Refrigerant Update

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Director of Technology, Energy Efficiency, and the Environment

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Region VI CRC
Key Points

- Concerns about climate change are driving a renewed discussion on alternative refrigerants.

- In the absence of an international agreement, regional regulations are becoming prevalent.

- While most regulations are structured reductions in HFC use, higher emitting applications are targeted for some specific bans (i.e. commercial refrigeration and mobile AC).

- The industry is evaluating an number of alternatives for each application. R-134a and R-410a are still viable, available options for equipment sold today and not yet subject to any bans for commercial AC Equipment.

- Availability, safety, efficiency, cost and reliability present challenges for low-GWP refrigerants to become viable solutions.

- Industry must address impact of mildly flammable refrigerants.

- Energy efficiency has the greatest impact on HVAC greenhouse gas emissions and cost of ownership.
Legislation has driven the refrigerant options. Investments are long-term and require thoughtful insight to how the equipment will be used and operated throughout its lifetime.

<table>
<thead>
<tr>
<th>Make it work</th>
<th>Make it safe &amp; efficient</th>
<th>Eliminate ozone depleting CFC’s &amp; HCFC’s</th>
<th>Address greenhouse gas emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1830’s</td>
<td>Available Chemicals</td>
<td>CFCs (i.e. R-11, R-12)</td>
<td>Natural Refrigerants</td>
</tr>
<tr>
<td>1930’s</td>
<td>Natural Refrigerants</td>
<td>HCFCs (i.e. R-22, R-123)</td>
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</tr>
<tr>
<td></td>
<td>Make it work</td>
<td>HFCs (i.e. R-410A, R-134a, R-404A, R-507)</td>
<td>HFOs* (i.e. R-410A, R-134a, R32)</td>
</tr>
<tr>
<td>1970’s</td>
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<td>1987</td>
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<td>2004</td>
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<td>???</td>
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</tbody>
</table>

Until 1987, developing nations were importing technology and products from developed nations. The Montreal Protocol recognized the need to treat developing nations different from developed nations.
HCFC phase-out schedule

Source: U.S. EPA
Globally, nations are less aligned on environmental priorities than in the past. All are likely to agree, but on different timelines.

- Committed to meeting Montreal Protocol phase out.
- Expediting HCFC phase out under MP
- Financial aid for implementation
- Import restrictions on HCFC from 2015

Developing Nations

- Includes China, India, Singapore, etc.

Developed Nations

- Includes USA, W. Europe, Japan, Australia, etc.

- Nearing completion all ozone obligations.
- Shifting focus towards greenhouse gas emissions
- Shorter timelines
- Provide funding for developing nations
Today’s climate change concerns play out differently than yesterday’s ozone depletion concerns

**1990’s: Ozone Depletion**

Successful and orderly refrigerant transition

- Ozone depletion concerns lead to international regulatory action
- Universally ratified global treaty
- Causality was direct and science understood
- North America centric

**Today: Climate Change**

Complex & uncertain refrigerant transition

- Regional regulations
- HFCs small part of a much larger problem. Climate science is complex less and understood.
- Globally diverse

Energy efficiency is the dominant environmental impact over the life of equipment and refrigerant choice cannot be at the cost of efficiency.
How much of the problem are HFCs?

**The Greenhouse Gases (GHG)**

Total gas emissions – assumes all gases vented to atmosphere (100% leakage)

- 84% CO₂
- 8% Methane
- 5% Nitrous Oxide
- 1% PFCs, SF₆, HFC-23
- 2% HFCs
HFC Emissions from Refrigeration and Air Conditioning

Figure 2-3: Global HFC Emissions in 2020 by Application Type (% of GWP-Weighted Emissions)

- Small Unitary AC, 31%
- Large Retail Food, 31%
- MVACs, 16%
- Refrigerated Transport, 8%
- Refrigerated Cold Storage, 6%
- Large Unitary AC, 2%
- Window Units & Dehumidifiers, 1%
- PTAC/PTH, <1%
- PD Chillers, <1%
- Centrifugal Chillers, 1%
- Small Retail Food, <1%
- Medium Retail Food, 2%
- Household Refrigerators, 1%

HFC reduction proposals

Source: Montreal Protocol HFC Workshop and OEWG Meeting, April 2015
Montreal Protocol: Meeting of the Parties, November 1-5, 2015

• EPA Administrator Gina McCarthy attended the meeting for the first time in an effort to reach an agreement and had high level consultations with opposing countries all week.

