What is the Future of Refrigerants?

2025 FDC Annual Technical Conference

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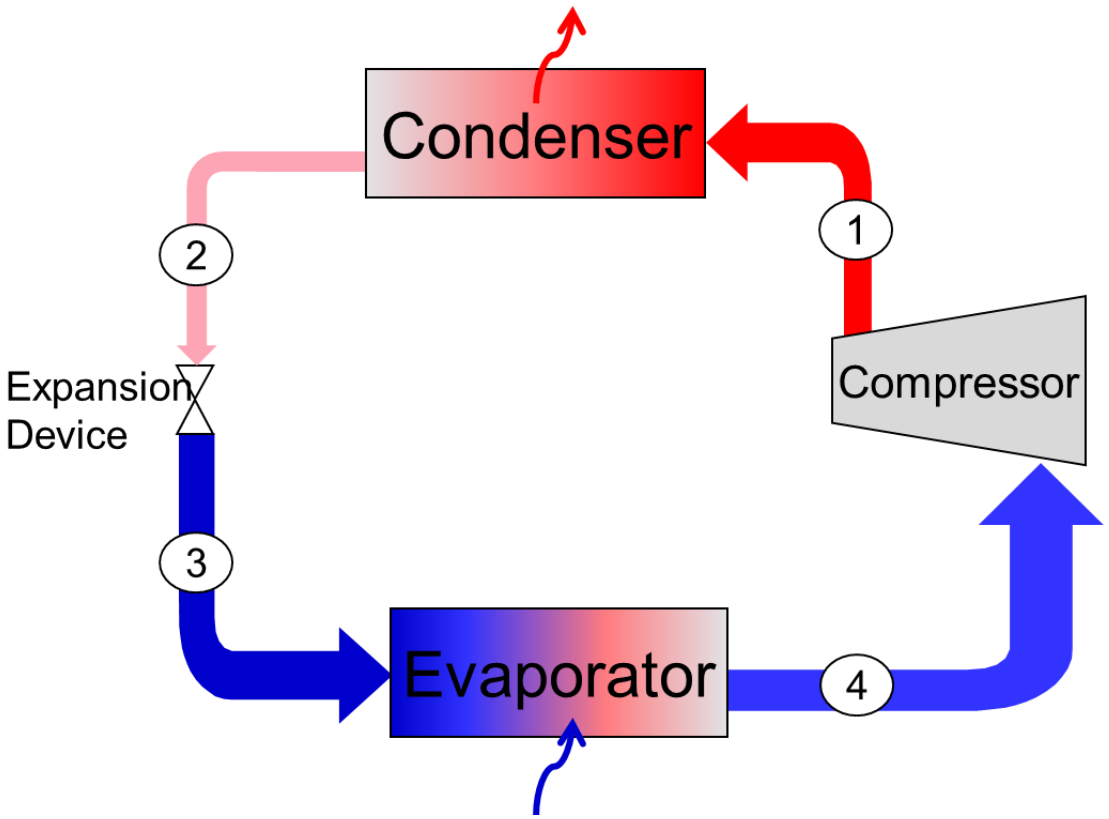
Refrigeration & Refrigerant



- Vapor compression refrigeration cycle is the most common method used by the air conditioning and refrigeration industry to cool
- All refrigeration systems contain some form of 4 components to operate:
  - Compressor
  - Condenser
  - Expansion Device
  - Evaporator
- The 5th necessary “component” is the refrigerant
  - the fluid used for heat transfer in a refrigerating system, which absorbs heat at a low temperature and a low pressure of the fluid and rejects heat at a higher temperature and a higher pressure of the fluid, usually involving changes of the state of the fluid.

