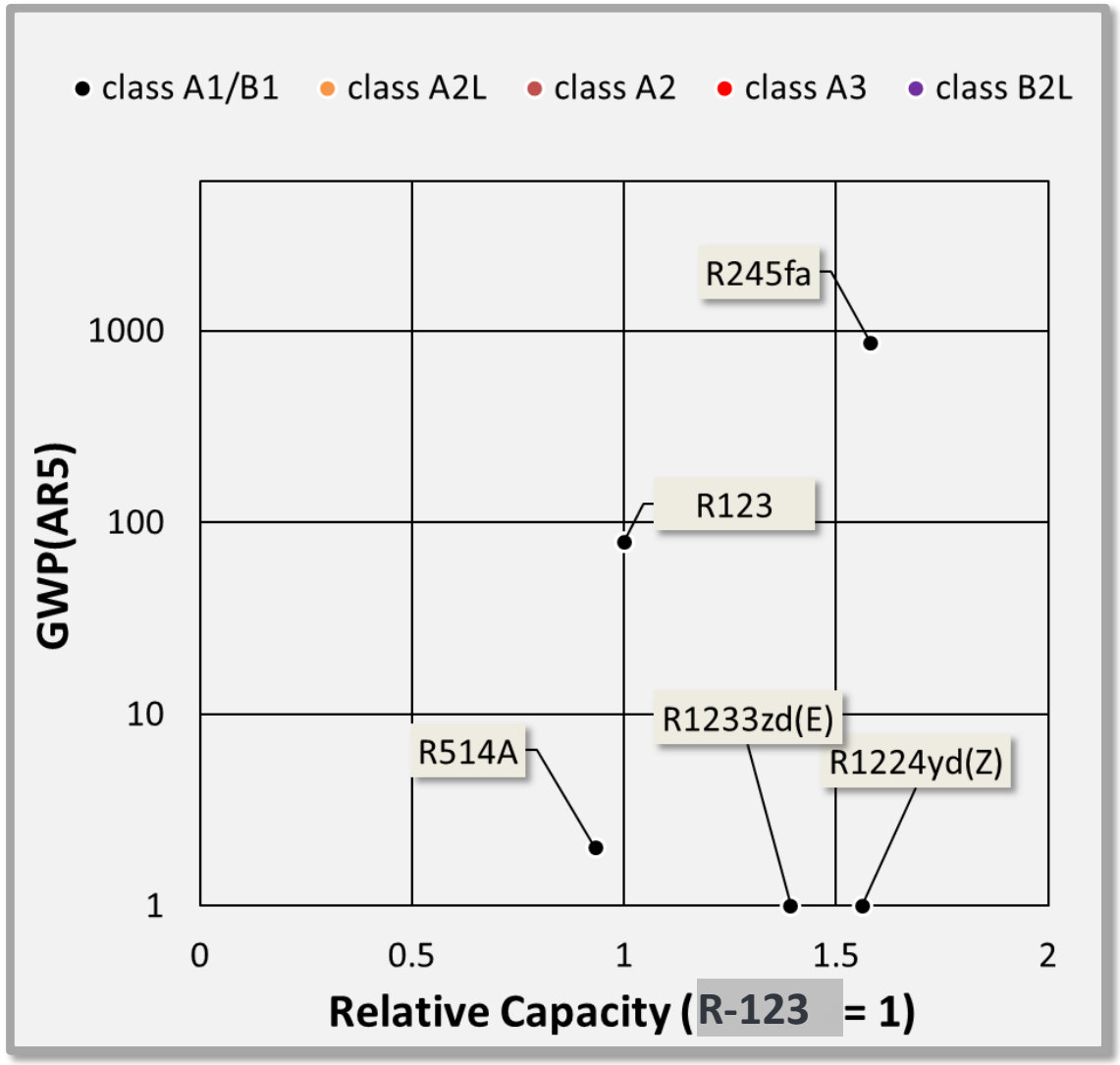


Flammable Refrigerants Required For Some Applications to Achieve a Low GWP Refrigerant Future