• Negotiations went on until 2:40 AM in the morning on the last day and the result was an agreement to work toward an amendment to address HFCs under the Montreal Protocol in 2016 by:
  • Working through list of about 20 challenges identified by a number of parties
  • Having additional meetings in 2016
  • Considering possible exemptions for high ambient countries.
  • Possible additional funding mechanisms for developing countries to transition.

• Schedule for 2016:
  • Open Ended Working Group: April 4 - 8, Geneva, Switzerland
  • Open Ended Working Group: July 18 – 21, Vienna, Austria
  • Extraordinary Meetings of the Parties: July 22 - 23, Vienna, Austria
  • 28th Meeting of the Parties: October 10 - 14, Kigali, Rwanda
Nations are looking toward their own domestic agendas & objectives. Progress on a global climate change treaty will be slow as nations agendas are diverging.

**USA/Canada/Mexico:**
North American Amendment – proposal to use Montreal Protocol to gradually reduce HFC use by 2033. USA EPA to use SNAP program to de-list approved refrigerants that have low-GWP alternatives.

**Europe (EU):**
Revised F-Gas regulation will gradually reduce HFC use by 79% by 2030.

**India / Middle East:**
Must also exit HCFCs from 2015. India blocking HFC reduction discussion in Montreal Protocol.

**China:**
Must exit HCFCs from 2015. Agrees to discuss HFC reduction under Montreal Protocol. Investing in non-proprietary alternatives (not HFOs).

**Japan:**
Market shift to HFC-32 in residential & light commercial. New regulations aiming to mitigate HFC emissions cover total life cycle of refrigerant from production to disposal.

**Investing in non-proprietary alternatives (not HFOs).**
Europe F-gas regulation created a harmonized approach within the EU to effect greenhouse gases, efficiency & renewable, but lacks global support outside of the EU.

- **Mobile AC**
  - R134a → R1234yf or CO₂

- **Commercial Refrigeration**
  - Eliminate high GWP emissions (R404A & 507)

- **Small Charge Systems (Charge <3Kg)**
  - Switch over to low GWP (<750)

- **Stationary HVAC, chillers, etc.**
  - Focus is on operation, maintenance & containment

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Minimal to no impact on stationary HVAC

* F-gas is abbreviated to refer to greenhouse gases with fluorine in them

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**R-134a and R-410A are not affected for stationary air conditioning**
SNAP Change of Status (De-listing rule)

No impacted stationary air-conditioning (chillers).

Although, you will see R-134a listed in other sectors, to quote the EPA, “recognize that things are on different time tables.”

EPA typically takes a worst first approach to make the biggest impact.

Applicable to **new** equipment only.
## PROPOSED CHANGE OF LISTING STATUS

<table>
<thead>
<tr>
<th>End-Uses</th>
<th>Substitutes</th>
<th>Proposed Effective Date</th>
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<tbody>
<tr>
<td><strong>Air Conditioning</strong></td>
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<tr>
<td>Centrifugal chillers (new)</td>
<td>FOR12A, FOR12B, HFC-134a, HFC-227ea, HFC-236fa, HFC-245fa, R-125/134a/600a (28.1/70/1.9), R-125/290/134a/600a (55.0/1.0/42.5/1.5), R-404A, R-407C, R-410A, R-410B, R-417A, R-421A, R-422B, R-422C, R-422D, R-423A, R-424A, R-434A, R-438A, R-507A, RS-44 (2003 composition), and THR-03</td>
<td>Unacceptable, except as otherwise allowed under a narrowed use limit, as of January 1, 2024</td>
</tr>
<tr>
<td>Centrifugal chillers (new)</td>
<td>HFC-134a for military marine vessels and for human-rated spacecraft and related support equipment</td>
<td>Acceptable, subject to narrowed use limits, as of January 1, 2024</td>
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<td>FOR12A, FOR12B, HFC-134a, HFC-227ea, KDD6, R-125/134a/600a (28.1/70/1.9), R-125/290/134a/600a (55.0/1.0/42.5/1.5), R-404A, R-407C, R-410A, R-410B, R-417A, R-421A, R-422B, R-422C, R-422D, R-423A, R-434A, R-437A, R-438A, R-507A, RS-44 (2003 composition), SP34E, and THR-03</td>
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- Published 4/18/2016, 45 day comment period for stakeholders to provide input
- Once revised based on those comments it goes OMB for review
- The goal of the agency is to publish the final rule by the November 2016 elections
Nations are looking toward their own domestic agendas & objectives. Progress on a global climate change treaty will be slow as nations agendas are diverging.

