Refrigerant Future

Steve Kujak
Director – Next Generation Refrigerant Research

10th WCEC Affiliates Forum
May 15, 2017

SUSTAINABLE PROGRESS

Sustainability at Ingersoll Rand:

Reducing Greenhouse Gas Emissions

Our Products

50% reduction in GHG via:

1) increased energy-efficient products; 2) use of next generation refrigerants with lower GWP in refrigerant-based products by 2020

50%

Our Operations

35% GHG reductions in our office buildings, manufacturing facilities and fleet by 2020

35%

Market Leadership and Convening

$500M in research to promote energy efficiency & solve refrigerant gaps via innovation, research, testing, policy over the next 5 years

$500M

Work Benefits the Business, People and the World – Now and in the Future

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HISTORY OF HVAC&R REFRIGERANTS

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 – 2010's**	**2010 - ??**
• Limited applications mainly industrial • "Poor safety & cost"	• Innovation enabled exponential societal improvements	Preserved 2nd gen. innovations, safety, stability and efficiency	• Fewer optimal 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 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 Continue To Drive Refrigerant Innovations

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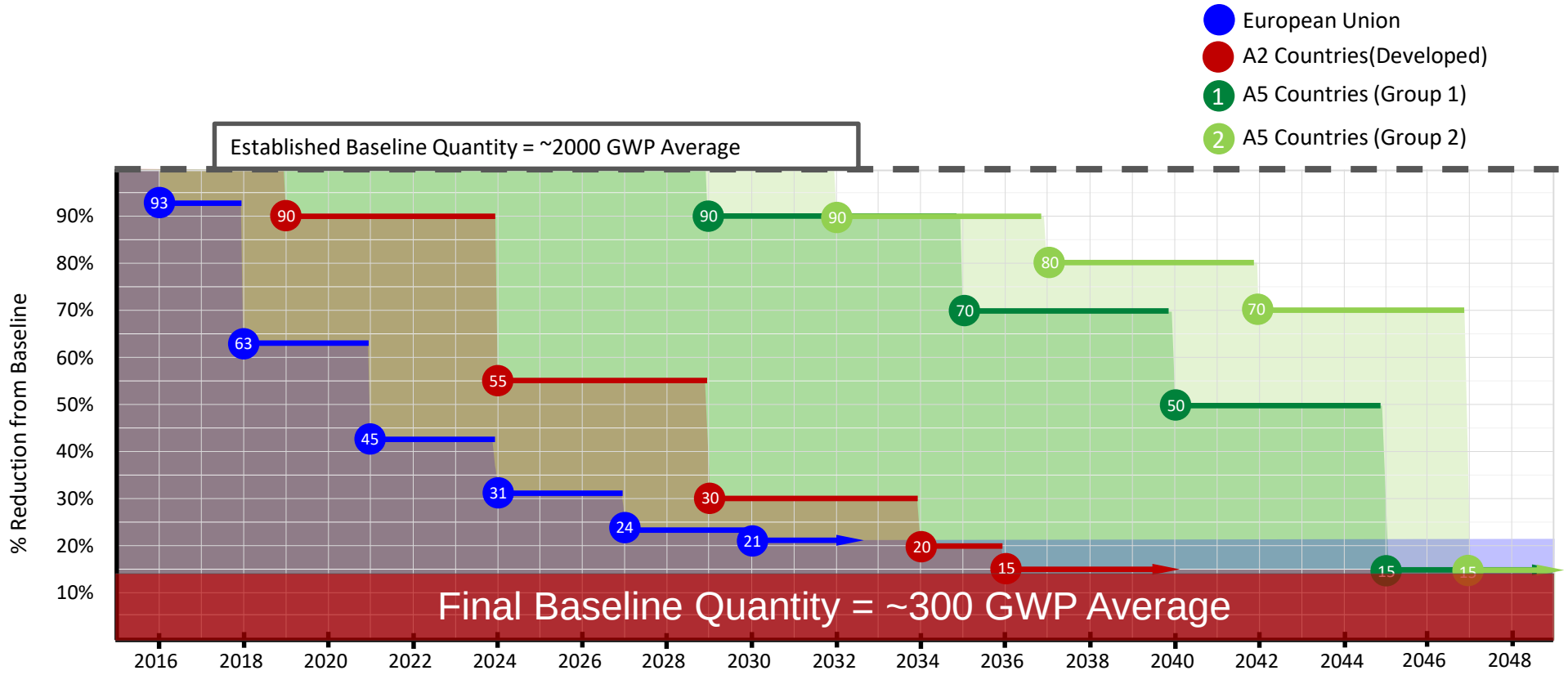
MONTREAL PROTOCOL HFC AMENDMENT AGREEMENT

