Role of Industry in implementation of HCFC Phase-out

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Agenda

Context and Background
Environmental Impact
Options for Tomorrow
Emerging Technologies and trends
Industry Initiatives towards National goals
Policy and Regulations ...
Industry Expectations
History

History of Refrigerants:
- 1834: CO₂, NH₃, HC - Natural refrigerants
- 1930: CFCs
- 1987: Montreal Protocol
- 1990: HCFCs
- 2010: HFOs, New synthetic refrigerants
- 2014: EU F-gas phase down
- 2020: CO₂, NH₃, HC - Natural refrigerants

Sustainable Technologies:
- Environmentally benign
- Safe in use
- Affordable
Refrigerant Progression

- **First Generation (1830-1930s)**
  - Whatever worked
  - Ethers, $\text{CO}_2, \text{NH}_3, \text{SO}_2,$
  - $\text{HCOOCH}_3, \text{HCs}, \text{H}_2\text{O},$
  - $\text{CCl}_4, \text{CHCs}, ...$

- **Second Generation (1931-1990s)**
  - Safety and Durability
  - CFCs, HCFCs, HFCs, $\text{NH}_3, \text{H}_2\text{O}, ...$

- **Third Generation (1990-2010s)**
  - Ozone Protection
  - (HCFCs), HFCs, $\text{NH}_3,$ $\text{H}_2\text{O}, \text{HCs}, \text{CO}_2, ...$

- **Fourth Generation (2010-2050w)**
  - Zero/low ODP, low GWP, short $\tau_{\text{atm}},$ high efficiency

**Future – Fifth Generation - ??**
ROADMAP FOR PHASE-OUT OF HCFCs IN INDIA

Figure-2: HCFC Phase-out Schedule for non-Article 5 Parties

Figure-3: HCFC Phase-out Schedule for Article 5 Parties

* Allowing 0.5% for servicing for the period 2020-2030

* Allowing for servicing an annual average of 2.5% during the period 2030-2040
Phase out dates for refrigerants

Figure 1. Legislative actions involving refrigerant

- **1990**: Montreal Protocol signed
  - All CFC production stopped (R-11, R-12) in developed countries

- **2000**: Kyoto Protocol went into effect
  - No CFCs for developing countries

- **2010**: No new R-22 for service in US, Canada
  - No new equipment with R-123 in developed countries

- **2020**: No new R-123 for service in developed countries, no HCFCs in new equipment in developing countries

- **2030**: No HCFC production in developing countries

- **2040**: Continued use of recycled R-22, R-123 for developing countries
  - Continued use of recycled R-123

- **2050**: Continued use of recycled R-22
  - Continued use of recycled CFCs

**Note:** Included in the use of "recycled" refrigerants is also the use of stockpiled supplies of the refrigerant produced before the phase-out date. In addition, there is no restriction on the importation of recycled and recovered supplies of refrigerant.
Refrigeration and Air Conditioning (RAC) applications, in the current era, touch our lives in far reaching areas with a wide range of fields. They have become essential not only for food security (post-harvest vegetable, fruit and grain storage, food processing and freezing), health security (healthcare, vaccine and pharmaceutical storage and cryosurgery), financial security (industrial development including IT, pharmaceuticals, chemicals, petrochemicals and many others) but also for human comfort (air conditioning). It is well known that with comfort air conditioning, the human productivity has increased. AC&R is now a backbone our lifestyle and also plays an important role in future sustainable development.
TEWI & Efficiency