Low Pressure Alternatives R123 and R245fa Replacements

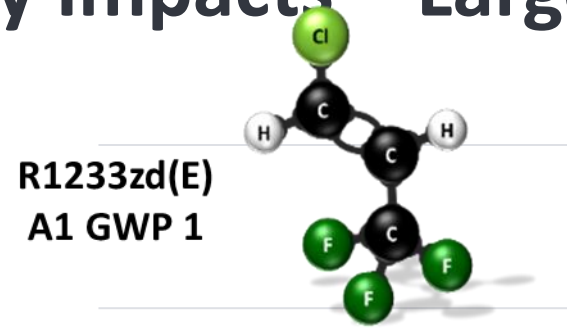
Alternatives Attributes

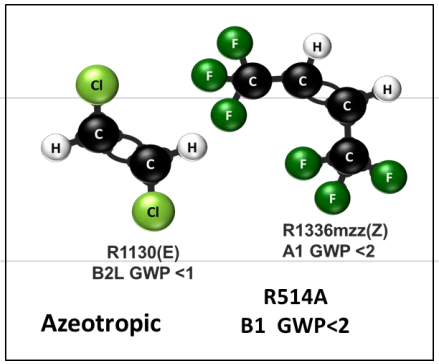
- Most Low GWP (<10)
- Non-flammable
- Good efficiency
- Near design compatible alternatives available
- Near R123 and R245fa capacities
- All with no glide
- Issues: none

