Refrigerants Update

Rajan Rajendran
Emerson Climate Technologies, Inc.
September 19, 2011
Environmental Drivers Affecting Industry

• Ozone Depletion Effect
  – Protective Ozone Layer Damaged By Chlorine & Bromine Gases
  – Montreal Protocol In September 16, 1987
    • Bans CFCs
    • HCFC R22 Elimination

• Climate Change Effect
  – “Greenhouse Gases” Contribute To Global Warming Is Theory
  – Kyoto Protocol (1997) Aims To Curb All Greenhouse Gases
  – Most Refrigerants In Use Today Are Classified As Greenhouse Gases
Ozone Depletion & Montreal Protocol

UV Protection by the Ozone Layer

Antarctic Ozone Hole

Montreal Protocol Agreement For Reducing ODP Refrigerants: R-22 Phase-Out Timeline

* All Reference Material Sourced From:
UNEP Ozone Layer Q&A
TWENTY QUESTIONS AND ANSWERS ABOUT THE OZONE LAYER
URL: http://www.epa.gov/Ozone/science/unepSciQandA.pdf
AHRI Sponsored Research - Alternative Refrigerant Evaluation Program (AREP)

**TABLE 1**
R-22 ALTERNATIVE REFRIGERANTS EVALUATION PROGRAM
LIST OF PARTICIPATING COMPANIES

<table>
<thead>
<tr>
<th>NORTH AMERICAN</th>
<th></th>
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<tbody>
<tr>
<td>Bristol Compressors</td>
<td>National Research Council of Canada</td>
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<tr>
<td>Carrier Corporation</td>
<td>Rheem Manufacturing Company</td>
<td></td>
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<tr>
<td>Copeland Corporation</td>
<td>Snyder/General Corporation</td>
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<tr>
<td>Dunham-Bush, Inc.</td>
<td>Tecumseh Products Company</td>
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<tr>
<td>Hussmann Corporation</td>
<td>Thermo King Corporation</td>
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<tr>
<td>Inter-City Products Corporation</td>
<td>The Trane Company</td>
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<tr>
<td>Lennox Industries, Inc.</td>
<td>Tyler Refrigeration Company</td>
<td></td>
</tr>
<tr>
<td>Matsushita Compressor Corporation of America</td>
<td>Wolverine Tube, Inc.</td>
<td>York International Corporation</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>EUROPEAN</th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Aspera Whirlpool Italia Srl</td>
<td>Officine Mario Dorin</td>
<td></td>
</tr>
<tr>
<td>Bitter Kühlmachinesbau GmbH</td>
<td>Stal Refrigeration AB</td>
<td></td>
</tr>
<tr>
<td>Bock GmbH &amp; Co. Kältemaschinen</td>
<td>Sulzer Brothers, Ltd.</td>
<td></td>
</tr>
<tr>
<td>Grasso Products BV</td>
<td>Unidad Hernética, S.A.</td>
<td></td>
</tr>
<tr>
<td>Novechi Compressori Srl</td>
<td>Zanussi Elettromeccanica SpA</td>
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<table>
<thead>
<tr>
<th>JAPANESE</th>
<th></th>
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<tbody>
<tr>
<td>Daikin Industries, Ltd.</td>
<td>Mitsubishi Electric Corporation</td>
<td></td>
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<tr>
<td>Hiachi, Ltd.</td>
<td>Mitsubishi Heavy Industries, Ltd.</td>
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<tr>
<td>Kobe Steel, Ltd.</td>
<td>Sanden Corporation</td>
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<tr>
<td>Matsushita Electric Industrial Company, Ltd.</td>
<td>Sanyo Electric Company, Ltd.</td>
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<tr>
<td>Matsushita Refrigeration Company</td>
<td>Sharp Corporation</td>
<td></td>
</tr>
<tr>
<td>Mayekawa Manufacturer Company, Ltd.</td>
<td>Toshiba Corporation</td>
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**TABLE 2**
ALTERNATIVE REFRIGERANTS FOR TESTING AND EVALUATION IN AREP