KIGALI AMENDMENT - GLOBAL TRANSITIONS BASED ON GWP

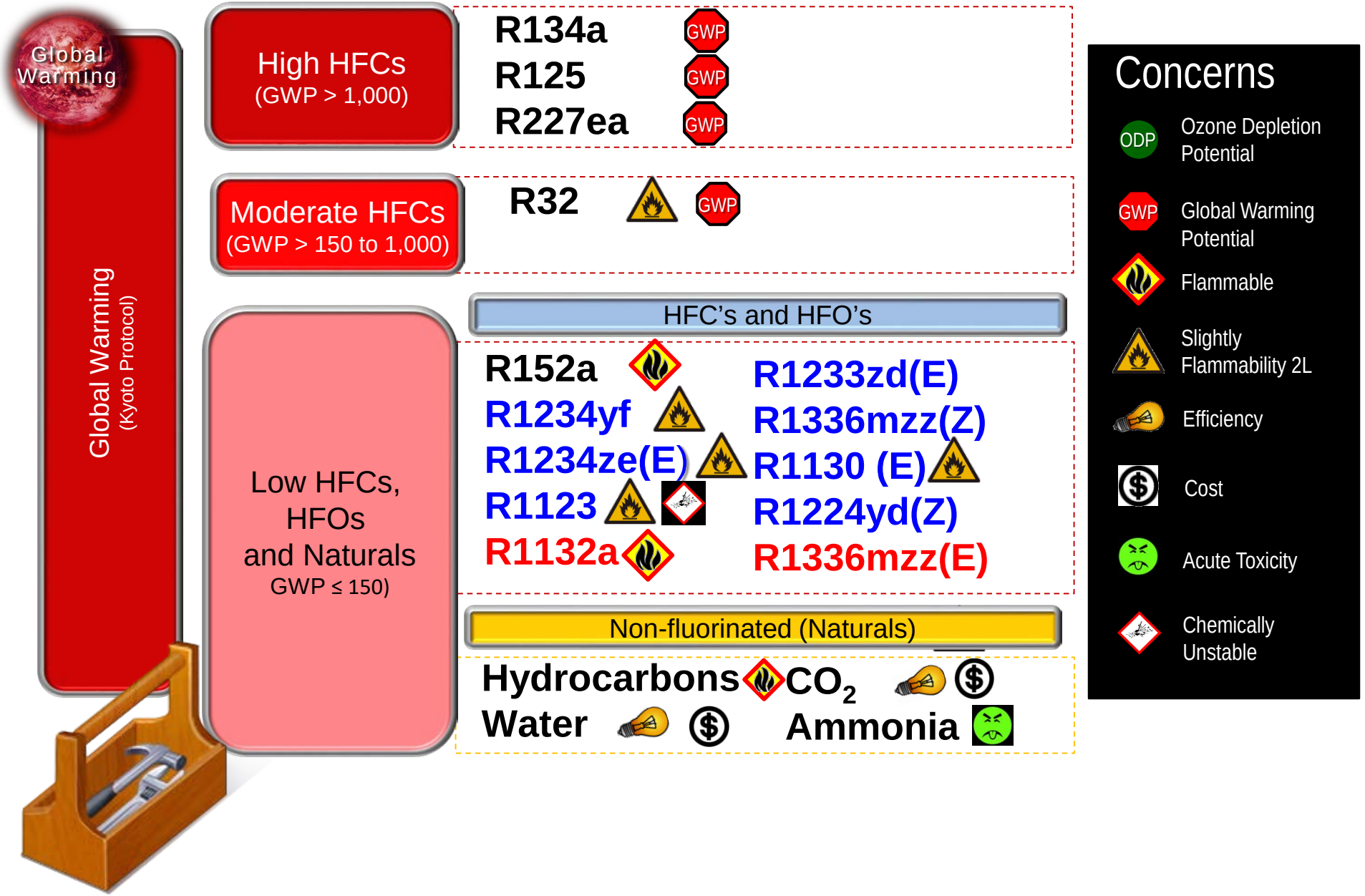
October 15, 2016



Phase Down not a Phase Out Program - Unlike First Montreal Agreement

Final GWP Average Allows for Products Without Ultra Low GWP Solutions

TOOL BOX FOR LOW GWP NGR'S



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REFRIGERANT SELECTION CHALLENGE

Balancing Key Factors for;