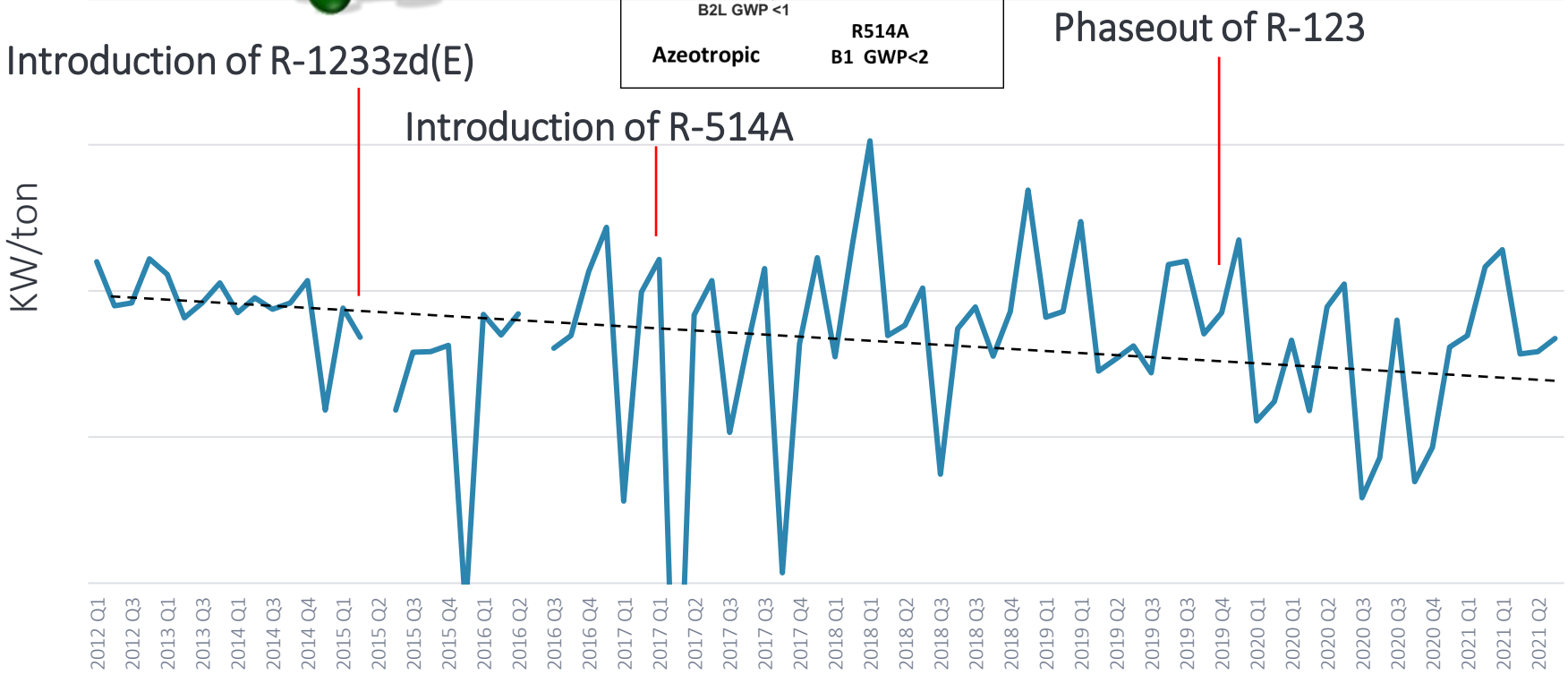


R1233zd(E), R514A and R1224yd(Z) – Good Choices Nonflammable, GWP <2, High Efficiency
All These Candidates Considered "Long Term Solutions"
R514A & R1233zd(E) Products Available in Market Place. R1224yd(Z) Emerging