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Each region faces different challenges, with some similarities across the spectrum, but most with different priority and timing.

<table>
<thead>
<tr>
<th>Technical issues</th>
<th>Europe</th>
<th>North America</th>
<th>China</th>
<th>Middle East</th>
<th>Developing Countries</th>
</tr>
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<tr>
<td>F-Gas regulation phase down of HFCs over time based on production allocations. Safety code changes for 2L refrigerants required.</td>
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<td>2L Flammability for direct systems will be paced by code changes. Indirect 2L systems will appear in the market and</td>
<td>Safety is a concern … service tech skills gap in market and code enforcement not consistent. Pace to develop safety code slower than expected.</td>
<td>High ambient operation a concern for high pressure alternatives in air-cooled equipment</td>
<td>Safety is a concern for 2L refrigerants. Service tech skills gap in market and code enforcement not consistent</td>
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<tr>
<th>Regulatory &amp; political</th>
<th>Europe</th>
<th>North America</th>
<th>China</th>
<th>Middle East</th>
<th>Developing Countries</th>
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</thead>
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<table>
<thead>
<tr>
<th>Commercial</th>
<th>Europe</th>
<th>North America</th>
<th>China</th>
<th>Middle East</th>
<th>Developing Countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sectorial bans do not affect Stationary AC but niche preference for low GWP.</td>
<td>Safety and liability concerns with direct systems will limit market acceptability ahead of regulatory mandates. Adoption of safety standards and building codes an issue.</td>
<td>Proprietary fluids disrupt local refrigerant supply base.</td>
<td>Customer bias against R-410a for air-cooled high ambient applications.</td>
<td>Low cost and availability the main driver.</td>
<td></td>
</tr>
</tbody>
</table>
Each product uses compressor types which require different refrigerants

Light Commercial
UPG, VRF, RTU, and small chillers
Rotary and scroll compressors
HFC-410A, HCFC-22

Mid-Market
small to medium chillers
Screw and small centrifugal compressors
HFC-134a, HCFC-22

Complex Market
medium to large chillers
Centrifugal compressors
HFC-134a, HCFC-123

Note: Screw market for industrial refrigeration (IR) dominated by natural refrigerants with low GWP today (e.g. Ammonia). GWP shift will largely not impact IR screws.
These guiding principles inform our selection of refrigerant for each product, customer application and design provides:

- Efficiency
- Capacity
- Low GWP

- Availability
- Cost of ownership
- Customer preference
- Intellectual property
- Regulatory certainty
- Adjacent sector demand

- Safety code compliance
- Operator training
- Insurance cost
- Reliability
- Legal risk
- Stability
Refrigerants are differentiated by pressure range, and have a wide range of uses. The primary market drivers for refrigerants various by low, medium and high pressure applications.

Refrigerant consumption as % of market

- **High Pressure** (i.e. R410A)
  - HVAC
  - Mobile AC
  - Unitary AC

- **Medium Pressure** (i.e. R134a, R1234yf)
  - Refrigeration
  - HVAC
  - Mobile AC
  - Foams
  - Aerosols

- **Low Pressure** (i.e. R123, R245fa)
  - HVAC
  - Solvents
  - Foams

Source: U.S. EPA
Refrigerant regulations such as EPA SNAP and European F-gas focus on a “worst-first” approach to target specific refrigerants for specific applications.
Global effort between industry, universities, research institutes, and refrigerant manufacturers in underway to identify the next generation of low-GWP refrigerants.