Figure 2. Overview of the environmental impact of current refrigerants

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>Energy Efficiency (COP)</th>
<th>ODP (R-11=1.0)</th>
<th>GWP (CO₂=1.0) (000s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFC-11</td>
<td>3.0-6.5</td>
<td>1.0</td>
<td>2</td>
</tr>
<tr>
<td>CFC-12</td>
<td>3.0-6.0</td>
<td>0.8</td>
<td>4</td>
</tr>
<tr>
<td>HCFC-22</td>
<td>3.5-5.5</td>
<td>0.6</td>
<td>6</td>
</tr>
<tr>
<td>HCFC-123</td>
<td>4.0-6.0</td>
<td>0.4</td>
<td>8</td>
</tr>
<tr>
<td>HFC-134a</td>
<td>4.5-6.5</td>
<td>0.2</td>
<td>10</td>
</tr>
<tr>
<td>HFC-410A</td>
<td>5.0-6.5</td>
<td>0.0</td>
<td>12</td>
</tr>
<tr>
<td>HFC-32</td>
<td>5.0-6.5</td>
<td>some flammability</td>
<td></td>
</tr>
<tr>
<td>HFC-152a</td>
<td>5.0-6.5</td>
<td>some flammability</td>
<td></td>
</tr>
<tr>
<td>HFC-245fa</td>
<td>5.5-6.5</td>
<td>some flammability</td>
<td></td>
</tr>
<tr>
<td>HFO-1234yf</td>
<td>5.5-6.5</td>
<td>some flammability</td>
<td></td>
</tr>
<tr>
<td>R-290 (propane)</td>
<td>6.0-6.5</td>
<td>flammability</td>
<td></td>
</tr>
<tr>
<td>R-600a (isobutane)</td>
<td>5.5-6.5</td>
<td>flammability</td>
<td></td>
</tr>
<tr>
<td>R-744 (CO₂)</td>
<td>6.0-6.5</td>
<td>flammability &amp; toxicity</td>
<td></td>
</tr>
<tr>
<td>R-717 (ammonia)</td>
<td>6.5-6.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

lower efficiency higher
Alternatives to HCFCs - Desirable Characteristics

- Low GWP
- Zero ODP
- Low Toxicity
- VOC
- Low Cost

Alternatives to HCFCs

- Flammability?
- Similar or better Performance

There is no ideal Refrigerants – Always some compromise
Alternatives to HCFC-22 for ACs

HCFC-22
- Montreal Protocol
- ODP
- GWP

HFCs (R-410A & HFC-32)
- Zero ODP
- R-410A - High GWP
- HFC-32 – Low GWP?
- Low GWP Blends - Cost and Timeline (uncertain)

HC-290 & Blends
- Zero ODP
- Negligible GWP
- Better energy efficiency
- Flammability
- Emerging Standards?

CO2/NH3
- Zero ODP
- Negligible GWP
- Matl Compatibility, Technology, Efficiency,
## HCFC-22 Alternatives

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>$T_b$ (°C)</th>
<th>$T_c$ (°C)</th>
<th>LFL (kg/m³)</th>
<th>ODP</th>
<th>GWP</th>
</tr>
</thead>
<tbody>
<tr>
<td>HCFC-22</td>
<td>-41</td>
<td>96</td>
<td>-</td>
<td>0.055</td>
<td>1780</td>
</tr>
<tr>
<td>R-410A</td>
<td>-52</td>
<td>72</td>
<td>-</td>
<td>0</td>
<td>2000</td>
</tr>
<tr>
<td>HFC-134a</td>
<td>-26</td>
<td>101</td>
<td>-</td>
<td>0</td>
<td>1430</td>
</tr>
<tr>
<td>R-407C</td>
<td>-43</td>
<td>86</td>
<td>-</td>
<td>0</td>
<td>1800</td>
</tr>
<tr>
<td>HC-290</td>
<td>-42</td>
<td>97</td>
<td>0.038</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>R-744</td>
<td>-78</td>
<td>31</td>
<td>-</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>HC-1270</td>
<td>-48</td>
<td>92</td>
<td>0.040</td>
<td>0</td>
<td>3</td>
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<tr>
<td>HFC-1234yf</td>
<td>-29</td>
<td>95</td>
<td>0.293</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>HFC-161</td>
<td>-38</td>
<td>102</td>
<td>0.076</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>HFC-32</td>
<td>-52</td>
<td>78</td>
<td>0.306</td>
<td>0</td>
<td>675</td>
</tr>
</tbody>
</table>
Sustainability is the Key

Diagram showing various factors like Affordability, LLCC, Service, COP, Flammability, GWP, Leak tight, Toxicity, Environment, Safety, and Emissions with a focus on sustainability and efficiency.
Industrial Viability

1. Investment cost  | Investments in Product development
2. Life cycle cost  | Life cycle cost for the consumer. Contains up front cost and running cost
3. Complexity       | Complexity associated with manufacturing and marketing of the product
4. Risk Awareness   | Difference between perceived and actual risk using the product
5. Market Readiness | Market competence in safe adoption of new technologies and products
6. Technical Ability| Ability and competence in developing new products
Refrigerant Options

Facing regulatory pressures to eliminate refrigerants with high GWP, many alternatives are being proposed to replace the current high GWP HFCs.