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

Challenge: Selecting Refrigerants with Balance

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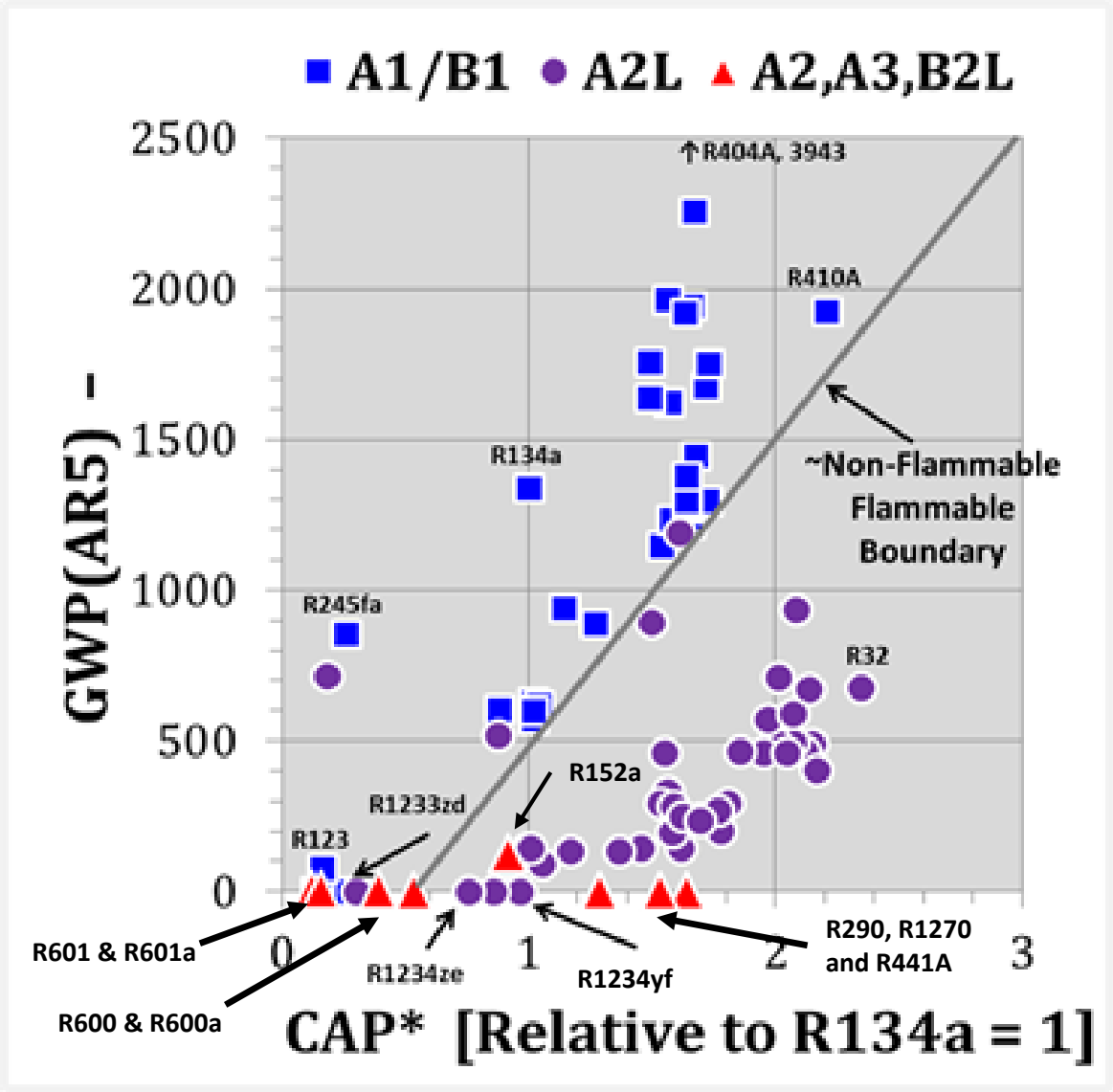
NEXT GEN REFRIGERANT ALTERNATIVES - FLAMMABILITY



Most Candidates HFOs and Blends of HFOs, HFC and Naturals Balancing Key Factors for;

- Direct Refrigerant GWP
- Efficiency
- Capacity
- Flammability
- Glide
- Intellectual Property
- Other Secondary Factors →(materials

Nonflammable GWP Limits
R123 - <150 GWP
R134a ~600 GWP
R404A ~1200 GWP
R410A – No Nonflammables

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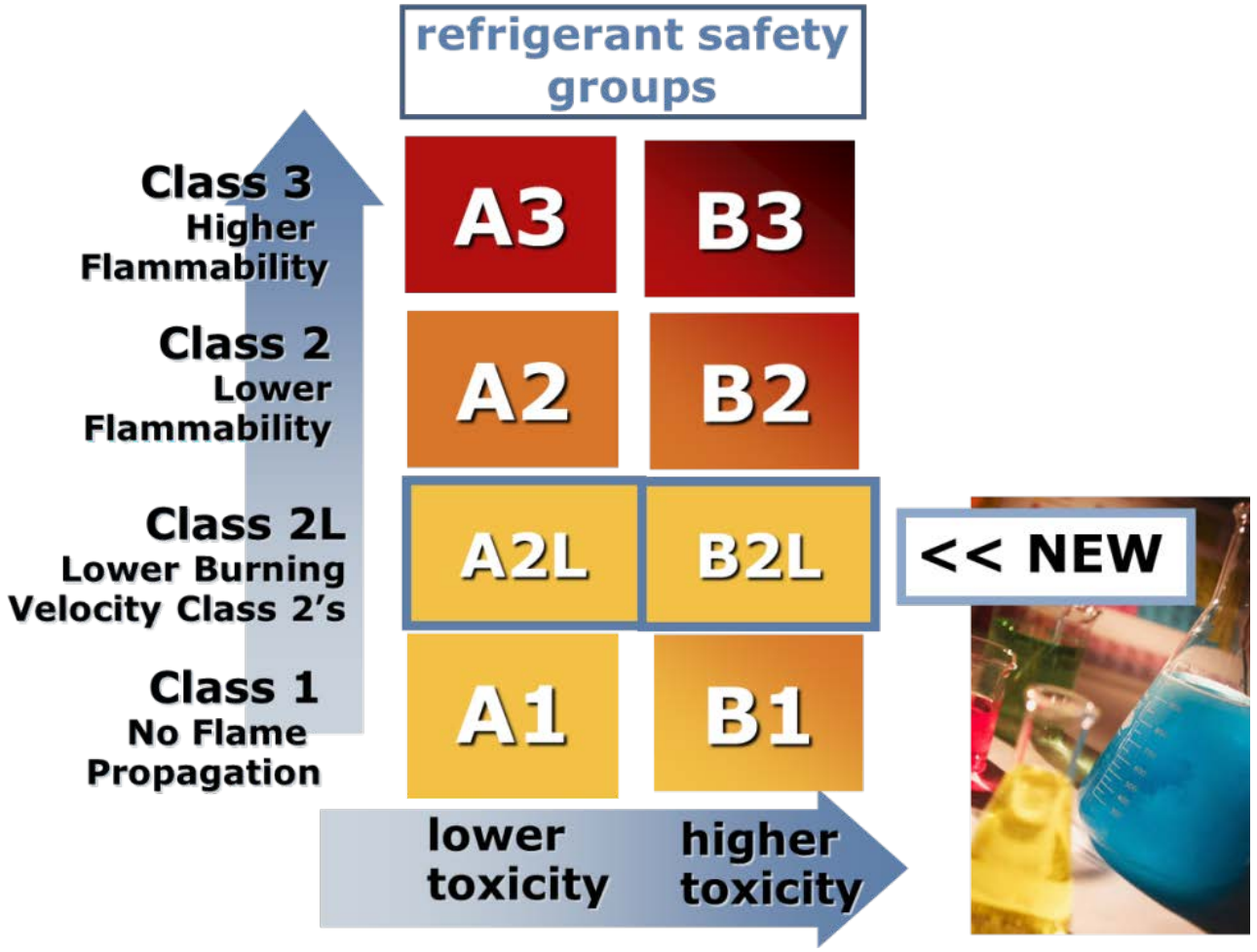
REFRIGERANT SAFETY CLASSIFICATIONS ASHRAE 34