Phase 1 included alternatives for:

- R22, R404A, R410A & R134a

Alternatives included:

- R1234yf, R32, ARM-70a, DR5, L-41a, L-41b, ARM-31a, D2Y-65, L-40, R32/R134a (50/50), R-32/R-152a (95/5), N13a, L-20, AC5, D52Y, HPR1D, D2Y-60, D4Y, N13b, R1234ze(E), DR4, ARM-42a, XP10, DR7, ARM-32a, LTR4X, LTR6A, N40a, R290, and ARM-30a

Collaboration continues with second phase of testing began in late 2014
Refrigerant thermodynamic efficiency – centrifugal chiller options

Larger components  More compact

GWP
- 4
- 500
- 1,000
- 1,430

Toxicity
● Non toxic
△ Toxic

Flammability
Orange: Mildly flammable
Blue: Non flammable
Refrigerant thermodynamic efficiency – screw chiller options

- Larger components
- More compact
Refrigerant thermodynamic efficiency – scroll chiller options

Larger components More compact
Many of the new HFO base molecules are being sold in adjacent sectors (foam and automotive).

Many of the medium and high pressure alternatives are mixtures of existing HFCs with HFOs.

HFOs will always be some multiple of current HFC prices because they are more complex molecules that require additional production steps to produce.
Safety: Implications for product design and service

Pressure:
- Pressure Code requirements become a cost driver as the design working pressure of the refrigerant increases.
- Individual country and regional requirements result in multiple versions of the same product platform. e.g. (ASME, PED, Chinese GB Pressure vessel Code)

Flammability
- Flammability has significant implications on cost, product configuration, and risk for the manufacturer
  - Compliance to regional equipment room and product safety codes:
    - Explosion proof wiring and electronic components
    - Explosion proof Motors and Drives
    - Equipment room ventilation requirements and leak detection
    - Liability risk for equipment that we may not maintain

Implication to Service
- Training of technicians on safe use flammable refrigerants.
- Cost of additional equipment an compliance with transportation regulations.
- Regional variation in technician capability and requirements
ASHRAE and ISO standards have added a *mildly flammable* refrigerant classification to distinguish low GWP refrigerants that are difficult to ignite and sustain a flame vs. more flammable types.

Designation and Safety Classification of Refrigerants ANSI/ASHRAE Standard 34

- Historical classification has included 6 safety groups, with three flammability groups
- Recently added was an optional flammability classification of 2L

Many Low-GWP alternatives are A2L, mildly flammable

A2L: R32, R1234yf, R1234ze
B2L: R717
Safety: Building codes & construction practices must be changed to address this change before they can be used.

Changes to standards take a long time for local adoption.
Historically, the code change process took a long time to process through changes.

Acceleration must happen through cooperation between industry and government.
Summary of Key Codes and Standards Updates to Accommodate A2L Refrigerants for HVAC

- **Safety Standards**
  - UL 60335-2-40 2\(^{nd}\) Edition
    - To enable A2L refrigerants in indirect systems
  - UL 60335-2-40 3\(^{rd}\) Edition
    - To enable A2L refrigerants in direct systems
  - ASHRAE 15
    - Adding A2L refrigerants for mechanical rooms
    - Adding A2L requirements for unitary and residential HVAC equipment

- **Building Codes**
  - Model codes
    - Should adopt A2L provisions from ASHRAE 15
    - Should cite the latest A2L refrigerants classified by ASHRAE 34
    - Should require compliance with UL 1995 and/or UL 60335-2-40
  - State codes
    - Need to reference A2L updates in ASHRAE 15 and model codes
Summary by Equipment Category

• Outdoor Chillers
  – SNAP approved A2L refrigerants could be used under the current ASHRAE 15 for equipment certified to UL 60335-2-40 (2nd Edition). SNAP approved refrigerants not listed in codes could require AHJ approval.

• Chillers in Mechanical Rooms
  – SNAP approved A2L refrigerants could be used in equipment certified to UL 60335-2-40 (2nd Edition) after States update their codes to reflect the updated A2L requirements from ASHRAE 15 and the model building codes.

