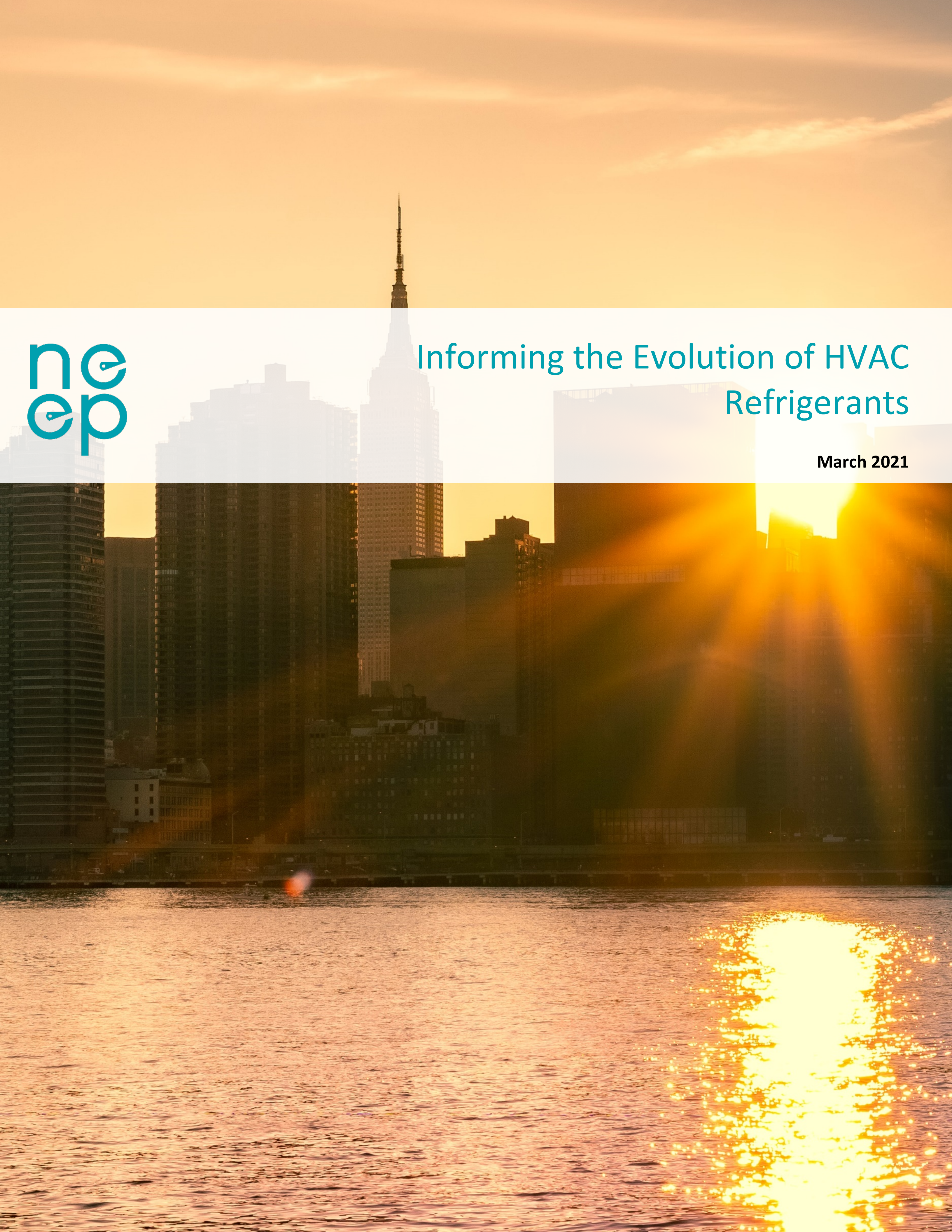
Informing the Evolution of HVAC Refrigerants

March 2021



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About NEEP

NEEP was founded in 1996 as a non-profit whose mission is to serve the Northeast and Mid-Atlantic to accelerate regional collaboration to promote advanced energy efficiency and related solutions in homes, buildings, industry, and communities. Our vision is that the region's homes, buildings, and communities are transformed into efficient, affordable, low-carbon resilient places to live, work, and play.

Disclaimer: NEEP verified the data used for this white paper to the best of our ability. This paper reflects the opinion and judgments of the NEEP staff and does not necessarily reflect those of NEEP Board members, NEEP Sponsors, or project participants and funders.

Executive Summary

Theoretical knowledge without practical application is not enough. This paper explains the politics, marketing, history, and science to prepare you to participate in the HVAC industry's fourth refrigerant phase down, now focused on reducing Global Warming Potential.

Manufacturers:

- The previous transitions to R-12, to R-22, and to R-410A show how manufacturers have handled phase outs/downs successfully three times before. Low GWP refrigerants are already available for many applications, and are becoming available for more, such as domestic water heating. Let your marketing be a force for education.