Source: *ASHRAE Terminology*

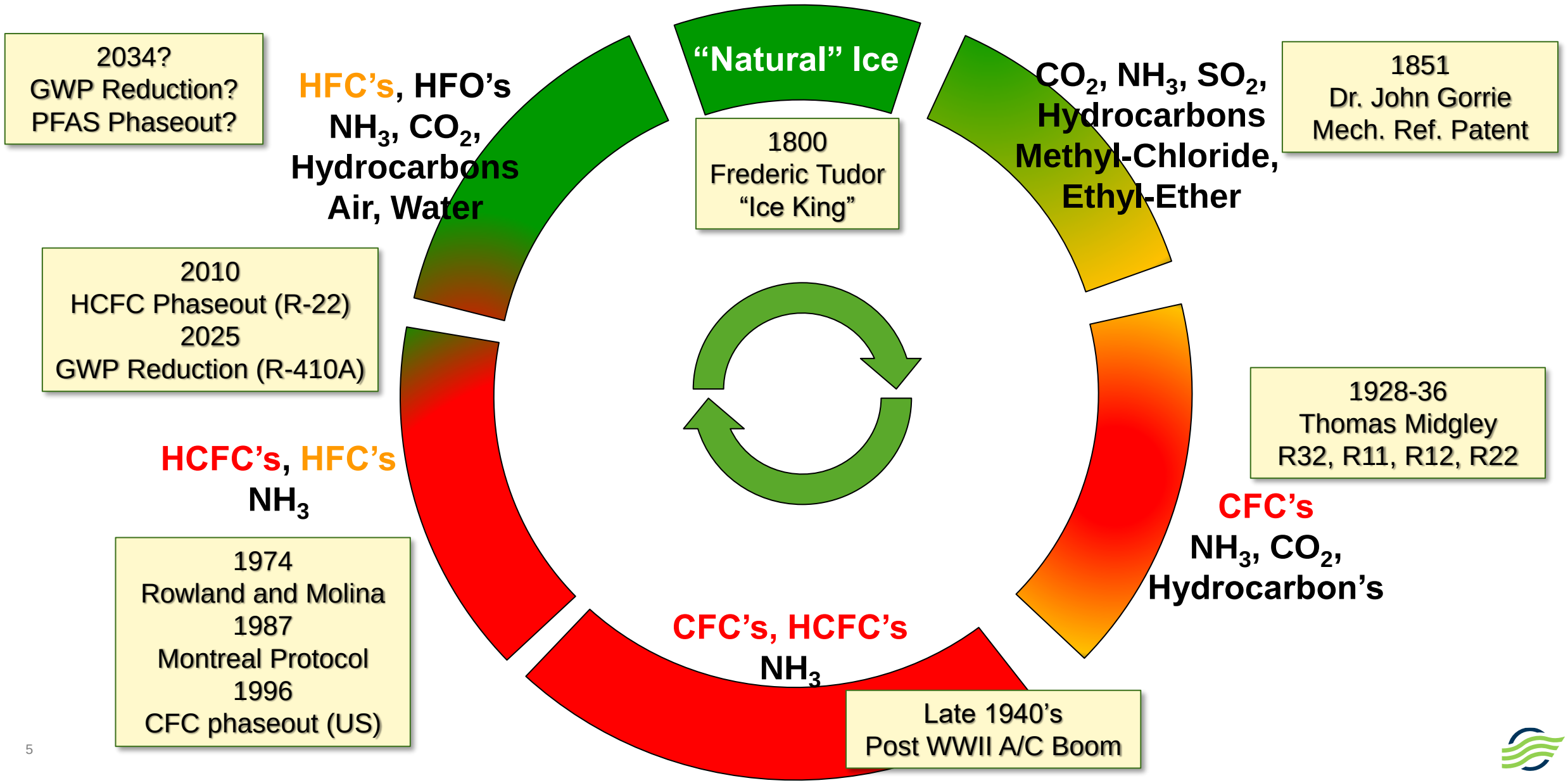
Refrigerant Selection Criteria

- Low cost (refrigerant and equipment)
- Nontoxic
- Low flammability
- Environmentally friendly
  - ODP, GWP, PFAS
- Thermodynamically efficient
- Compatible with a wide range of materials
- Likelihood of future availability

Refrigerant Phaseout Terminology

- Ozone Depleting Potential (ODP)
  - Represents the relative amount of degradation to the ozone layer a chemical can cause relative to R-11
  - R-11's ODP is defined as 1.0
- Global Warming Potential (GWP)
  - Represents how much a given mass of a chemical contributes to global warming over a given time period compared to the same mass of carbon dioxide [*EPA 2011*]
  - Carbon dioxide's GWP is defined as 1.0
- Per- & PolyFluoroAlkyl Substances (PFAS)
  - Large group of synthetic chemicals widely used since the 1950s for their resistance to heat, water, oil, and stains
  - "Forever Chemicals"

Refrigerant Phaseout History



Refrigerant Categories

Halocarbons or "Freon"

- **Chloro-fluoro-carbons (CFCs)**
  - Phased out of production in 1996
- **Hydro-chloro-fluoro-carbons (HCFCs)**
  - Phased out 2010 (R-22, R-123)
- **Hydro-fluoro-carbons (HFCs)**
  - Replacements for HCFC & CFC (R-404A, R-410A, R-32, R-134a)
  - Currently being phased down, high GWP (2023 to 2028)
- **Hydro-fluoro-olefins (HFOs)**
  - Replacements for HFC's (R-1234yf, R-1233zd)
  - Newest class of refrigerants with lower global warming potential
  - Mostly used as a blend with HFCs to reduce overall GWP

"Natural" refrigerants

- **Organic**
  - R-744 (CO_2)
- **Inorganic**
  - R-702 (H_2), R-717 (NH_3), R-718 (H_2O), R-728 (N_2)
- **Hydrocarbon Organic**
  - R-290 (propane), R-600 (Butane/Iso-butane)

What do the letters at the end mean?

Capitol letters – Same components blended at different levels (e.g. R454B vs. R454C)

Small letters – Different isomers of the same chemical formula (e.g. 134a)