<table>
<thead>
<tr>
<th>Refrigerant or Refrigerant Blend</th>
<th>Percent Composition (by weight)</th>
<th>Baseline Reference</th>
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</thead>
<tbody>
<tr>
<td>R-134a</td>
<td>100</td>
<td>R-22</td>
</tr>
<tr>
<td>R-290 (propane)</td>
<td>100</td>
<td>R-22</td>
</tr>
<tr>
<td>R-717 (ammonia)</td>
<td>100</td>
<td>R-22</td>
</tr>
<tr>
<td>R-32/125</td>
<td>60/40</td>
<td>R-22</td>
</tr>
<tr>
<td>R-32/134a</td>
<td>20/80</td>
<td>R-22</td>
</tr>
<tr>
<td>R-32/134a</td>
<td>25/75</td>
<td>R-22</td>
</tr>
<tr>
<td>R-32/134a</td>
<td>30/70</td>
<td>R-22</td>
</tr>
<tr>
<td>R-32/134a</td>
<td>40/60</td>
<td>R-22</td>
</tr>
<tr>
<td>R-32/227ea</td>
<td>35/65</td>
<td>R-22</td>
</tr>
<tr>
<td>R-125/143a</td>
<td>45/55</td>
<td>R-22</td>
</tr>
<tr>
<td>R-32/125/134a</td>
<td>10/70/20</td>
<td>R-22</td>
</tr>
<tr>
<td>R-32/125/134a</td>
<td>24/16/60</td>
<td>R-22</td>
</tr>
<tr>
<td>R-32/125/134a</td>
<td>30/10/60</td>
<td>R-22</td>
</tr>
<tr>
<td>R-32/125/290/134a</td>
<td>20/55/5/20</td>
<td>R-22</td>
</tr>
<tr>
<td>R-125/143a</td>
<td>45/55</td>
<td>R-502</td>
</tr>
<tr>
<td>R-32/125/134a</td>
<td>20/40/40</td>
<td>R-502</td>
</tr>
<tr>
<td>R-32/125/143a</td>
<td>10/45/45</td>
<td>R-502</td>
</tr>
<tr>
<td>R-125/143a/134a</td>
<td>44/52/4</td>
<td>R-502</td>
</tr>
</tbody>
</table>

**Notes:**
- Refrigerants are not listed in any particular ranking order.
- Compositions are nominal, and do not include deviations of charged or circulating compositions from nominal.

- AREP Results Led To Selection Of R134a, R404A, R407C & R410A In Various Applications
- Higher Pressure Refrigerants Like R410A Performed Better In Actual Systems; Adoption In Efficiency Regulated AC Applications Grew In US/Europe
Global Warming & Impact Of HFCs

Greenhouse Effect & Global Warming Concerns

- Some of the infrared radiation passes through the atmosphere, and some is absorbed and re-emitted in all directions by greenhouse gas molecules. The effect of this is to warm the Earth’s surface and lower atmosphere.
- Solar radiation passes through the clear atmosphere.
- Infrared radiation is emitted from the Earth’s surface.
- Most radiation is absorbed by the Earth’s surface and warms it.

What Is The Effect Of HFCs On Global Warming?

- CO₂ Equivalent
- CO₂
- Methane
- N₂O
- HFCs
- PFCS, & SF₆


Direct Effect (Emission) Is Small

Indirect Effect Is Large Due To Impact On Energy Efficiency

Less Than 2% Of Greenhouse Gas Emissions From HFCs (Adjusting These Gases To CO₂ Equivalent Warming Impact)

10% Of Global Carbon Emissions (And Energy Use) Due To Refrigeration, A/C And Heat Pumps

High GWP HFCs Coming Under Pressure To Be “Phased-Down” Or “Eliminated”

North American Proposal For Consumption Phase-Down Of HFCs’ GWP

Efforts To Make NAP Part Of Montreal Protocol Continue – Over 91 Countries Signed On So Far
Global Warming Potential (GWP) & Values For Some Refrigerants (IPCC-AR4 Report)

- Measure Of How Much Given Mass Of Greenhouse Gas Is Estimated To Contribute To Global Warming