Flammability is a Continuum and Not Specific Limits
"Flammable is Flammable"

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BACKGROUND - FLAMMABILITY BASICS

ASHRAE Journal
May 2017

Flammability and New Refrigerant Options

BY STEVE KUJAK, MEMBER ASHRAE

Increasing concerns about the impact of refrigerants on the environment and on climate change are driving new regulatory policies to restrict and lower the global warming potential (GWP) impact of fluorocarbon refrigerants used in the HVAC&R industry. In response, the industry is developing and examining a new class of lower GWP refrigerants. As this transition moves forward, many questions exist about changing refrigerants options and requirements to use them safely. This article highlights some important considerations, particularly flammability, that engineers, designers, and building owners should keep in mind regarding next-generation refrigerants.

Not all next-generation refrigerants are flammable. Numerous ultralow GWP refrigerants (defined in this article as having a GWP of less than 10) are nonflammable.

And, some flammable next-generation refrigerants are blended with nonflammable refrigerants, much like many of the refrigerant blends we use today. For example, the blend R-410A mixes a flammable refrigerant (R-32, ASHRAE Class 2L) with a nonflammable refrigerant (R-125, ASHRAE Class 1).

ASHRAE Standard 34-2016, *Designation and Classification of Refrigerants*, defines flammability in three separate classes:

- Class 1 (No Flame Propagation);
- Class 2 (Lower Flammability); and
- Class 3 (Higher Flammability).

ASHRAE has established a new 2L subclassification for refrigerant flammability to address new next-generation refrigerants that have lower flammability characteristics, which this article will discuss further.

Therefore, throughout this discussion it's important to keep in mind that flammability is a continuum and not a set of absolutes as determined by Standard 34.

What Should You Know About Flammability?

Safety—including the issues of flammability and toxicity—is a key consideration when evaluating next-generation refrigerants.

The HVAC&R industry has been asked to consider lower GWP refrigerants with both Class 2 (lower flammability refrigerants) and Class 3 (higher flammability refrigerants).

At a high level, the industry will likely select refrigerants that both meet regulations and are nonflammable or that have the lowest level of flammability possible. The lower the flammability, the lower the risk.

Refrigerant flammability is classified by Standard 34-2016 or the newly published ISO Standard 817-2014, *Refrigerants—Designation and Safety Classification*. Both

Steve Kujak is director next generation refrigerant research at Trane, La Crosse, Wis. He is chair of TC 3.1, Refrigerants and Secondary Coolants, and a member of SSPC 34.

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 industries. In response, all 197 member countries, including the U.S. and Canada, agreed last year to amend the Montreal Protocol to phase down hydrofluorocarbons (HFCs).

On Oct. 16, 2016, the Kigali Amendment to the Montreal Protocol was passed, paving the way for the global phasedown of HFCs. *Figure 1* shows the phasedown schedule agreed to by the parties. It also shows the European Union F-gas law, providing a perspective on how existing regional laws influenced the phasedown schedule.