Blends of Refrigerants
400 – separate
500 – don't separate

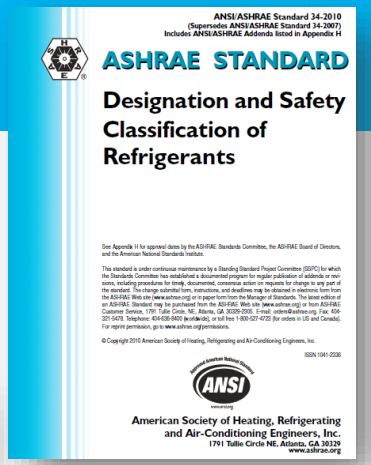
ASHRAE Std. 34 Naming System

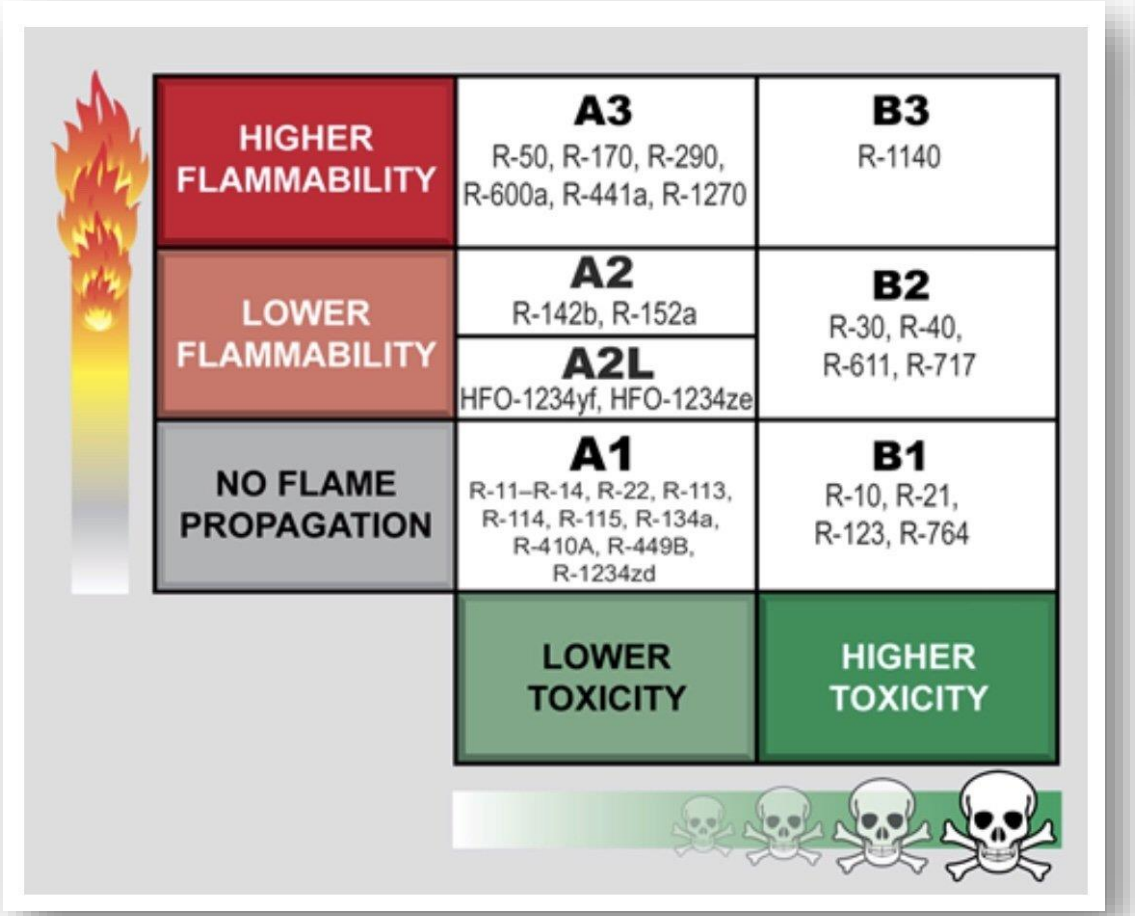
Series	Description
000	Methane Based
100	Ethane Based
200	Propane Based
300	Cyclic Organic Compounds
400	Zeotropes
500	Azeotropes
600	Organic Compounds
700	Inorganic Compounds
1000	Unsaturated Organic Compounds

Refrigerant Safety Classifications

- A1
  - R22, R134a, R-410A
- A2L
  - R32, R143a, R1234yf
- B2L
  - R717 (ammonia)
- A3
  - R600a (isobutane), R290 (propane)