• Unitary and Residential
  – SNAP approved A2L refrigerants could be used in equipment certified to UL 60335-2-40 (3rd Edition) after States update their codes to reflect the updated A2L requirements from ASHRAE 15 and the model building codes.
<table>
<thead>
<tr>
<th>Equipment</th>
<th>Progress on Allowing A2L Refrigerants for HVAC in U.S. Codes and Standards</th>
<th>Est. Timing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outdoor Chillers</td>
<td><strong>UL Listing</strong> - No UL listing is currently available since UL 1995 does not address flammable refrigerants. but UL 60335-2-40 (2nd Edition), which provides compliance with UL 1995, is on track to allow Class A2L refrigerants.</td>
<td>2016</td>
</tr>
<tr>
<td></td>
<td><strong>ASHRAE 15</strong> is silent on flammable refrigerants in indirect systems (e.g. chillers) outside mechanical rooms.</td>
<td>Complete</td>
</tr>
<tr>
<td></td>
<td>Model codes already require compliance with UL 1995 and ASHRAE 15</td>
<td>Complete</td>
</tr>
<tr>
<td></td>
<td>State codes already reference UL 1995 and ASHRAE 15.</td>
<td>Complete</td>
</tr>
<tr>
<td>Chillers in Mechanical Rooms</td>
<td><strong>UL Listing</strong> - UL 60335-2-40 (2nd Ed.) to enable A2L refrigerants in indirect systems</td>
<td>2016</td>
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<td></td>
<td><strong>ASHRAE 15</strong> to include requirements for use of A2L refrigerants</td>
<td>2017</td>
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<tr>
<td></td>
<td>Model codes to adopt updated A2L provisions from ASHRAE 15</td>
<td>2021</td>
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<tr>
<td></td>
<td>State codes to reference updated A2L provisions in the 2021 model codes</td>
<td>TBD</td>
</tr>
<tr>
<td>Unitary and Residential</td>
<td><strong>UL Listing</strong> - UL 60335- 2-40 (3rd Edition) to enable A2L refrigerants in direct systems</td>
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</table>
There are no existing broad-market bans for the use of R134a and R410A in commercial air conditioning equipment
Today’s refrigerant choices are determined by availability, legislation, cost, safety, building codes, service & operator capabilities and local design practices.

<table>
<thead>
<tr>
<th>Today’s Choices</th>
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<tbody>
<tr>
<td><strong>Mobile AC</strong></td>
</tr>
<tr>
<td>- R134a, R1234yf</td>
</tr>
<tr>
<td>- Carbon dioxide</td>
</tr>
<tr>
<td><strong>Comm Refrig</strong></td>
</tr>
<tr>
<td>- R404A, R407C, R507A, R134a, R1234yf</td>
</tr>
<tr>
<td>- Carbon dioxide</td>
</tr>
<tr>
<td><strong>Chillers</strong></td>
</tr>
<tr>
<td>- R134a, R410A</td>
</tr>
<tr>
<td>- Ammonia, water</td>
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<tr>
<td><strong>Heat Pumps</strong></td>
</tr>
<tr>
<td>- R134a, R410A, R245fa</td>
</tr>
<tr>
<td>- Ammonia, carbon dioxide</td>
</tr>
<tr>
<td><strong>Residential</strong></td>
</tr>
<tr>
<td>- R410A, R32</td>
</tr>
<tr>
<td><strong>Room AC</strong></td>
</tr>
<tr>
<td>- R410A, R32</td>
</tr>
<tr>
<td>- Carbon dioxide, propane</td>
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</tbody>
</table>

* Source: Benefits of Addressing HFCs under the Montreal Protocol, June 2013
Some changes can be expected, but will be application-specific changes & will consider lifetime emissions due to design, maintenance, disposal, etc.