Ahead of the Kigali Agreement, the U.S. Environmental Protection Agency (EPA) issued two rules regarding the change of listing status of certain HFCs in the U.S. The first rule[1] establishes phaseout dates for HFCs in retail food refrigeration, aerosols, propellants, and motor vehicles. The EPA used its regulatory authority through the Significant New Alternative Policy (SNAP) by designating particular SNAP-listed HFC refrigerants as "unacceptable" and SNAP delisting these refrigerants for new retail food refrigeration in 2017, aerosols and propellants in 2018, and motor vehicles in 2021. The second EPA rule[2] establishes the phaseout date for HFCs in chillers. Specifically, R-134a, R-410A and R-407C are banned from use in new chillers (air-cooled and water-cooled, scroll, screw, and centrifugal) beginning Jan. 1, 2024.

In a separate rule,[3] the EPA also made several other changes to management requirements for refrigerants in Section 608 of the Clean Air Act, effective Jan. 1, 2019, to include the following:

- Extending the requirements previously in place for chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) to include all replacement substances, including HFCs and the new hydrofluoroolefin (HFO) options. Hydrocarbons in small, self-contained systems are given an exception for venting.
- Reduced leak trigger rates, which in turn requires enhanced leak tightness requirements. This may push or incentivize the industry to move to technologies that are more hermetic with fewer joints and seals, for better long-term refrigerant containment.
- New requirements for mandatory leak inspections on equipment and increased record keeping requirements.

FIGURE 1 The HFC phasedown schedule agreed to by the parties of the Kigali Amendment to the Montreal Protocol.[4,5]

Group 1: Kigali Amendment Article 5 parties not part of Group 2
Group 2: Bahrain, India, the Islamic Republic of Iran, Iraq, Kuwait, Oman, Pakistan, Qatar, Saudi Arabia, and the United Arab Emirates

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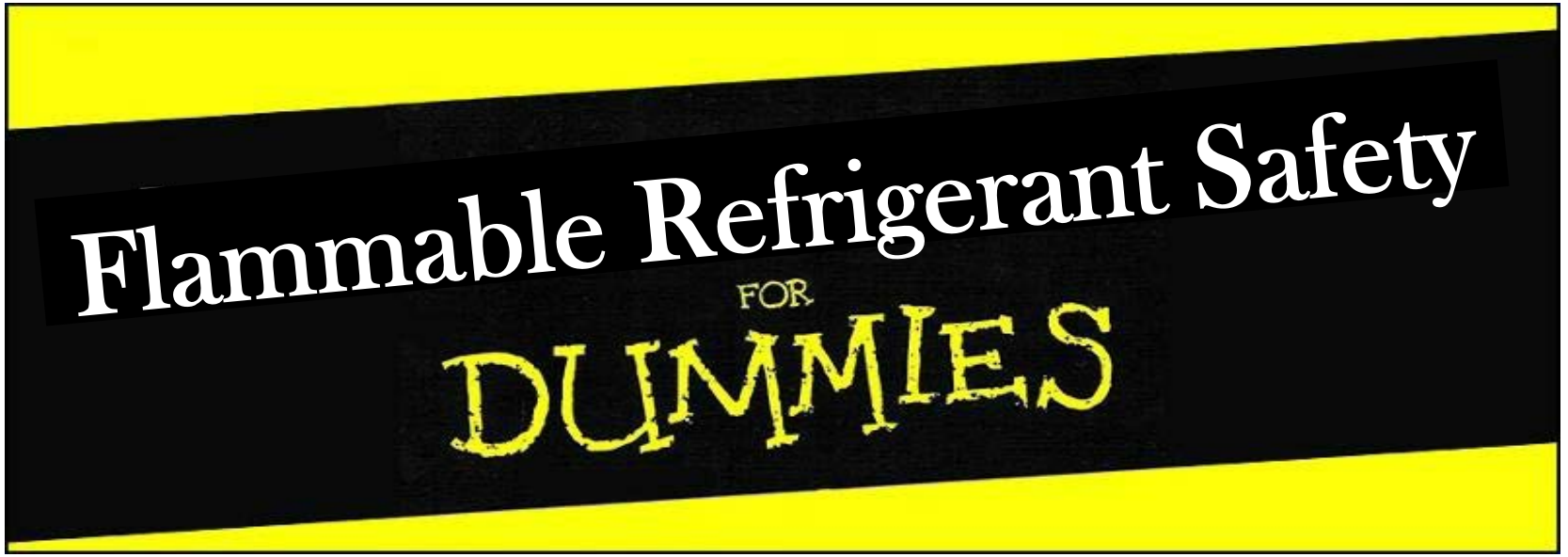
IDENTIFYING REFRIGERANT FLAMMABILITY RISKS

Refrigerant Manufacturing → Product Manufacturing → Delivery & Installation → Product Operation & Application → Service and Installation → End of Life