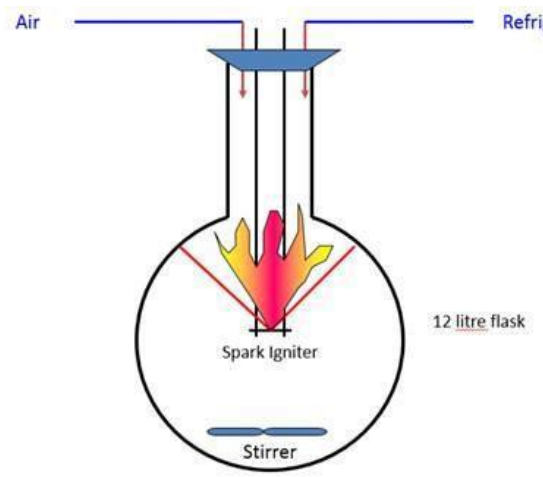
ASHRAE Standard 34



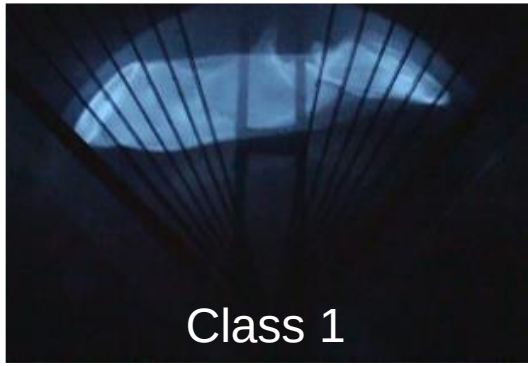


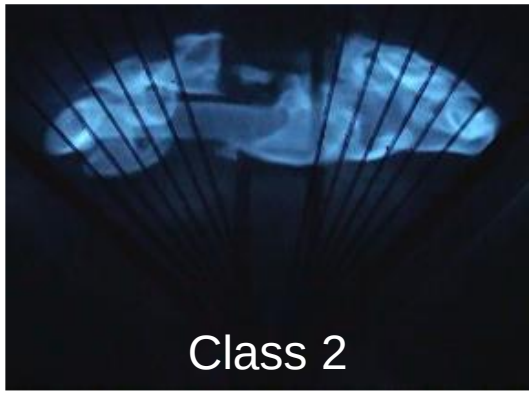
Primary Flammability Parameters

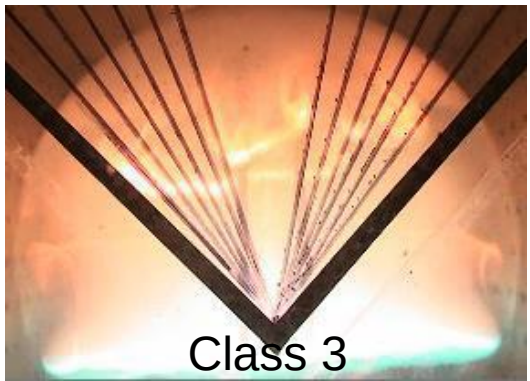
- Flammability Limits (LFL / UFL)
  - Minimum/Maximum concentrations of a substance in air that exhibit flame propagation (usually shown as volume % in air).
- Minimum Ignition Energy (MIE)
  - Minimum energy required to ignite a flammable gas/air mixture. Sources with energy below this value will not result in an ignition.
- Burning Velocity (S_u)
  - The velocity of a laminar flame under given values of composition, temperature and pressure.
- Heat of Combustion (HOC)
  - Heat per unit mass (or mole) released by the combustion of a substance.



ASTM E681 Test







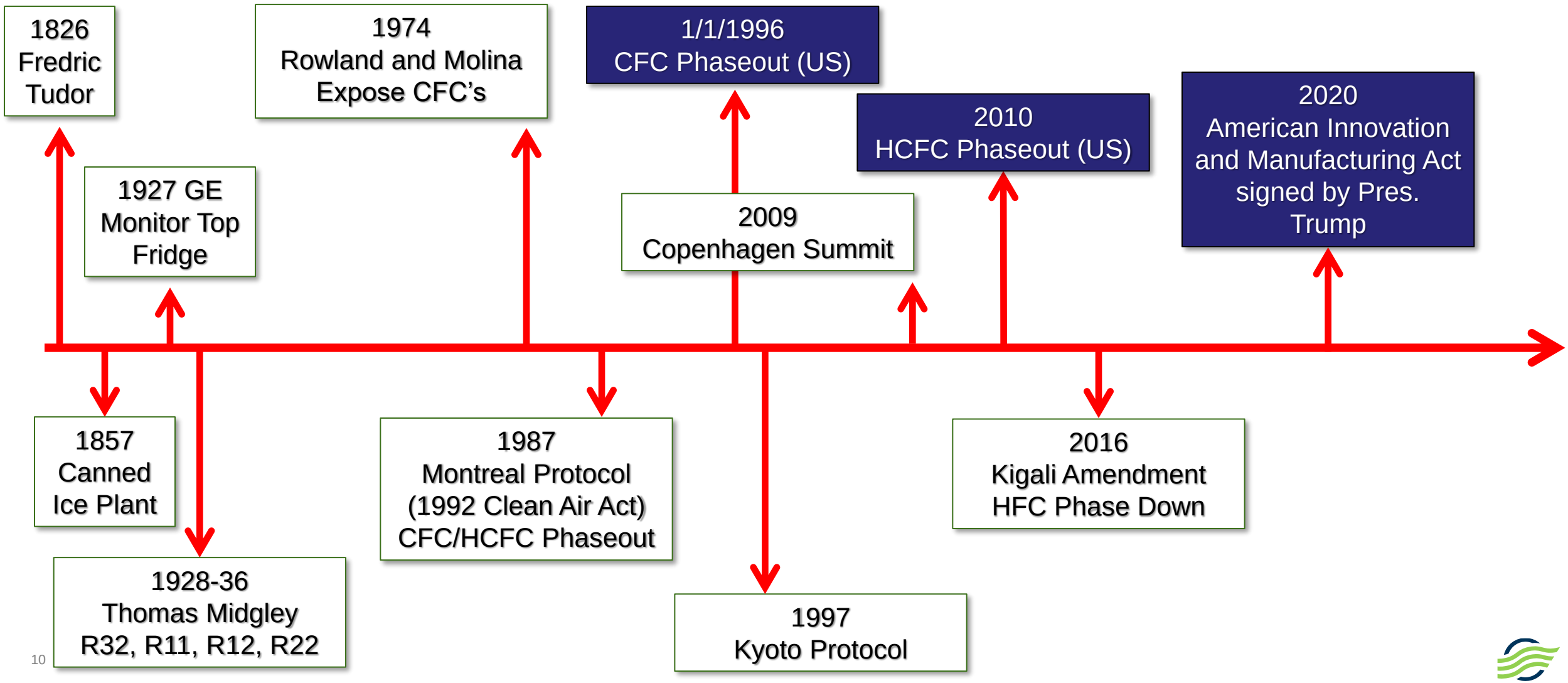
Properties of R-454B and Constituents vs. R-290

