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

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

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

Work Benefits the Business, People and the World – Now and in the Future
HISTORY OF HVAC&R REFRIGERANTS

1st Generation
“What Ever Worked”
1830’s – 1930’s

- Limited applications
  mainly industrial
- “Poor safety & cost”
- NH₃
- CO₂
- Various Hydrocarbons
- H₂O
- Sulfur Dioxide
- Methyl Chloride (R40)

2nd Generation
“Safety and Stability”
1930’s – 1990’s

- Innovation enabled
  exponential societal
  improvements
- NH₃
- CFCs and HCFCs
  - R11
  - R12
  - R22
  - R502

3rd Generation
“Ozone Protection”
1990’s – 2010’s

- Preserved 2nd gen.
  innovations, safety,
  stability and efficiency
- NH₃
- HCFCs & HFCs
  - R123
  - R134a
  - R410A
  - R404A
  - Many Blends

4th Generation
“Global Warming”
2010 - ??

- Fewer optimal choices
- Safety and design
  challenges
- NH₃
- Low GWP HFCs & HFOs
  - R1233zd (E)
  - R1234yf & R1234ze(E)
  - HFC/HFO blends
- Renewed “Natural” interest
  - CO₂
  - Hydrocarbons

Societal Demands Continue To Drive Refrigerant Innovations
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

- High HFCs (GWP > 1,000):
  - R134a
  - R125
  - R227ea

- Moderate HFCs (GWP > 150 to 1,000):
  - R32

- Low HFCs, HFOs and Naturals (GWP ≤ 150):
  - R152a
  - R1234yf
  - R1234ze(E)
  - R1123
  - R1132a
  - R134a
  - R125
  - R227ea
  - R1130 (E)
  - R1130 (E)
  - R1233zd(E)
  - R1336mzz(Z)
  - R1336mzz(E)

- Non-fluorinated (Naturals):
  - Hydrocarbons
  - CO₂
  - Water
  - Ammonia

Concerns:
- ODP: Ozone Depletion Potential
- GWP: Global Warming Potential
- Flammable
- Slightly Flammability 2L
- Efficiency
- Cost
- Acute Toxicity
- Chemically Unstable
Balancing Key Factors for:
- Direct Refrigerant GWP
- Efficiency (Indirect GWP)
- Safety
- Transition Costs
- Intellectual Property
- Product Sustainability

Challenge: Selecting Refrigerants with Balance
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 compatibility, product costs, lubricants available, compressor discharge temp)

### NEXT GEN REFRIGERANT ALTERNATIVES - FLAMMABILITY

**Nonflammable GWP Limits**
- R123 - <150 GWP
- R134a ~600 GWP
- R404A ~1200 GWP
- R410A – No Nonflammables
REFRIGERANT SAFETY CLASSIFICATIONS
ASHRAE 34

Flammability is a Continuum and Not Specific Limits
“Flammable is Flammable”
BACKGROUND - FLAMMABILITY BASICS

ASHRAE Journal
May 2017

Flammability and New Refrigerant Options

Technological advances in air-handling units and building automation systems have made HVAC&R equipment more reliable and efficient. Now, with increasing concerns about the impact of refrigerants on the environment and climate change, industry is developing and examining new classes of refrigerants. 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.

For all next generation refrigerants are flammable. Numerous substances, ODP refrigerants defined in this article as having an ODP less than 0.3 are non-flammable.

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-404A enters a flammable refrigerant OR-12. ASHRAE Class 1 is a nonflammable refrigerant OR-125, ASHRAE Class I.

ASHRAE Standard 34-2016, Design and Construction of Refrigerating Systems, defines flammability in three different classes.

- Class 1 (Flame Propagation):
  - Class 1A (Non-flammable)
  - Class 1B (Flammable)

ASHRAE has established a new 2-1 classification for refrigerant flammability in order to best measure the new generation refrigerants that have lower flammability characteristics, which this article will discuss further.

What Should You Know About Flammability?

- Class 1 (Non-flammable):
  - Class 1A (Non-flammable)
  - Class 1B (Flammable)

ASHRAE has established a new 2-1 classification for refrigerant flammability in order to best measure the new generation refrigerants that have lower flammability characteristics, which this article will discuss further.

What is Driving the Refrigerant Transition?