- Relative Scale, Compares Gas To Same Mass Of Carbon Dioxide (Whose GWP By Convention Is 1)

- GWP Is Calculated Over A Specific Time Interval, Typically 100 Years

- Intergovernmental Panel On Climate Change (IPCC), A UN Body Issues Reports That, Among Other Things, Updates The GWP Values For Various Global Warming Gases

**Selected Refrigerant GWPs**

<table>
<thead>
<tr>
<th></th>
<th>SAR 1995</th>
<th>TAR 2000 Used by F-Gas</th>
<th>AR4 2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>HFCs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HFC-32</td>
<td>650</td>
<td>550</td>
<td>675</td>
</tr>
<tr>
<td>HFC-134a</td>
<td>1300</td>
<td>1300</td>
<td>1430</td>
</tr>
<tr>
<td>R-407A</td>
<td>1770</td>
<td>1990</td>
<td>2107</td>
</tr>
<tr>
<td>R-407C</td>
<td>1526</td>
<td>1653</td>
<td>1774</td>
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<tr>
<td>R-404A</td>
<td>3260</td>
<td>3784</td>
<td>3922</td>
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<tr>
<td>R-410A</td>
<td>1725</td>
<td>1975</td>
<td>2088</td>
</tr>
<tr>
<td>R-507</td>
<td>3300</td>
<td>3850</td>
<td>3985</td>
</tr>
<tr>
<td>R-422D</td>
<td>2232</td>
<td>2623</td>
<td>2729</td>
</tr>
<tr>
<td>R-427A</td>
<td>1826</td>
<td>2013</td>
<td>2138</td>
</tr>
<tr>
<td>HCFC-22</td>
<td>1500</td>
<td>1700</td>
<td>1810</td>
</tr>
</tbody>
</table>

For comparison not covered by F-Gas or Kyoto

GWP – Is Important But Not The Only Measure Of Environmental Impact!

Refrigerants Should Be Measured On Life Cycle Performance – TEWI Or LCCP

TEWI (Total Equivalent Warming Index)

10% Global Warming Impact

= Direct Global Warming + Indirect Global Warming

Refrigerant Leakage

• Leak During Life
• End Of Life Recovery Leak
• Leak During Production

Energy Consumption

• Energy Used During Life
• Source Of Energy
• Embodied Energy Of All Material Used For Manf. Of Fluid

Adding This Makes It Life Cycle Climate Performance, “LCCP”
Life Cycle Performance: Typical Low Charge Systems (AC, Heat Pump, Reach-In, Walk-In, Transport Applications)

- **For Hermetic Systems, Global Warming Is An Efficiency Issue***
  (Therefore, Future Refrigerants Must Be Equal Or Higher Efficiency)

* Simple Analysis To Show Relative Impact Only; Not Based On Field Data
**Life Cycle Performance: Typical Large Refrigeration Systems**

For Large Systems, Global Warming Becomes An Efficiency Issue If Charge/Leaks Are Reduced

*Therefore, Future Refrigerants Must Be Equal Or Higher Efficiency*

* Simple Analysis To Show Relative Impact Only; Not Based On Field Data
Emerging Low GWP Candidates

Whatever The Regulation, Low GWP Refrigerants Will Be Needed In Future...

Current Applications

Unitary A/C
Small Chillers
(OEM/Service?)

Refrigeration
(OEM/Service?)
AC Service?

Large Chillers
Refrigeration
Mobile
(OEM/Service?)