Composition of R-454B

- 68.9% Difluoromethane (R-32)
- 31.1% 2,3,3,3-Tetrafluoropropene (R-1234yf)

	GHS classification	LFL	UFL	Autoignition Temp	NFPA 704	Initial boiling point	MIE (mJ)	Su (cm/s)	HOC (kJ/g)
R-454B (A2L)	Flammable Liquified Gas	11.3%	23.6%	925 F	4	-59.F			
R-32 (A2L)	Flammable Liquified Gas	14%	31%	986 F	4	-60.9F	30-100	6.7	9.4
R-1234yf (A2L)	Flammable Liquified Gas	6.2%	12.3%	761 F	4	-20F	>5,000	1.5	10.7
R-717 (B2L) ***(ammonia)***	Flammable Gas	16%	28%	1,204 F	1	-28F	680	7	19.0
R-290 (A3)	Flammable Liquified Gas	2.2%	9.5%	874 F	4	-43.2F	0.25	46	46.3

Refrigerant Transition Timeline



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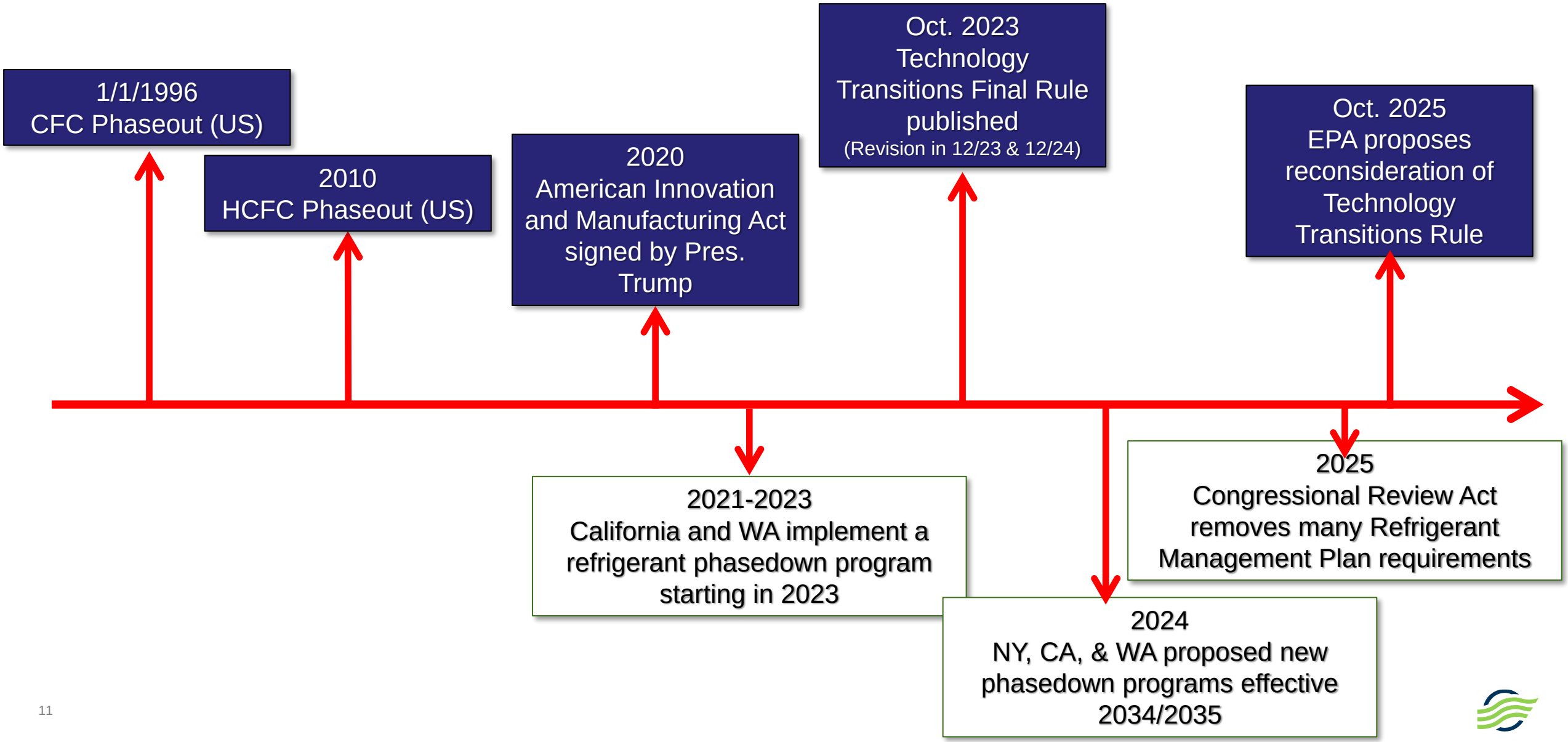