To date, most attention has been given to new unsaturated fluorochemical molecules, especially R1234yf and R1234ze, both also known as HFOs. There are also other molecules proposed such as R1233zd and R1336mzz(\(Z\)), which have not yet received as much attention.
There is, however, a trade off between lower GWP and flammability. As seen on the figure 7, for most of the popular refrigerants there are no simple low GWP drop-in solutions. When low GWP substitutes are chosen flammability needs to be considered. The flammability seems to be linked with the capacity of the refrigerants; higher capacity comes with a higher flammability, while low capacity refrigerants like the HCFC R123 have non-flammable substitutes.
Safety Standards

**ASHRAE 15**: Linked to building regulations

**EN 378**: Linked to compliance with EU laws (MD and PED directives)

- **North America**: ASHRAE 15 or ISO 5149: Voluntary
- **South America**: ASHRAE 15 or ISO 5149: Voluntary
- **Europe**: ISO 5149: Mandatory
- **India**: ISO 5149: Available but voluntary
- **Australia & New Zealand**: AS/NZS 1677: Partly mandatory but changing to ISO 5149
In the graphic below, you can see an overview of refrigerants divided into classes depending on toxicity and flammability. A1 refrigerants are also called safety refrigerants. They have no flame propagation and have very low toxicity. On the other end of the scale, with high flammability and high toxicity, no refrigerants are available. Hydrocarbons are characterized by
<table>
<thead>
<tr>
<th>Increasing Flammability</th>
<th>Lower Toxicity</th>
<th>Higher Toxicity</th>
</tr>
</thead>
<tbody>
<tr>
<td>No flame Propagation</td>
<td>A1: CFC, HCFC, most HFCs</td>
<td>B1: Seldom used</td>
</tr>
<tr>
<td>Lower Flammability</td>
<td>A2L: Most HFOs, R32</td>
<td>B2L: Ammonia</td>
</tr>
<tr>
<td>Flammable</td>
<td>A2: R152</td>
<td>B2: Seldom used</td>
</tr>
<tr>
<td>Higher Flammability</td>
<td>A3: Hydrocarbons</td>
<td>B3: no refrigerants</td>
</tr>
</tbody>
</table>

Low toxicity and high flammability; special precautions have to be taken when dealing with these. Ammonia, on the other hand, has a high toxicity and low flammability. Ammonia is widely used, especially in industrial refrigeration, and is a very efficient and effective refrigerant.

A2L refrigerants are a new classification of refrigerants with low toxicity and a low flammability. The flame propagation speed is low and often these refrigerants are not able to sustain a flame once ignited. These refrigerants are assumed to play a significant role in the future, moving away from the old HFCs.
### Refrigerant properties

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>R22</th>
<th>R134a</th>
<th>R404A</th>
<th>R410A</th>
<th>R717 (NH₃)</th>
<th>R744 (CO₂)</th>
<th>R290 (propane)</th>
<th>R1234ze</th>
<th>R407A/F</th>
<th>R32</th>
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<tbody>
<tr>
<td>Efficiency</td>
<td>🔺</td>
<td>🔺</td>
<td>🔺</td>
<td>🔺</td>
<td>🔺</td>
<td>🔺</td>
<td>🔺</td>
<td>🔺</td>
<td>🔺</td>
<td>🔺</td>
</tr>
<tr>
<td>Safety</td>
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<td>🔺</td>
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<td>🔺</td>
</tr>
<tr>
<td>Environment (ODP, GWP)</td>
<td>🔺</td>
<td>🔺</td>
<td>🔺</td>
<td>🔺</td>
<td>🔺</td>
<td>🔺</td>
<td>🔺</td>
<td>🔺</td>
<td>🔺</td>
<td>🔺</td>
</tr>
<tr>
<td>Pressure &amp; temperature</td>
<td>🔺</td>
<td>🔺</td>
<td>🔺</td>
<td>🔺</td>
<td>🔺</td>
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<tr>
<td>Chemical properties</td>
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<td>🔺</td>
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<tr>
<td>Economic aspects</td>
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<td>🔺</td>
<td>🔺</td>
<td>🔺</td>
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<tr>
<td>Availability</td>
<td>🔺</td>
<td>🔺</td>
<td>🔺</td>
<td>🔺</td>
<td>🔺</td>
<td>🔺</td>
<td>🔺</td>
<td>🔺</td>
<td>🔺</td>
<td>🔺</td>
</tr>
</tbody>
</table>

Table 2: Properties of various refrigerants for Refrigeration, air conditioning and heat pump applications

- *: Some refrigeration applications
- **: Heat pumps, secondary media, and some refrigeration applications
- ***: Higher taxes (for instance in Nordic countries and Spain)
- ****: Restricted in developed countries
Assessment Metrics Of Primary Candidates

1. Compressor Capacity
2. System Impact
3. Environmental Impact
2. Heat Transfer Pressure Drop
2. No Glide
3. Non-Flammable A1
3. Low GWP (<150)
3. Non Toxic
1. Compressor Efficiency
1. Compressor Impact
1. Compressor & System Cost
Equivalent Replacement For HFCs?