Pressure
Or Capacity

New LGWP Refs
“For OEM Use”

R-410A-Like
R404A-Like
R407-Like
R22-Like
R134a-Like

New “Replacement Refs”

Today’s Refs

R410A
R404A
R407C
R407A
R134a

HFO 1234yf
HFO 1234ze

DP: DR5
HWL: L41

A2L
400-675

DP: DR7
HWL: L40, L20
A2L
150-300

DP: ?
HWL: N20, N40
A1
< 1500

DP: XP10
HWL: N13
A1
~600

Source: Papers by DuPont, Honeywell, Daikin, Panasonic, Mitsubishi Electric
NEDO Symposium 2/17/2010 Japan
Purdue Refrigeration Conf July 2010
ASHRAE Jan 2011

Feb 24, 2011: US EPA Approves HFO 1234yf For Use In Automobile AC Applications – New Systems
Holistic Approach To Refrigerant Selection

Review Topics In This Order……

1. Physical Properties
2. Environment
   - GWP & (TEWI/LCCP)
3. Safety

Toxicity
(Montreal Protocol)
Stratospheric Ozone

Performance
- Energy (Annual/Peak) Capacity

Economics
- Total Cost

Integrated Analysis
Leading To The Selection Of The Best Refrigerant

* Key Hurdles
Search For Lower GWP Refrigerants – Performance Evaluation Steps

• Five Basic Steps In Performance Evaluation:
  1. Compare Saturation Pressure – Temperature (P-T) Data
  2. Perform Simple Thermodynamic Analysis
  3. Perform Analysis (Performance/TEWI) Including System Effects
     1. Pressure Drop
     2. Heat Transfer
     3. Discharge Temperature Effects (Additional Cooling)
     4. High Condensing, Low Condensing Temperatures
     5. Annual & Peak Power Consumption
  4. Perform “Drop-In” System Tests/TEWI Analysis
  5. Perform “Soft-Optimized” System Tests/TEWI Analysis
  6. Continue To Optimize & Improve System Performance

Decision After Step 2 Without Step 3 Could Be Erroneous…!
**Difference Between Simple Thermodynamic Analysis & System Analysis**

Cavallini et al Propose A “Penalty Factor” (PF) For Analytical Consideration Of System Effects

- PF = Pressure Drop Impact + Heat Transfer Impact
- Lower PF Is Better For System Performance
- PF Leads To “Two Temperature Penalty” (TTP) Term For Refrigerant Side

- TTP = Pr Drop Temperature Effect + Heat Transfer Temperature Effect

Condenser Example, TTP For:
- R32 = 1.37K; R410A = 1.83K; R134a = 3.19K
### Annual & Peak Power Comparison Also Important (AC System Example)

#### SEER Comparison (cooling mode)

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>Charge Volume (kg)</th>
<th>Efficiency Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>R22</td>
<td>1.14</td>
<td>0.8</td>
</tr>
<tr>
<td>HFO1234yf</td>
<td>1.32</td>
<td>0.9</td>
</tr>
<tr>
<td>R32</td>
<td>0.84</td>
<td>1.0</td>
</tr>
<tr>
<td>Propane</td>
<td>0.37</td>
<td>1.1</td>
</tr>
<tr>
<td>CO2</td>
<td>0.84</td>
<td>1.3</td>
</tr>
<tr>
<td>R410A</td>
<td>1.2</td>
<td>1.0</td>
</tr>
</tbody>
</table>

#### Peak power comparison (R410 ratio) under cooling condition

Outside 35°C, room 27°C DB, 19.5°C WB

- If IEC is disregarded, the charge volume is 0.58kg, and SEER could be same as R22

Consideration:
- In terms of SEER, CO2 is the worst, and the rest of candidates are equivalent to R410A.

(Precondition for Calculation) Note: HX = Heat Exchanger
- *1 Taking low pressure loss into consideration, narrower heat exchanger was used to reduce charge volume.
- *2 To improve efficiency, HX size was increased: Indoor HX x 1.1 + Path x 2, Outdoor HX x 1.2, and connecting pipe increased from 3/8 -> 5/8
- *3 To meet IEC requirements, charge volume was reduced: Indoor HX x 0.8, Outdoor HX x 0.5, narrower piping was used.
- *4 To improve efficiency: Outdoor unit HX was increased x 1.1

Consideration:
- A big difference exists in the peak power under cooling condition. HFO and CO2 will cause peak power supply problems in large cities.
R32 + HFOs Blends Perform Well Compared To Today’s HFCs - Refrigeration