Technology Transitions (AIM Act) – 2023 Final Rule

Subsector	Products	Global Warming Potential Limit or Prohibited Substances	Manufacture and Import Compliance Date	Installation Compliance Date
Stationary residential and light commercial air conditioning and heat pumps	Stationary residential and light commercial air conditioning and heat pumps (e.g., window units, portable room air conditioning)	700	1/1/25	1/1/2026
Chillers (as a stand-alone product)	Industrial process refrigeration with exiting fluid below -50 °C (-58 °F)	Not covered	Not covered	Not covered
	Industrial process refrigeration with exiting fluid greater than or equal to -50 °C (-58 °F) and less than -30 °C (-22 °F)	700	1/1/28	1/1/28
	Industrial process refrigeration with exiting fluid equal to or above -30 °C (-22 °F)	700	1/1/26	1/1/26
Industrial process refrigeration (not using chillers)	With refrigerant entering the evaporator below -50 °C (-58 °F)	Not covered	Not covered	Not covered
	With refrigerant entering the evaporator equal to or above -50 °C (-58 °F) and less than -30 °C (-22 °F)	700	1/1/28	1/1/28
	With less than 200 lb refrigerant charge and temperature of the refrigerant entering the evaporator equal to or above -30 °C (-22 °F)	300	1/1/26	1/1/26
	With 200 or more lb refrigerant charge and temperature of the refrigerant entering the evaporator equal to or above -30 °C (-22 °F)	150	1/1/26	1/1/26
Retail food - refrigeration stand-alone units	Retail food - refrigeration stand-alone units	150	1/1/25	
Retail food - refrigerated food processing and dispensing equipment	500 g of refrigerant or less and outside scope of UL 621, edition 7	150	1/1/27	
	More than 500 g of refrigerant and outside scope of UL 621, edition 7	Multiple prohibited including R-404A and R 507A	1/1/27	1/1/27
	Ice cream makers within the scope of UL 621, edition 7	Multiple prohibited including R-404A and R 507A	1/1/27	1/1/27

Technology Transitions (AIM Act) – 2025 Proposed Rule

- *On September 30, 2025, U.S. Environmental Protection Agency (EPA) proposed changes to regulations promulgated under the Technology Transitions subsection of the American Innovation and Manufacturing (AIM) Act of 2020, which authorizes the Administrator to restrict the use of particular hydrofluorocarbons (HFCs).*
- *In reconsidering this rule, the Trump EPA is proposing to provide flexibility by extending compliance deadlines for supermarket systems, industrial process refrigeration equipment used in semiconductor manufacturing, remote condensing units, cold storage warehouses, and certain refrigerated laboratory equipment that need additional time to transition.*
- October 2025 – Reconsideration of Certain Technology Transitions Requirements Promulgated under the Technology Transitions Provisions of the AIM Act

Equipment Category Impacted by Petition/Request	Changes under Consideration
Refrigerated Transport – Intermodal Containers	Exempt certain intermodal containers by adjusting the temperature threshold at which restrictions do not apply and the location where the temperature is measured. Currently, containers that have temperature of the refrigerant entering the evaporator (for direct heat exchange systems) or the temperature of the fluid exiting (for chillers) below −50 ^{0}C are exempted. Expand this exemption by adjusting this threshold such that intermodal refrigerated transport units designed to achieve box temperatures below −35 ^{0}C are exempt.
Industrial Process Refrigeration (IPR) – Chillers and IPR Equipment Used in Semiconductor Manufacturing	Extend compliance dates for IPR equipment, with a refrigerant charge capacity of 100 pounds or less, used as chillers or temperature control units for process equipment used in the manufacture of semiconductors, from 2026 or 2028, as applicable, to 2030.1
Retail Food Refrigeration – Remote Condensing Units and Supermarket Systems	Provide compliance flexibility by raising the GWP threshold to 1,400 starting in 2026 for remote condensing units and starting in 2027 for supermarket systems, both followed by a GWP threshold of 150/300 starting in 2032.
Cold Storage Warehouses	Provide compliance flexibility by raising the GWP threshold to 700 starting in 2026, followed by a GWP limit of 150/300 in starting in 2032.
Industrial Process Refrigeration – Refrigerated Centrifuges and Laboratory Shakers	Extend compliance dates for refrigerated centrifuges and laboratory shakers from 2026 to 2028.
Residential and Light Commercial Air Conditioning and Heat Pump Systems	Remove installation compliance date for equipment manufactured or imported before January 1, 2025.

The Next Refrigerant Phasedown? (2034?)

- Washington State: On May 17th, Governor signed into law HB 1462 Washington Department of Ecology to adopt rules to implement, includes rules to encourage refrigerant recovery and reclamation.
  - Requires the publication of a plan by June 1, 2027 to transition to low GWP (150 or less) and ultra-low GWP (10 or less) by 2035.
- California: California's SB 1206 directs CARB to issue a draft plan by 1/1/2025, but it has not been published as of this time. Must transition to ultra-low and no-GWP refrigerants by 2035.
  - Additional proposed legislation, but still no draft plan
  - California AB 663 – Can only used CERTIFIED reclaimed refrigerants
- New York: Still has ban on refrigerants above a 10 GWP used most Madison Air products by 2034.
  - On July 31st:
    - NYS DEC responded to the petition denying all the allegations by HARDI and AHRI and requested that the court dismiss the case
    - Natural Resources Defense Council (NRDC) filed a motion to defend New York's hydrofluorocarbon regulations
    - AHRI/HARDI have responded to NRDC's motion and the court hearing oral arguments 10/31