<table>
<thead>
<tr>
<th>Today’s Choices</th>
<th>Potential Future Choices</th>
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<tr>
<td><strong>Mobile AC</strong></td>
<td><strong>R134a, R1234yf</strong></td>
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<td>Carbon dioxide</td>
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<td><strong>Comm Refrig</strong></td>
<td><strong>R404A, R407C, R507A, R134a</strong></td>
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<td><strong>Chillers</strong></td>
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<td><strong>Room AC</strong></td>
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<td>Carbon dioxide, propane</td>
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<tr>
<td></td>
<td><strong>R1234yf</strong></td>
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<td></td>
<td>Carbon dioxide, R152a</td>
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<td><strong>HFO blends, ammonia, hydrocarbons, CO2</strong></td>
</tr>
<tr>
<td></td>
<td><strong>R134a, R410A, R32, R1234ze, R1336mz, R1233zd, HFC/HFO blends</strong></td>
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<tr>
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<td><strong>Ammonia, water (absorption)</strong></td>
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<tr>
<td></td>
<td><strong>R134a, R410A, R245fa, R32, HFC/HFO Blends, ???</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Ammonia, carbon dioxide</strong></td>
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<td><strong>R32, HFOs, HFO blends, hydrocarbons</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Hydrocarbons, CO2, R32, R1234yf, HFC/HFO Blends</strong></td>
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</table>

* Green text indicates refrigerant is available, approved for use and in-use in volume today

* Source: Benefits of Addressing HFCs under the Montreal Protocol, June 2013
To reduce greenhouse gas emissions, focusing only on a refrigerant’s GWP can lead to unintended consequences for the environment.
Environmental Impact: To make correct decisions regarding refrigerant choice, it is important to first understand how it’s use affects our environment.

With proper design, installation, operation, and maintenance – equipment leakage can be nearly zero.

Based on energy source mix of power generation [renewable vs. fossil fuels], the indirect environmental impact can be very significant.
Here is the typical chiller’s carbon footprint.

If you completely eliminate the refrigerant charge…

(which eliminates all of the direct global warming potential)

How much of the carbon footprint remains?
Here is the typical chiller’s carbon footprint.

If you completely eliminate the refrigerant charge…

(which eliminates all of the direct global warming potential)

How much of the carbon footprint remains?

95% of the total global warming impact is indirect emissions of CO2 due to electric energy usage, production and disposal of the equipment.
Energy consumption over the life of the system has a greater impact on carbon footprint than refrigerant GWP.

Lower GWP alternative can not be at cost of efficiency.
A holistic life-cycle cost and climate performance view of your HVAC&R system provides you with the best operating cost and environmental performance.

**Direct**

**Appropriate Actions**
- Minimize refrigerant charge
- Leak detection
- Reclaim and re-use

i.e. European F-gas regulations

**Indirect**

**Appropriate Actions**
- Evaluate investment in HVAC system based on life cycle cost and climate performance
- Invest in service to maintain operating performance and cost

i.e. EcoDesign, ASHRAE 90.1
Reliability: New refrigerants require evaluation and testing to ensure long-term product dependability

Chillers are unique in compared to other stationary equipment because the design life can be 15-40 years.

New refrigerants require evaluation to ensure long term product reliability:

- Compatibility with components in the chiller system:
  - Lubrication oils
  - Metals (Cl containing compounds like 1233zd(E) require special consideration)
  - Gaskets
  - O-rings
  - Thread locking compounds
  - Charging hoses and recover equipment
  - Pressure transducers, temperature probes, etc.
  - Valves and pressure relief systems
  - Leak detection devices
Reliability: New refrigerants require evaluation and testing to ensure long-term product dependability (Continued)

- Stability in the presence of air and moisture
  - Tube leaks
  - Poor maintenance practices
  - Low pressure systems leak air into the evaporator
  - Moisture can create acids with some refrigerants
  - Air and water can degrade the lubricating oil in the systems
  - Hydroxyl groups can be contained in air

- Stability of the molecule in the presence of high temperatures (>100°C)
  - Motor windings in hermetic/semi-hermetic systems
  - Thrust bearing faces
  - High discharge temperatures
  - Heat pump and heat recovery applications
  - Isomerization potential and impact
1. HCFCs are no longer viable options.

2. HFO offerings may be viable once proven to be safe, cost effective, efficient, and reliable, and when commercially available in local markets. Reliability needs further testing for long-term stability and material compatibility.

3. Natural refrigerants commonly found in refrigeration applications and are suitable where efficiency is better than HFC alternatives, and where they can be used safely and efficiently.

4. Life-cycle cost and climate performance is more important to carbon footprint than refrigerant type.

5. R134a and R410A are your best choices available today, that are efficient, safe, affordable and reliable. They are not subject to bans, and will continue to be available for the life of equipment purchased today and beyond.