Refrigerant Leaks Are Possible With Each Operation

Specific Processing Changes Are Needed To Minimize Flammability Risk

Flammability Risks : A Cradle to Grave Understanding Needed



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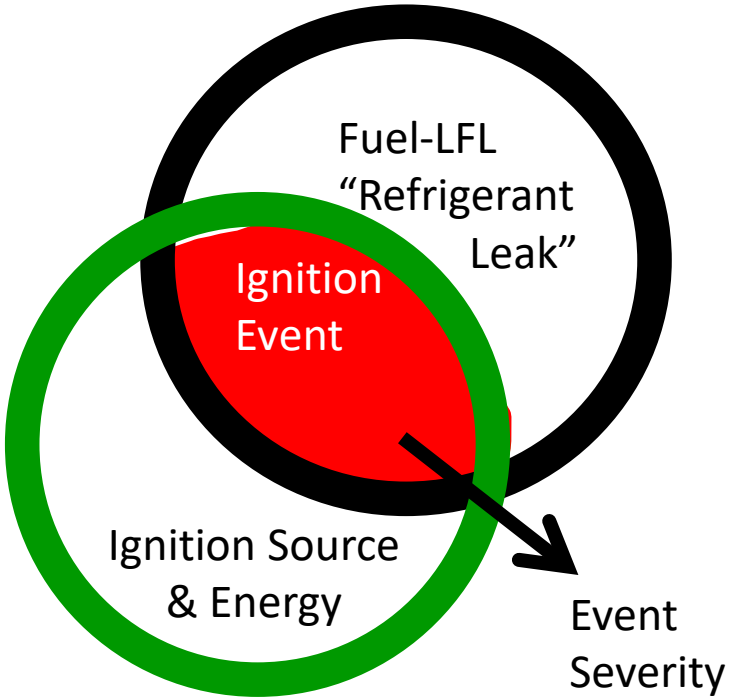
PRIMARY FLAMMABILITY CHALLENGE - REFRIGERANT INDOORS

RELEASABLE CHARGE SIZE, IGNITION SOURCES, MITIGATION & MINIMIZING EVENT SEVERITY



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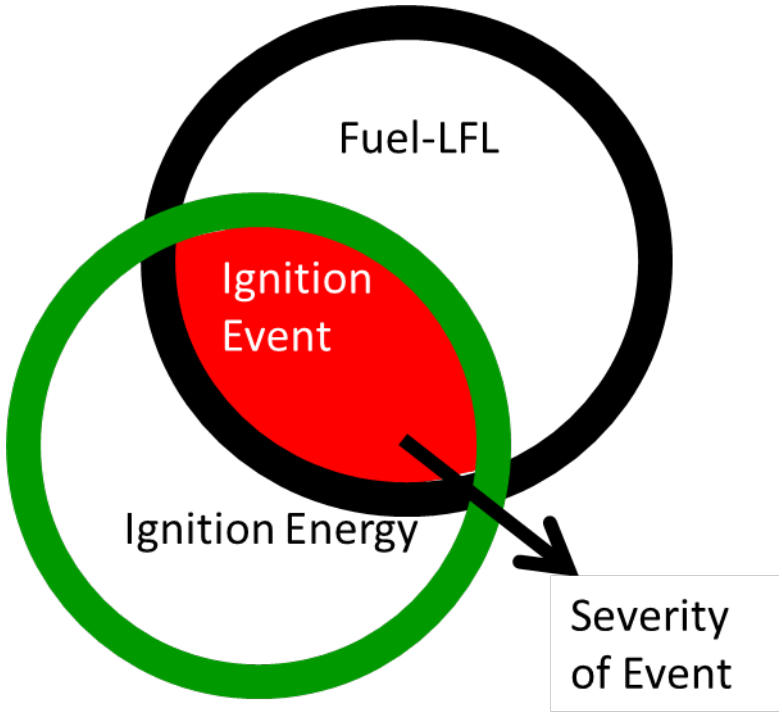
FLAMMABILITY SAFETY CONTROLLING & DESIGNING FOR KEY FACTORS



- Fuel – Refrigerant Concentration (LFL)
  - —Refrigerants with higher LFLs are safer as higher refrigerant concentrations are required to obtain a flammable mixture
- Ignition Sources and Energy (MIE)
  - —Restrict or Enclose
  - —Refrigerants with higher MIEs are safer because it requires a stronger ignition sources to be present to start the combustion process
- Severity of Event
  - —Design application to handle the pressure rise (venting)
  - —Design refrigerant to minimize potential secondary issues
  - —Refrigerants with lower burning velocities can reduce the flame propagation of an event