With growing concern about the impact of refrigerants on the environment and climate change, increasing in-use of HFCs in HVAC&R has been mounting for years to reduce the use of high ODP refrigerants across many applications and industries. The phase-down schedule agreed to by the parties also adopts the Montreal Protocol to phase down hydrofluorocarbons (HFCs). On December 15, 2015, the Kigali Amendment to the Montreal Protocol was signed, setting the pace for the global phase-out of HFCs. Article 7 of the Kigali Amendment to the Montreal Protocol was signed, setting the pace for the global phase-out of HFCs. Article 7 of the Kigali Amendment to the Montreal Protocol was signed, setting the pace for the global phase-out of HFCs. Article 7 of the Kigali Amendment to the Montreal Protocol was signed, setting the pace for the global phase-out of HFCs.

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IDENTIFYING REFRIGERANT FLAMMABILITY RISKS

Refrigerant Leaks Are Possible With Each Operation
Specific Processing Changes Are Needed To Minimize Flammability Risk

Flammability Risks : A Cradle to Grave Understanding Needed

Flammable Refrigerant Safety FOR DUMMIES
PRIMARY FLAMMABILITY CHALLENGE - REFRIGERANT INDOORS
RELEASABLE CHARGE SIZE, IGNITION SOURCES, MITIGATION & MINIMIZING EVENT SEVERITY
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
**Risk = Likelihood & Severity**

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>Probability of Event</th>
<th>Severity of Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequently</td>
<td>$10^{-2}$</td>
<td>Acceptable</td>
</tr>
<tr>
<td>Occasionally</td>
<td>$10^{-3}$</td>
<td>Acceptable with Controls</td>
</tr>
<tr>
<td>Rare</td>
<td>$10^{-4}$</td>
<td>Not Acceptable</td>
</tr>
<tr>
<td>Usually not</td>
<td>$10^{-5}$</td>
<td>Acceptable with Caution</td>
</tr>
<tr>
<td>Very Difficult</td>
<td>$10^{-6}$</td>
<td>Acceptable with Caution</td>
</tr>
<tr>
<td>Extremely Difficult</td>
<td>$10^{-7}$</td>
<td>Acceptable with Caution</td>
</tr>
<tr>
<td>Near Zero</td>
<td>$10^{-8}$</td>
<td>Acceptable with Caution</td>
</tr>
</tbody>
</table>

- **No Damage**: 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

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**UNDERSTANDING FLAMMABILITY RISKS & IMPACTS**

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
COMPARISON OF HVAC&R APPLICATION FLAMMABILITY RISKS

Lower Flammability Limit (LFL)

- RCLs (LFLs) for Various Refrigerants in Std 34 (g/m³)
  - R410A = 420
  - R404A = 500
  - R407C = 290
  - R452A = 440
  - R32 = 77 (308)
  - R452B = 77 (308)
  - R1234yf & ZE 72 (288), 75 (300)

Air Compressor Driers
Flammable Refrigerant Compressed in Air?

- Trailer Multi-Temp (80% Fill)

Chillers
(750 ton, ~800% LFL)

Increasing Refrigerant Charge

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

• Autos
• Residential (22.5 m²/kw)
• Office (10.4 m²/kw)
• Dining (4.9 m²/kw)
• Commercial Kitchen (2.5 m²/kw)
• VRF (Small Office, 9 m²)
• Rail (80% Fill)
• Rail (Cabin)
• Rail (Saloon)
• Trailer Multi-Temp (80% Fill)
• Trailer (Saloon)
• Portables

RCL R404A

100% LFL
308 g/m³

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R1234yf & ZE 72 (288), 75 (300)
ULTRA LOW GWP PRODUCT INTRODUCTIONS (<150 GWP)

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

- Autos (R1234yf, Few CO₂)
- Small Packaged/Portable Products (hydrocarbons, New HFO/HFC Blends)
- Large Charge WC Systems Mechanical Equipment Rooms (MER)
  Low GWP Nonflammable Available
  Some A2Ls Introduced
  Air-Cooled & Water-Cooled Chillers - Europe
- Larger Charge AC Systems (Outside)
  A2Ls Being Introduced

- R1234yf
- R1233zd(E)
- R1234ze(E)
- R600a
- R290
- R1130(E)
- R1336mzz(Z)
- R514A
- R1130(E)
- R1336mzz(Z)
- R514A

100% LFL

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

Few CO₂

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