Efficiency Impacts – Large Centrifugal WC Chillers





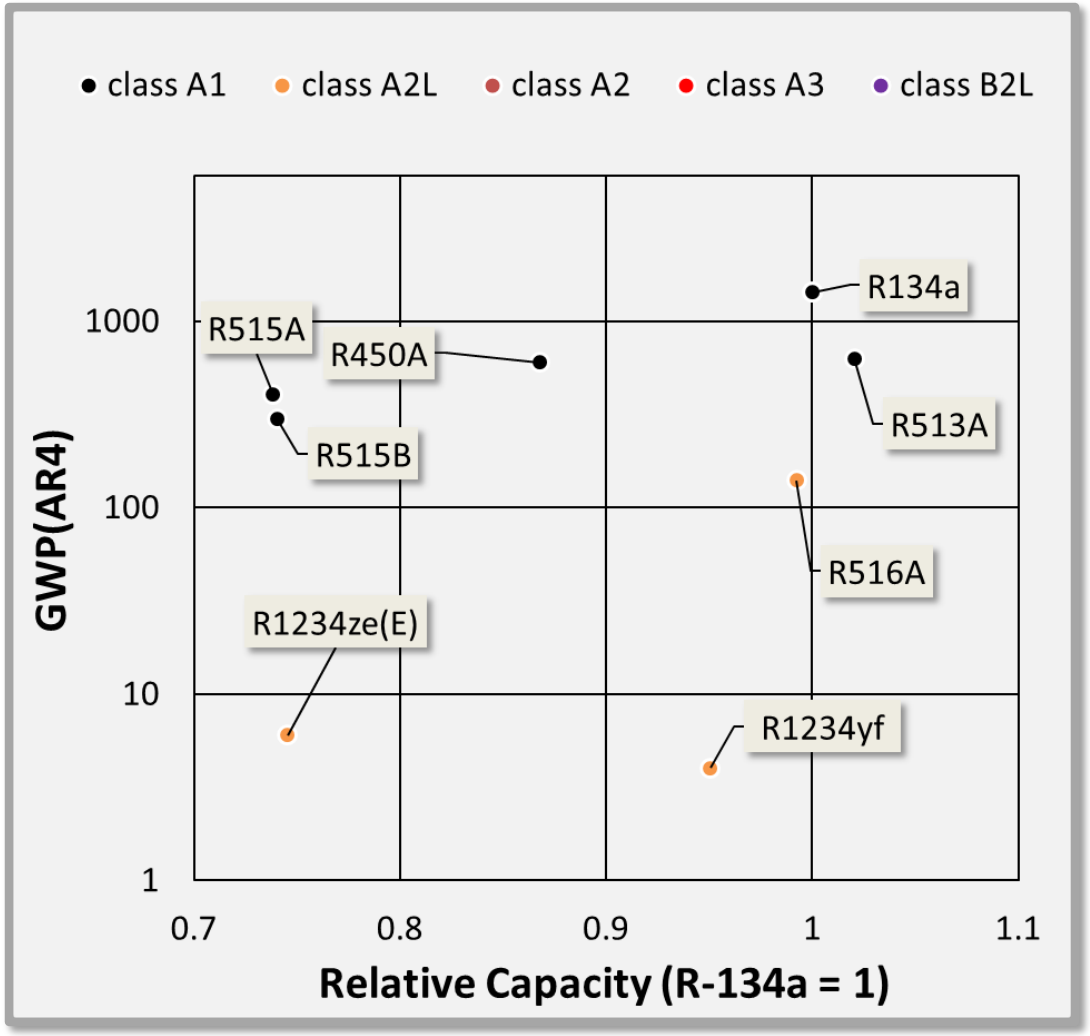


Non-Flammable Options – Early Adoption Possible
No Efficiency Impacts - Possible Gains

Medium Pressure Alternatives R134a Replacements

Alternatives Attributes

- Flammability
  - GWP 300-600 nonflammable
  - GWP <150 flammable
- Good to ok efficiency
- Near design compatible alternatives available
  - Near R134a capacity (R513A & R516A)
  - R1234ze(E) = -25% capacity
- All with no glide (azeotropes)
- Issues: Lower superheat than R134a