- 3. Environmental Impact
- 3. Low GWP (<150)
- 3. Non-Flammable A1
- 2. Heat Transfer Pressure Drop
- 2. No Glide
- 2. System Impact
- 1. Compressor Efficiency
- 1. Compressor Impact
- 1. Compressor Capacity
- 1. Compressor & System Cost

- HC (R-290)
- R410A
- R-32
- CO₂
- HFO (1234yf)
ISHRAE Position Document on Refrigerants for Indian Refrigeration & Air Conditioning Industries - Challenges & Responsibilities
<table>
<thead>
<tr>
<th>Sector</th>
<th>Current Refrigerants Used</th>
<th>Alternative Refrigerants</th>
<th>Low GWP Refrigerants (GWP &lt; 750)</th>
<th>ISHRAE Assessment of Low GWP options for India</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Domestic Refrigeration</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single/Double Door</td>
<td>HC-600a, HFC-134a</td>
<td></td>
<td>HC-600a, HFC-1234yf,</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>HFC-1234ze</td>
<td></td>
</tr>
<tr>
<td><strong>Commercial Refrigeration</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stand-alone units (Display Cabinet, Water Cooler, Bottle Cooler, Visi Coolers, Ice Cream Cabinets and Chest Freezers)</td>
<td>HC-600a, HC-290, HCFC-22, HFC-134a, R-404A, R-744</td>
<td>HFC-134a, HC-600a, HC-290, R-404A, R-507A, R-407 (A, C or F)</td>
<td>HC-600a, HC-290, HFC-1234yf, HFC-1234ze, R-744</td>
<td></td>
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<tr>
<td><strong>Room ACs (1 to 1)</strong></td>
<td></td>
<td>R-407C, R-410A, HFC-32, HC-290, HFC-161</td>
<td>HFC-32, HC-290, R-446A, R-447A</td>
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</tr>
<tr>
<td><strong>Large ACs</strong></td>
<td></td>
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<tr>
<td><strong>VRF ACs</strong></td>
<td></td>
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</tr>
<tr>
<td><strong>Ducted, Packaged, Roof Top</strong></td>
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<td></td>
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<tr>
<td>Sector</td>
<td>Current Refrigerants Used</td>
<td>Alternative Refrigerants</td>
<td>Low GWP Refrigerants (GWP &lt; 750)</td>
<td>ISHRAE Assessment of Low GWP options for India</td>
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<td>-------------------------------------</td>
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<td>-----------------------------------------------</td>
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<tr>
<td>Mobile AC Car, Van</td>
<td>HFC-134a</td>
<td>HFC-152a, R-744, R-444A, R-445A</td>
<td>HFC-1234yf, R-744</td>
<td>HFC-1234yf, R-744</td>
</tr>
<tr>
<td>Bus, Truck, Train</td>
<td>HCFC-22, R-134a, R-407C</td>
<td>R-744, R-450A, R-513A,</td>
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<td>HFC-1234yf, R-744</td>
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<tr>
<td>Transport Refrigeration</td>
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<tr>
<td>Refrigerated Transport Supply Chain</td>
<td>HCFC-22, HFC-134a, R-404A</td>
<td>HFC-134a, R-407C, HFC-1234yf, R-744</td>
<td></td>
<td>None at the moment.</td>
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<tr>
<td>Industrial Refrigeration</td>
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<tr>
<td>Small and Medium Size</td>
<td>R-717, HCFC-22, HFC-134a</td>
<td>R-717, HFC-134a, R-407A, R-407F</td>
<td>R-717, HFC-1234ze</td>
<td>R-717</td>
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<tr>
<td>Large Industrial Chiller</td>
<td>R-717, HCFC-22, HFC-134a</td>
<td>R-717, HFC-134a</td>
<td>R-717, HFC-1234ze</td>
<td>R-717</td>
</tr>
<tr>
<td>Chillers</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Screw</td>
<td>HCFC-22, HFC-134a</td>
<td>HFC-134a</td>
<td>HFC-1234ze, HC-1270</td>
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<tr>
<td>Centrifugal</td>
<td>HFC-134a, HCFC-123</td>
<td>HFC-134a</td>
<td>HFC-1234ze, HCFO-1233zd, HFC-1336mzz</td>
<td></td>
</tr>
</tbody>
</table>
**HFCs**