Defining Flammability Safety a Large Industry Challenge

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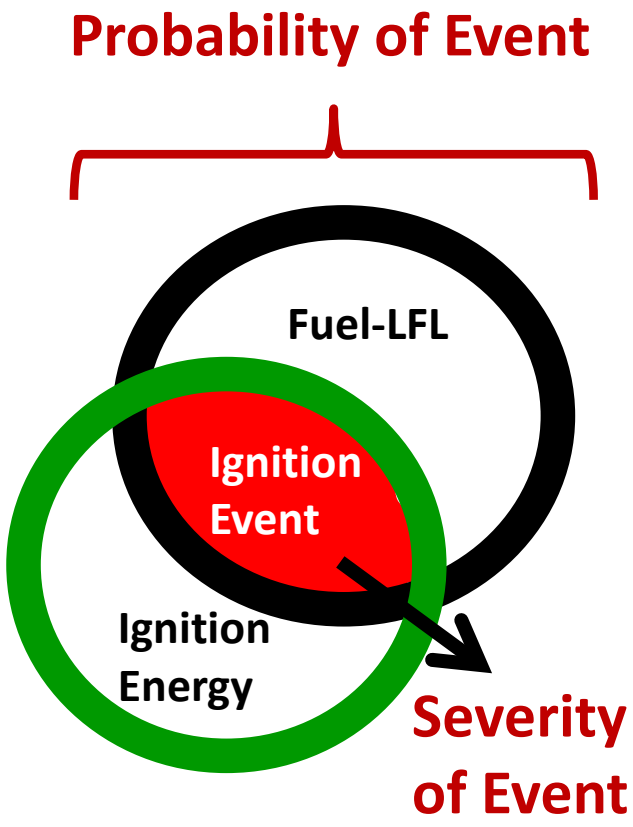
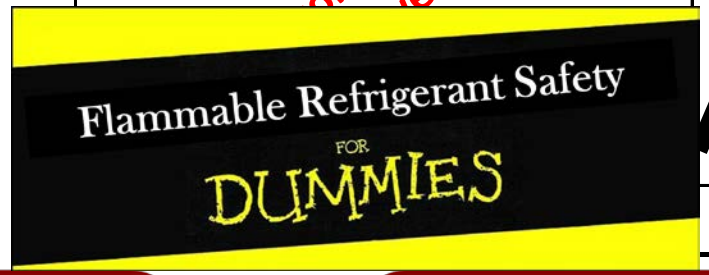
UNDERSTANDING FLAMMABILITY RISKS & IMPACTS



Risk = Likelihood & Severity

→Likelihood→			0	I	II	III	IV
			No Damage	Minor Damage (smoke, small localized events)	Light Damage (Fire from product, minor pressure rise, light injury)	Major Damage (fire and human injury)	Lethal Damage (permanent injury, death, burn down house)
	Frequently	10^{-2}	Always Acceptable			Not Acceptable	
	Occasionally	10^{-3}			Acceptable with Controls		
	Rare	10^{-4}					
	Usually not	10^{-5}		Acceptable with Caution			
	Very Difficult	10^{-6}					
	Extremely Difficult	10^{-7}					
	Near Zero	10^{-8}					

→Severity→



Industry Conducting Risk Assessments by Application Type to Understand Probability of Event

Severity of Events Not Well Understood, Industry Recently has Completed Work in Whole Rooms

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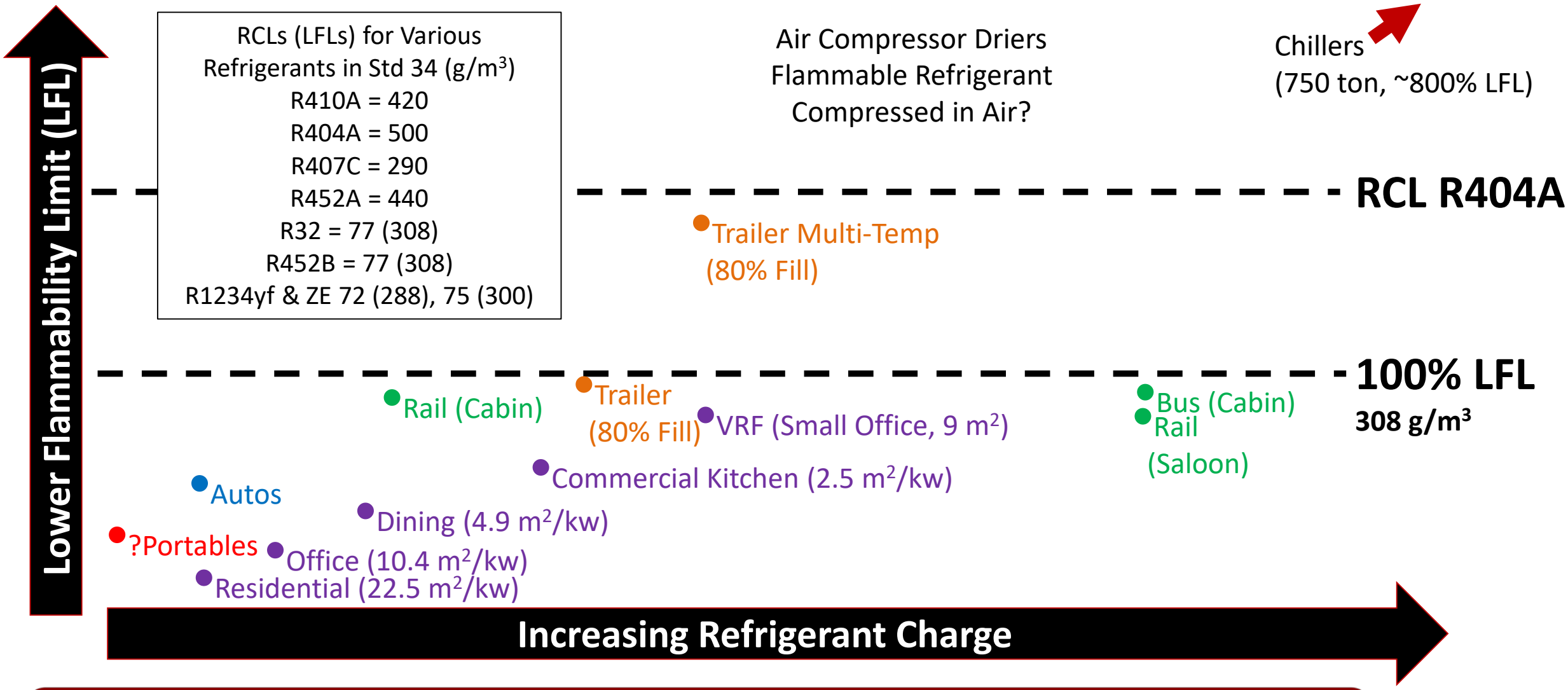
COMPARISON OF HVAC&R APPLICATION FLAMMABILITY RISKS