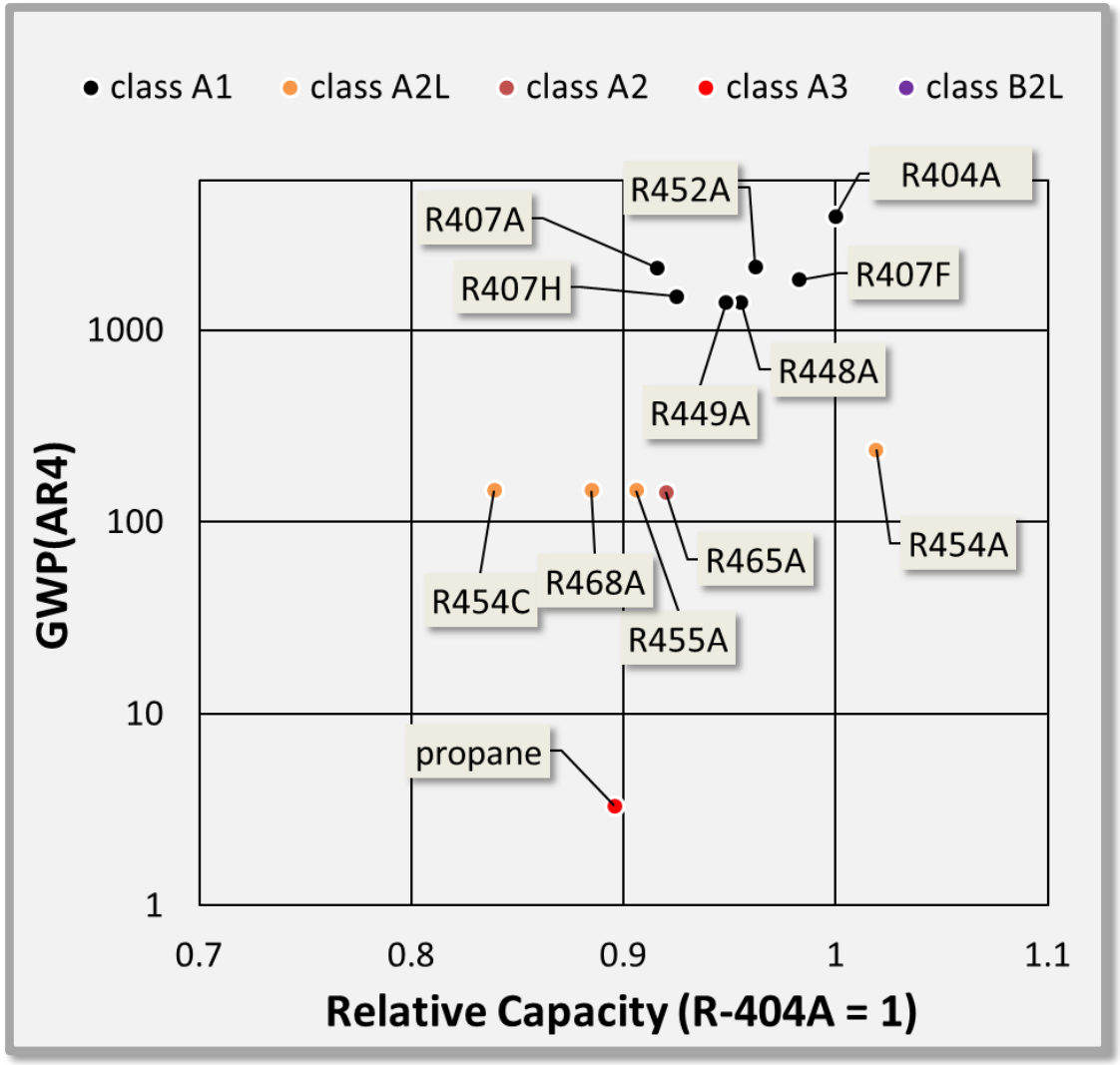


R513A & R515B (nonflammable) and R1234ze(E) Good Choices
R513A Products Available In Market Place (USA) – ZE, 515B, YF in EU

High Pressure Alternatives R404A Replacements

Alternatives Attributes

- Flammability
  - R452A, R448A, R449A, R407's (Nonflams)
  - R454A, R454C, R455A leading flams
  - R600a, R290, leading hydrocarbons
- Efficiency - equal or greater
- Design compatible alternatives available
  - R452A widespread use in Transport
- Issues: High glide, high CDT, <150 GWP lower capacity, all flammable
- No low glide blends for low temperature refrigeration flooded evaporator chillers