HFC-134a is the most widely used across many RAC sectors. R-410A is currently the most popular alternative to HCFC-22 in AC sector. However, in view of the HFC phase down program, the long term future of HFC-134a and R-410A is uncertain. There is no immediate regulation restricting their use within India but may face problems when dealing with exports to some countries. Room ACs with HFC-32 are commercially available in many countries including India. It is yet to be approved by US-EPA SNAP for safety reasons. HFC-1234yf seems to be most favoured choice for mobile AC and has already been commercialised. Its use in other sectors is not yet certain. Trials using other HFOs for other RAC are underway and not yet commercialised.
ISHRAE POSITION ON REFRIGERANTS

ISHRAE is committed to the following:

- Environmental parameters are more critical than the traditional thermo-physical, thermodynamic and engineering parameters for the choice of refrigerants.
- To protect the environment, promote the use of refrigerants with zero ODP and low GWP, wherever suitable alternatives are available.
- For climate change benefits, energy efficiency is a key parameter for a given application.
- Use of flammable and toxic refrigerants mandates special requirements with respect to safety for systems and installations, for the place where they are located, and for the community who use or handle them.
- Develop and use advanced design and installation codes, guidelines and practices to reduce the direct refrigerant emissions.
- Develop and use advanced practices and standard operating procedures and guidelines as well as use appropriate tools and trained personnel to minimise refrigerant losses during installation, operation, maintenance and decommissioning.
- Promote recovery, recycle, reclamation and destruction through appropriate mechanisms.
- Train personnel and support student community, through information dissemination and collaborative research, towards responsible use of refrigerants.
- Promote sustainable RAC practices with a holistic approach.
HCFC Phase out Management Plan (HPMP) - Recommendations to MLF

- HPMPs should also address climate change by using alternatives with lower GWP taking into account energy efficiencies, equipment, and climate circumstances.
- Conversion policy would consider discouraging the use of HCFC alternatives with high GWP.
- Strategic activities be identified between now and the establishment of the baseline (at the end of 2010). These might include, demonstration projects with no or very low GWP technology and effective energy conservation measures.
- The choice of technologies should also ensure that environmentally-safe substitutes and related technologies are transferred to Article 5 countries under fair and most favourable conditions.
Alternatives (HFC Blends) to HCFC-22

• **R-407C (HFC-32/125/134a)**: Retrofit candidate with HFCs; Lower energy efficiency and capacity, Lubricant change; Material compatibility; Was used in developed countries for early phase out of HCFC-22 but is decreasing.

• **R-410A (HFC-32/125)**: For new systems (OEMs); Significant design changes (New compressor, HXs, Lubricant, Capillary etc.). Only HFC blend extensively used in many countries, including some A5 countries. China mainly exports R-410A products.

• **R-417A (HFC-125/ HFC-134a/ HC-600)**: Retrofit candidate with HFCs; Material compatibility; Similar capacity; Not seriously considered in developed countries;

• **R-422A, B & D (HFC-123/HFC-134a/ HC-600a)**: Retrofit candidate with HFCs; Material compatibility; Fall in capacity; Not seriously considered in developed countries;

• **R-433A (HC-290/HC-1270)**: Retrofit candidate, Fall in capacity about 5% than HCFC-22, 5-8% more energy efficiency than HCFC-22, Safety considerations, Not seriously considered in developed countries.
Summary of Refrigerant Options and Challenges

- HFC blend mainly R-410A is the most likely near-term refrigerants; this technology is well proven but requires significant design changes.
- R-410A Residential ACs with comparable energy efficiency are commercially available including some Article 5 countries.
- As there is some proposal to consider phase-down of HFCs under Montreal Protocol, there is more interest on low GWP refrigerants.
- HC refrigerants are applied in low charge residential Air-conditioning and are in commercial use in many countries including India. China is yet to use HC AC in the local market as the local standards are yet to be revised but is exporting HC ACs.
- HFC-32 is being used by some manufacturer.
- HFO-1234yf /ze and their mixtures are under evaluation. There is not much open domain information on cost, performance and reliability.
Many of the new refrigerants are flammable or mildly flammable!

The choice of the refrigerant has an impact on the (energetic) systems performance and reliability (GWP in brackets).
Summary

Refrigerants ... we are now heading for the futh generation of change
Should get used to flammable refrigerants
Hence codes need a change...
Industry is ready always for this change
Technology upgrade and learnings are important
Thank You

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