HFO Blends for Stationary Applications

<table>
<thead>
<tr>
<th>N Series (A1)</th>
<th>L Series (A2L)</th>
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</thead>
<tbody>
<tr>
<td>Current Product</td>
<td>Reduced GWP Option (Non-flammable)</td>
</tr>
<tr>
<td>R-404A GWP=3922</td>
<td>N-40 GWP ~1300 (retrofit)</td>
</tr>
<tr>
<td>HCFC-22 GWP=1810</td>
<td>N-20 GWP ~1000</td>
</tr>
<tr>
<td>HFC-134a GWP=1430</td>
<td>N-13 GWP ~600</td>
</tr>
<tr>
<td>R-410A GWP=2088</td>
<td></td>
</tr>
</tbody>
</table>

Supermarket Freezer Cases (LT)
Supermarket/Deli Cases (MT)

> 50% GWP Reduction From R-404A
> 65%
> 90%

All options offer significantly improved efficiency & GWP reduction compared to R-404A

R-422 Replacements in Refrigeration: Options with Lower GWP than R-404A

R407-Series Of HFCs Would Be Similar (RR Note)

**R32 + HFOs Blends Perform Well Compared To Today’s HFCs – Air Conditioning**

Stationary Air Conditioning: L-20 & N-20 as Replacements in Equipment Designed for R-22

- L-20 offers a significant GWP reduction with respect to R-22 (over 80%)
- Non-flammable N-20 offers close to 50% reduction

Stationary Air Conditioning: L-41 as Replacement for R-410A

- L-41 offers a significant GWP reduction with respect to R-410A (over 75%)

**DuPont’s XP10 Compared To R134a**

<table>
<thead>
<tr>
<th></th>
<th>R-134a</th>
<th>XP10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical Formula</td>
<td>CF₃CH₂F</td>
<td>Azeotrope</td>
</tr>
<tr>
<td>100 yr GWP (AR4)</td>
<td>1430</td>
<td>near 600</td>
</tr>
<tr>
<td>Toxicity/Flammability</td>
<td>A1</td>
<td>A1 expected</td>
</tr>
<tr>
<td>Boiling Point °C (°F)</td>
<td>-26 (-15)</td>
<td>-29 (-20)</td>
</tr>
<tr>
<td>Critical Point °C (°F)</td>
<td>101 (214)</td>
<td>98 (208)</td>
</tr>
<tr>
<td>Temperature Glide °C (°F)</td>
<td>0</td>
<td>Negligible (Azeotrope)</td>
</tr>
</tbody>
</table>

**Calorimeter Testing in a Recip Compressor**
- EER 2% higher, Capacity 5% higher on average

**Calorimeter Testing in a Scroll Compressor**
- EER 1% lower, Capacity 5% higher on average

*Experimental Study Of R134a Alternative In A Supermarket Refrigeration System by Barbara Minor, Dr. Frank Rinne, Dr. Katan Salem. Ashrae Annual Meeting, Montreal, Canada, June 26-29, 2011*
**DuPont’s XP10 Compared To R134a**

**Energy Consumption Comparison**

XP10 energy consumption is 3.3% lower than R-134a.

**System Operating Temperatures**

Operating temperatures are similar.

**Data Becoming Available From Chemical Manufacturers On Lower GWP Options**

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Experimental Study Of R134a Alternative In A Supermarket Refrigeration System by Barbara Minor, Dr. Frank Rinne, Dr. Katan Salem.
Ashrae Annual Meeting, Montreal, Canada, June 26-29, 2011
Public R-32/1234yf Blend AC System Data – Trade Off Between GWP & Efficiency

Source: Panasonic, Mitsubishi, Daikin, DuPont, Honeywell Papers from Univ. Tokyo, NEDO Symposium 2/17/2010 Japan & Purdue Refrigeration Conf July 2010

A/C Efficiency vs. R-410A

Range Of Low GWP Without Loss Of Efficiency - Good TEWI

Significant Efficiency Penalty With Pure HFO-1234yf
Energy Consumption Becomes The Largest Driver Of Emissions – Lowest GWP Does Not Equal Best Life Cycle Performance