Cooling Load, Space Volume & Space Fill Important Factors in Assessing Risk

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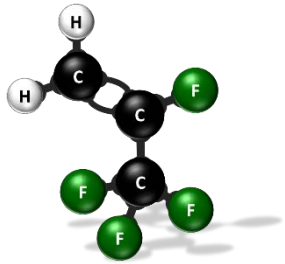
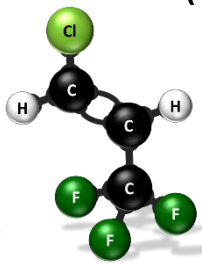
ULTRA LOW GWP PRODUCT INTRODUCTIONS (<150 GWP)

Lower Flammability Limit (LFL)

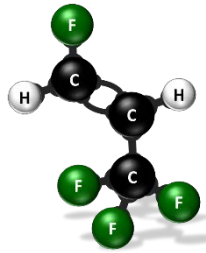
R1234yf



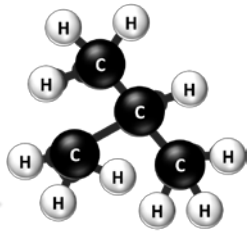
R1233zd(E)



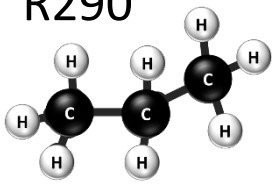
R1234ze(E)



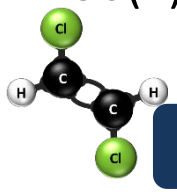
R600a



R290

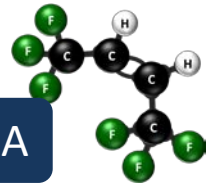


R1130(E)



R514A

R1336mzz(Z)



Large Charge WC Systems
Mechanical Equipment Rooms (MER)
Low GWP Nonflammable Available
Some A2L's Introduced

zd(E) & R514A)

Air-Cooled & Water Cooled Chillers - Europe

Larger Charge AC Systems (Outside)
A2Ls Being Introduced

100% LFL

Very Small
Charge Systems
<150 grams HC
<1 kg for A2Ls

Few CO_2)

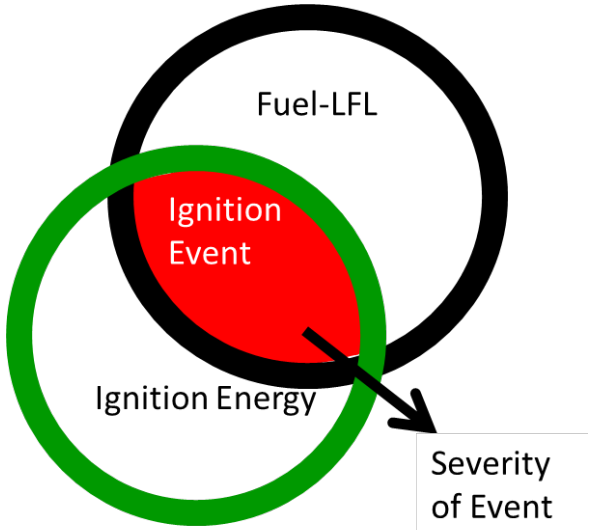
gd/Portable Products (hydrocarbons, New HFO/HFC Blends)

Increasing Refrigerant Charge

Where Nonflammables Available – Introductions in Large Charge Products
Flammables – Restricted to Small Charge or Indirect Outside Products
Numerous Moderate GWP Products Introduced (nonflammable) Filling Gap

REFRIGERANT FUTURE INSIGHTS

- Limited Nonflammable Alternatives
  - R123: Ultra low GWP nonflammables available (<10 GWP)
  - R134a: 400-600 GWP limit for nonflammables
  - R404A/R407C: 1200-1400 GWP limit for nonflammable
  - R410A: all candidates 2L
  - Innovation is constant and evolving – new alternatives being identified
- Flammability a Technical & Application Challenge
  - No History/Experience – Industry Learning and Conducting Research
  - Designing Refrigerants for Lowest Possible Flammability Risk Possible
  - Industry Working on Defining Flammability Safety
  - Industry Standards for Handling Flammables Starting to Appear
- Design Compatible Alternatives Identified –But..
  - More Zeotropic Blends Possible
  - New Design Centerlines Likely
  - Product Category Fragmentation by Refrigerant Likely



Meeting Montreal Protocol Goals Possible

Interim Moderate GWP Nonflammable Refrigerant Available

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