All Refrigerants Must Have “SNAP” Approval

- “*Under Title VI of the Clean Air Act, the SNAP program identifies and evaluates substitutes in end-uses that have historically used ozone-depleting substances (ODS). SNAP listings of acceptable alternatives can also help sectors transition away from high global warming potential hydrofluorocarbons (HFCs) addressed under the American Innovation and Manufacturing (AIM) Act including its Technology Transitions Program. For example, some substitutes that are listed as acceptable under the SNAP program, starting with the first SNAP rulemaking in 1994, might be subject to more recent restrictions established under the Technology Transitions Program. For detailed information on specific restrictions and guidance, please refer to the Technology Transitions Program.*”
- Translation: To use a refrigerant, it must appear on the SNAP acceptable substitute list for that application
  - https://www.epa.gov/snap/substitutes-refrigeration-and-air-conditioning
  - Sometimes, there are conditions placed on the use of that refrigerant such as:
    - Inclusion of warning labels
    - Limiting charge
    - Requirements for safety certification and/or installation per specific ANSI approved standards
- SNAP Rule 26 provided conditional approval to most Industrial Refrigeration refrgierants

Substitutes in Industrial Process Refrigeration

Substitute	Trade Name(s)	Retrofit/New	ODP	GWP	ASHRAE Designation	Listing Status
Ammonia Absorption		N	0	0	B2	Acceptable
Ammonia Vapor Compression		N	0	0	B2	Acceptable
Direct Nitrogen Expansion		N	0	0	A1	Acceptable
HFO-1234yf		N	0	1	A2L	Acceptable subject to use conditions: See rule for detailed conditions.
HFO-1234ze(E)		N	0	1	A2L	Acceptable subject to use conditions: See rule for detailed conditions.
R-1224yd(Z)	AMOLEA™ yd	R/N	0.00012	1	A1	Acceptable
R-744 (Carbon Dioxide, CO_2)		R/N	0	1	A1	Acceptable
HC Blend A	OZ-12	R/N	0	3	A3	Acceptable
R-290 (Propane)		R/N	0	3	A3	Acceptable
R-600 (Butane)		R/N	0	3	A3	Acceptable
HCFO-1233zd(E)	Solstice® N12, Solstice® 1233zd(E)	R/N	<0.0004	3.7	A1	Acceptable
HC Blend B	Original formulation of HC-12a	R/N	0	4	A3	Acceptable
R-1270 (Propylene)		R/N	0	5	A3	Acceptable
HFE-569sf2 (ethoxynonafluorobutane, iso and normal)	Novec™ 7200 Engineered Fluid (HFE-7200)	N	0	59	N/A	Acceptable: Only acceptable for use as a secondary heat transfer fluid in not-in-kind systems.
HCFC-123		R/N	0.02	77	B1	Acceptable
R-457A	Forane® 457A	N	0	137	A2L	Acceptable subject to use conditions: See rule for detailed conditions.
R-516A	Forane® 516A	N	0	140	A2L	Acceptable subject to use conditions: See rule for detailed conditions.
R-471A	Solstice® N71	R/N	0	144	A1	Acceptable
R-454C	Opteon™ XL20	N	0	146	A2L	Acceptable subject to use conditions: See rule for detailed conditions.
R-455A	Solstice® L40X	N	0	146	A2L	Acceptable subject to use conditions: See rule for detailed conditions.
R-454A	Opteon™ XL40	N	0	237	A2L	Acceptable subject to use conditions: See rule for detailed conditions.
HFE-449s1 (methoxynonafluorobutane, iso and normal)	Novec™ 7100 Engineered Fluid (HFE-7100)	N	0	297	A1	Acceptable: Only acceptable for use as a secondary heat transfer fluid in not-in-kind systems.
R-454B	Opteon™ XL41	N	0	465	A2L	Acceptable subject to use conditions: See rule for detailed conditions.
R-513A	Opteon™ XP 10	R/N	0	630	A2L	**Acceptable**

Summary of Requirements for Refrigeration Equipment (US)

- Refrigerants
  - Must have EPA SNAP approval to be used
  - Must meet the ODP/GWP requirements of the AIM Act, as well as any additional state requirements (e.g. CA, NY, WA)
- Commercial Equipment must be “listed”, meaning it has been safety certified by a Nationally Recognized Testing Lab
  - NRTLs: UL (UL mark), Intertek (ETL mark), CSA, QPS, etc.
  - Most likely listed to UL 60335-2-89 (refrigeration) or UL 60335-2-40 (cooling)
- Commercial/Industrial equipment must be installed to local building code
  - Most local building codes reference ASHRAE Standard 15 and/or IIAR Standards
    - ASHRAE 15: Safety Standard for Refrigeration System
    - IIAR 2: American National Standard for Safe Design of Closed-Circuit Ammonia Refrigeration Systems
    - IIAR CO2-2021: Safety Standard for Closed- Circuit Carbon Dioxide Refrigeration Systems
    - IIAR Standard for Hydrocarbon refrigerants under development