* 3-ton A/C, 2% Leak, 15-yr Life, 0.65 kg CO2/kwh
Supermarket Example - Architecture Can Reduce Equivalent CO$_2$ Emissions By 46–57%

Estimated Total Equivalent Warming Impact (TEWI), lbs of CO$_2$/yr

- **Centralized DX Racks**
  - LT Indirect
  - MT Indirect
  - LT Direct
  - MT Direct
  - Base

- **Distributed DX**
  - Base

- **Parallel Secondary**
  - Base

- **Compact Secondary**
  - Base

- **Cascade CO2**
  - Base

- **Comparison Contains Multiple Assumptions & Should Be Used For General Comparisons. Emerson Recommends Completing Similar Analysis On Specific Store Cases Before Making Decisions As Results May Change Based On Store Specifics.**
  - **Fixed Load; US Avg 0.65 kg CO2/kWh; Parameters Held Constant Expect For Architecture.**
AHRI Study Announced For Low GWP Refrigerants

• Low GWP AREP Objectives
  – Identify Potential Replacements For Today’s High GWP HFCs
  – Test & Present Performance In A Consistent & Standard Manner
  – A/C, Heat Pumps, Dehumidifiers, Chillers, Water Heaters, Ice Makers, Refrigeration

• Testing Approach For Evaluation
  – Compressor Calorimeter
  – System Drop-In
  – Soft-Optimized System
  – Heat Transfer

• Global In Scope; Started July 2011, Complete December 2012 – Over 36 Candidates Submitted For Study

Reports Will Be Released For Public Use By AHRI
Holistic Approach To Refrigerant Selection

Integrated Analysis
Leading To The Selection Of The Best Refrigerant
Refrigerant Safety Groups


New Classification – Applies To Most Low GWP Candidates

<table>
<thead>
<tr>
<th>Refrigerant Safety Groups (ASHRAE 34 and ISO 817)</th>
<th>Lower Toxicity</th>
<th>Higher Toxicity#</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Flame Propagation</td>
<td>A1</td>
<td>B1 (includes R123)</td>
</tr>
<tr>
<td>2L</td>
<td>A2L (includes HFO 1234 YF)</td>
<td>B2L (includes ammonia)</td>
</tr>
<tr>
<td>Lower Flammability</td>
<td>A2</td>
<td>B2</td>
</tr>
<tr>
<td>Higher Flammability</td>
<td>A3 (includes hydrocarbons)</td>
<td>B3</td>
</tr>
</tbody>
</table>

# Except for ammonia, refrigerants classified as Bx are not permitted in appliances.
Flammability is evaluated by ‘Chance of Flame occurring’ and ‘Effect of Flame occurring’.

- **Chance of Flame occurring** -> Lower Flame Limit, Minimum Ignition Energy

![Diagram showing Minimum Ignition Energy (MIE) and Lower Flame Limit (LFL)]

**Easy To Ignite**

- Acetylene
- Propane
- Methane
- Iso-Butane
- Ammonia

**Difficult To Ignite**

- R-152a
- Refrigerant R-32
- HFO-1234yf

> 5000 times more energy to ignite!

**Small Leak Can Ignite**

**Large Leak To Ignite**

Reference: Low GWP Refrigerant Options For Unitary AC & Heat Pumps – Mark Spatz, ASHRAE Jan 2011
Flammability is evaluated by ‘Chance of Flame occurring’ and ‘Effect of Flame occurring’.
- Effect of Flame occurring -> Burning Velocity, Heat of Combustion

**Burning Velocity – Basis For 2 & 2L Classification**

Reference: Low GWP Refrigerant Options For Unitary AC & Heat Pumps – Mark Spatz, ASHRAE Jan 2011

Emerson Confidential
Flammability Impact During Life Of System: R290 Risk Assessment In Japan

While risk of R290 (propane) can be addressed with several measures (e.g., forced fan operation to lower concentration below LFL), repair and disposal risks remain considerable high.


Estimated Incidents/year in Japan with R290 room air conditioners, after Measures

- Human errors during repair & disposal, which is beyond the control of manufacturers
- During repair & disposal there is no power supply for the unit, so measures such as forced fan operation do not work.