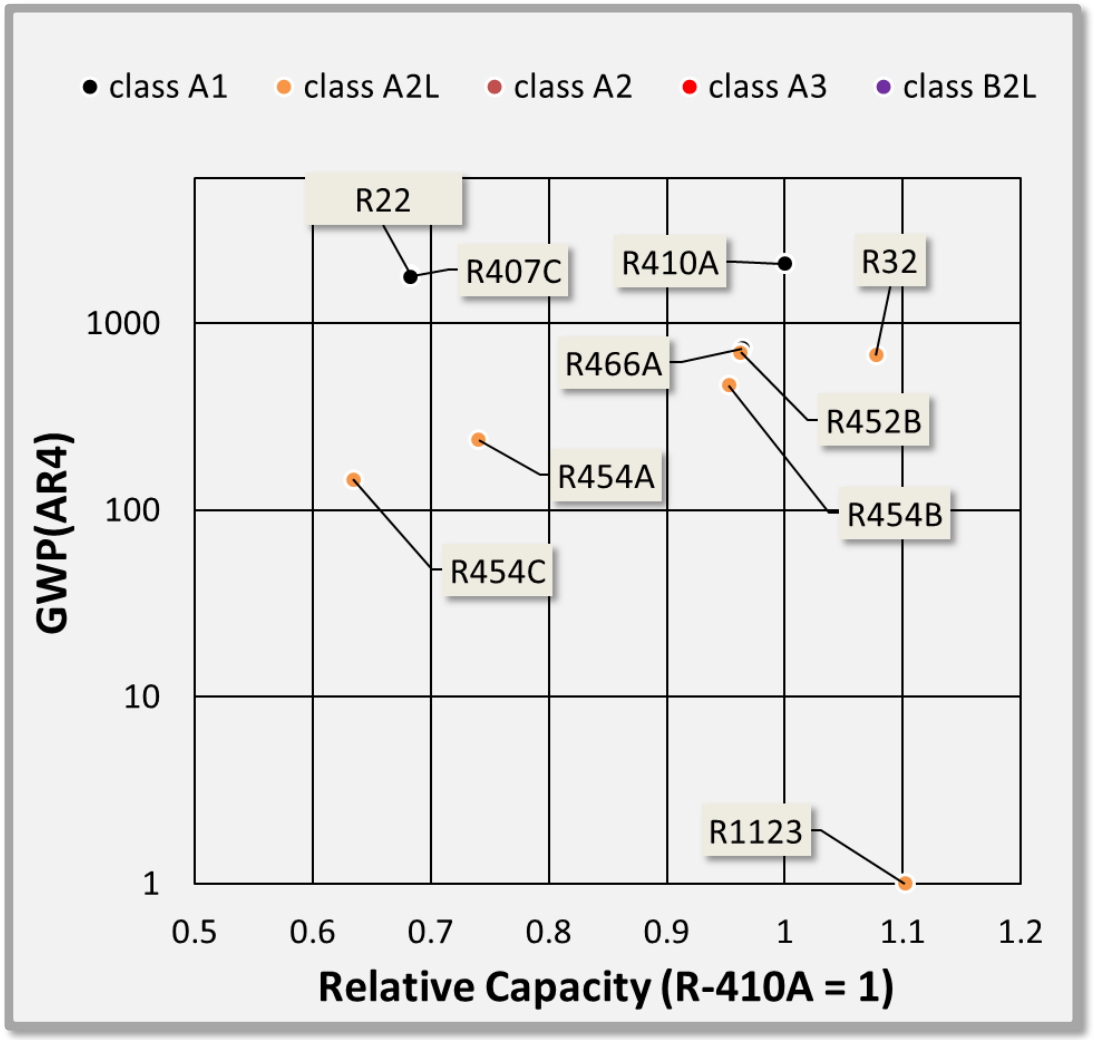


R448A, R449A, R452A Good Interim Candidates (Nonflammables)
Innovation Still Needed and Underway <150 GWP Possible - Tradeoffs

High Pressure Alternatives R410A Replacements

Alternatives Attributes

- Flammability
  - R32, R452B, R454B & C are all 2L
  - R466A first nonflammable <750 GWP
- Efficiency - equal or greater
- Near design compatible alternatives available
  - R466A (Nonflammable), R32, R454B, R452B
- Many with glide
  - Most R410A like with low glide (0 to <2K)
  - R454C is R407C like (5 to 6K)
- Issues: No <300 GWP "R410A Like" Candidates
- Issues: <300 GWP "R404A Like", but with high glide/CDT



R-454B & R-32 Primary "Interim" GWP Phasedown Refrigerants
Innovation Still Needed and Underway to Achieve <300 for All Products

Conclusions

Conclusions

The Transition is Underway

- USEPA/ECCC have regulation of HFCs by cap and phasedown methodology (↓10% 2022/↓40% 2024)
- HFC phasedown is successfully underway in many parts of the world

Lower GWP Fluorocarbon Refrigerant Technology Available to Achieve HFC Goals

- Non-Flammable Lower GWP and Ultra Low GWP (<10) Refrigerant Products Available and In Use Today
- 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)
- Flammable Lower GWP and Ultra low GWP Refrigerants Products Available and in Use Today
  - Small Portable Appliances, Cars, Refrigerators and Freezers That Only Require Small Refrigerants Charges
  - Larger Charge Products using Flammables Available Once Standards and Codes Implemented

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

Reaching final GWP goals requires more refrigerant technology innovation (Interim Adoptions)

Expect more product fragmentation by refrigerant. A single refrigerant may not be used from small to large capacity products

Men Continue to Argue…

Nature Acts

Kilauea Volcano - Volcano National Park – Big Island, Hawaii March 2021

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