New Requirements for A2L Refrigerants

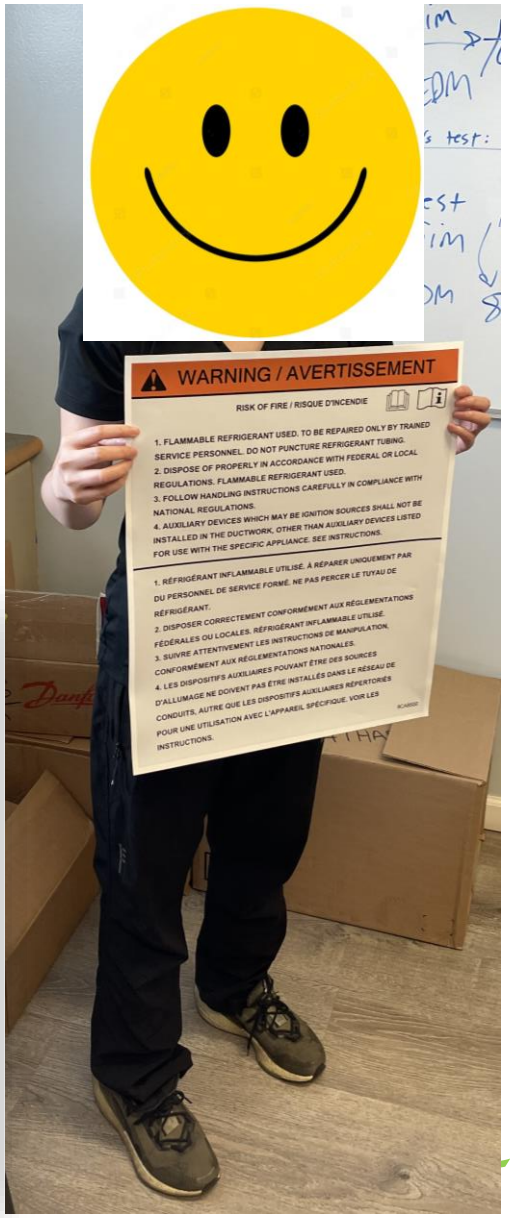
- AHRI Guideline N, Assignment of Refrigerant Container Colors, specifies that all refrigerant containers should have one uniform paint color, a light-green/grey (RAL 7044), and that existing individually assigned container paint colors should be transitioned to the new standard color by 2020.
  - Flammable refrigerants must continue to include a red band on the top of the container.
  - The connection will be reverse threaded and require an adaptor
- When working with flammable refrigerants, it is critical that tools such as the gauge manifold, refrigerant hoses, vacuum pump, recovery machine, and recovery tank are rated for use with flammable refrigerants.

- When brazing a system that has been charged with a flammable refrigerant, the system charge must be recovered first. The system should then be swept with nitrogen to ensure that there is no residual refrigerant. A low-pressure nitrogen purge (1/2 to 2 psig) should be done during the brazing process.

Refrigerant cylinders used to be color coded. A2L refrigerants all have a red band and labeled

New Warning Labels required

- Conditional use of A2L refrigerants require new warning labels to be placed on the equipment by the US EPA
  - Not all warnings are in agreement with the requirements of UL 60335-2-40 and UL 60335-2-89
  - Watch the font size, EPA requires 6.4 mm font vs. UL's 3.2 mm
  - Quebec Bill 96 requires the French translation to be the same size as English
- Examples:
  - WARNING—Risk of Fire due to Flammable Refrigerant Used. Follow Handling Instructions Carefully in Compliance with National Regulations.
  - To Be Repaired Only By Trained Service Personnel. Do Not Puncture Refrigerant Tubing.
  - Minimum room area (operating or storage)…



New Technologies?

- Liquid Desiccant
  - Lithium Chloride is the ultimate desiccant, but very corrosive
  - Used in combination with indirect/direct evaporative cooling
- MOF (Metal Organic Framework) Desiccant
  - Next generation desiccants, beyond Silca Gel and molecular sieves
  - Increased holding capacity, but little reduction in energy use
- Natural Refrigerants
  - Ammonia
  - Carbon Dioxide (especially in cascade systems)
  - Hydrocarbons/hydrocarbon blends
  - Adsorption systems

Other Sources of Information

- EPA's Technology Transitions Program is the implementation of the Final Rule for the Aim Act
  - https://www.epa.gov/climate-hfcs-reduction/technology-transitions
  - Regulatory Actions: https://www.epa.gov/climate-hfcs-reduction/regulatory-actions-technology-transitions
    - October 2023 – Final Rule
    - December 2023 – Revision of sell through periods
    - December 2024 – Revision of VRF effective date
  - FAQ page: https://www.epa.gov/climate-hfcs-reduction/frequent-questions-phasedown-hydrofluorocarbons
  - EPA SNAP (Refrigerant) Substitutes by Sector: https://www.epa.gov/snap/snap-substitutes-sector
- California's *Stationary Refrigeration & Air Conditioning* Rulemaking: https://ww2.arb.ca.gov/rulemaking/2020/hfc2020
- AHRI Safe Refrigerant Transition Task Force
  - https://www.ahrinet.org/safe-refrigerant-task-force (Information on safety, storage, technician best practices)
  - AHRI 3-part webinar series for Fire Marshals/AHJ's
    - *Part 1: An Introduction to A2L Refrigerants,* Recording: Webinar Recording.
    - *Part 2: Updates to Standards and Model Codes:* Webinar Recording.
    - *Part 3: State and Local Codes & Available Resources:* Webinar Recording.

Question?

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