Repair & Disposal Pose Biggest Challenge

Copyright Daikin, OEWG 31 Montreal 11

The Road To Next Generation Refrigerants For Stationary Air-Conditioners, Heat Pumps & Chillers - Daikin’s Viewpoint
Hilde Dhont _ Daikin Europe; EPEE side event, OEWG31, 2 August 2011, Montreal
# Global A2L Regulatory Activities

<table>
<thead>
<tr>
<th>Standards Working Group</th>
<th>Focus Of Standards Activity For A2L Refrigerants</th>
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<tbody>
<tr>
<td>ISO (Intl.)</td>
<td>ISO 5149 Safety &amp; Use; General equipment requirements</td>
</tr>
<tr>
<td>IEC 60335-2-40</td>
<td>AC &amp; Heat Pump application equipment &amp; use requirements</td>
</tr>
<tr>
<td>IEC 60335-2-89</td>
<td>Commercial refrigeration application equipment &amp; use requirements</td>
</tr>
<tr>
<td>CEN (EU)</td>
<td>EN 378 Safety &amp; Use; General equipment requirements</td>
</tr>
<tr>
<td>EN-IEC 60335-2-40</td>
<td>AC &amp; Heat Pump application equipment &amp; use requirements</td>
</tr>
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<td>EN-IEC 60335-2-89</td>
<td>Commercial refrigeration application equipment &amp; use requirements</td>
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<tr>
<td>ASHRAE (US/Intl)</td>
<td>Standard 15 Safety &amp; Use; General equipment requirements</td>
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<tr>
<td>UL (US)</td>
<td>Working Group #1 AC &amp; Heat Pump application equipment &amp; use requirements (UL 1995)</td>
</tr>
<tr>
<td>Working Group #2</td>
<td>Commercial refrigeration application equipment &amp; use requirements (UL 250, UL 471)</td>
</tr>
<tr>
<td>Working Group #3</td>
<td>Refrigerant chemistry &amp; requirements</td>
</tr>
<tr>
<td>China</td>
<td>R32 A2L Committee Develop R32 specific application requirements – AC, Heat Pump, Ref</td>
</tr>
</tbody>
</table>

**A2L Refrigerant Use Rules Only Now Being Developed Worldwide**
**Refrigerant Options To Replace HFCs – High Level Summary (AC & Ref)**

<table>
<thead>
<tr>
<th></th>
<th>Current HFCs</th>
<th>R32 (HFC)</th>
<th>HFO Blends</th>
<th>Carbon Dioxide</th>
<th>Hydrocarbons</th>
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<tbody>
<tr>
<td><strong>Global Warming Potential (GWP)</strong></td>
<td>~2,000 To 4,000</td>
<td>675</td>
<td>4-650</td>
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<td>&lt;10</td>
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<tr>
<td><strong>Compressor Design &amp; Cost</strong></td>
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<tr>
<td><strong>Energy Efficiency</strong></td>
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<td><strong>Safety</strong></td>
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<td>Highly Flammable</td>
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<td><strong>Refrigerant Cost</strong></td>
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<td><strong>System Cost</strong></td>
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</tbody>
</table>

*Future Refrigerants May Differ By Application & Region, More Than Today’s*
**Summary**

- Many New Lower GWP Refrigerant Candidates Becoming Available For Air Conditioning, Heat Pump And Refrigeration Applications
- Minimizing System’s Life Cycle Impact On Environment Should Be The Goal In Narrowing Choice
  - Reducing Leaks & Charge Through Systems Technology Changes Is Of Benefit Today & In The Future As Refrigerant Costs Increase
  - End Of Life Refrigerant Management Is Very Important
  - In Selecting Future Refrigerants, System Efficiency Impacts Energy Consumption, Its Cost Of Operation, And The Environment Should Be Kept Flat At A Minimum
- Important For Industry To Stay Engaged In:
  - “Low GWP AREP”, The AHRI Sponsored Study That Will Help Guide The Selection Process
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(937) 726 0620 – Cell