Policy Makers:

- States must update applicable UL and model mechanical codes to allow Class 2L refrigerants in high pressure applications. So far, only Washington state has completed the necessary changes. It will require a much larger critical mass of states for manufacturers to take the leap of selling Class 2L systems in the United States. Uniformity in regulation helps everyone from manufacturers to fire marshals plan appropriately for a smooth transition. Congress has created an orderly path for HFC and GWP reduction in line with the Kigali Amendment to the Montreal Protocol, led by the U.S. EPA.
- Efforts should be taken to mitigate the direct impacts of refrigerants, increase renewable power sources, and incentivize heat pumps. For commercial refrigeration, the largest source of leaks, CO_2 and other natural refrigerants are one solution to reduce direct emissions.

Consumers:

- The most significant reductions in both the cost and environmental impact of HVAC systems come from improved system efficiency. From a site energy perspective, a heat pump is always more efficient than burning fossil fuels for heat. Consider the payback and incentives for any long term investment in an HVAC system, and consider using a low GWP refrigerant if one is available.

Introduction

Many states in the Northeast have established aggressive long-term greenhouse gas (GHG) reduction goals in line with the United Nations' modeled path[1] to reduce global carbon dioxide emissions 45 percent from 2010 levels by 2030, achieve net zero emissions by 2050, and limit the global average temperature increase to 1.5° Celsius. As states put measures in place to achieve these goals, one mechanism with significant potential to reduce global warming is building electrification – the process of replacing building technologies that use fossil fuels with technologies that use electricity. According to NEEP's report, Action Plan to Accelerate Strategic Electrification in the Northeast, building electrification relies heavily on the broad adoption of electric heat pumps.

Over the past several years, many Northeast states have begun implementing measures to transition the electric grid to clean energy and increase the adoption of technologies that use electricity as a source of energy. This has fueled rapid growth of the heat pump market in the region. More recently, however, concerns have been raised about the impact these systems' refrigerants may have on the environment. NEEP's 2019 VRF Market Strategies Report highlights these concerns and emphasizes the need to develop a comprehensive regional strategy for addressing the climate impact and safety risks of refrigerants. After years of no regulatory scheme at the federal level, most Northeast states began considering regulations to limit the use of certain refrigerants and to introduce alternatives with lower global warming potential. Recent federal legislation may now usher in a new national regulatory scheme for refrigerants.

In cold climates, heating is a large portion of building energy use. Heat pumps use refrigerants to transfer heat from outdoors to indoors and are always more efficient from a site energy use perspective than comparable systems that burn fossil fuels. Within the last five years, heat pumps have become increasingly capable of low ambient operation suitable for the cold winters in the region. Although refrigerants are typically associated with cooling, their role in heating could have an even larger impact on the environment by replacing natural gas.[2]

The story of HVAC refrigerants is complicated, but this paper attempts to explain the basics. The history, chemistry, safety concerns, environmental impact, and regulatory landscape all help inform the promotion and regulation of HVAC systems. Often framed as part of the problem due to the potential of leakage, HVAC refrigerants are, in fact, part of the solution to climate challenges of the 21st century. Energy efficiency is the most important factor in both the environmental impact and lifetime cost of a typical HVAC system, which offers a focal point for collective stakeholder and industry efforts going forward. To clear through the cobwebs of politics and marketing, let's start at the beginning.

[1] https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_SPM_version_report_LR.pdf
[2] https://www.epa.gov/ghgemissions/overview-greenhouse-gases

History of Refrigerants

Early Refrigerants

In 1902, the Sacket & Wilhelms printing plant in Brooklyn, New York, hired Willis Carrier to solve a humidity problem. Inconsistent humidity in the plant was causing the paper to expand and contract between each printing run, misaligning the colors as they were layered onto the page. Carrier's "apparatus for treating air" provided 54 tons of cooling and maintained 55 percent relative humidity using ammonia as a refrigerant, earning Carrier the distinction of inventing the modern air conditioner.[3]

Ammonia proved to be one of the most toxic and flammable commonly used refrigerants. From 1902-1928, alternative refrigerants included sulfur dioxide (a lung and eye irritant), and methyl chloride (acutely toxic to humans and highly flammable). Widely reported accidents with these refrigerants led to increasing concerns about safety.

In 1928, Frigidaire and parent company General Motors determined that finding a safer refrigerant would be necessary for the market to take off.[4] The task was assigned to Dr. Thomas Midgley Jr., who was by then the award-winning inventor of leaded gasoline. Looking at the periodic table, Midgley noticed that many of the elements of the refrigerants already in use were adjacent to one another: carbon, nitrogen, oxygen, sulfur, and chlorine. He hypothesized that there might be a similar element that could be added to make the compound less toxic and less flammable. Sure enough, fluorine did the trick.

Midgley and his team quickly synthesized the first chlorofluorocarbon (CFC) refrigerant. It was composed of two chlorine atoms, two fluorine atoms, and one carbon atom, which can be written as CCl_2F_2, or dichlorodifluoromethane, and was sold under the brand name "Freon." General Motors and DuPont formed Kinetic Chemicals to produce Freon. DuPont came up with an easier naming scheme, and dichlorodifluoromethane became "R-12." Swapping out one fluorine atom for one chlorine atom turned R-12 into "R-11." Over time, the name Freon came to refer to many similar refrigerants. Modern refrigerants that contain fluorine are called "F-gases."

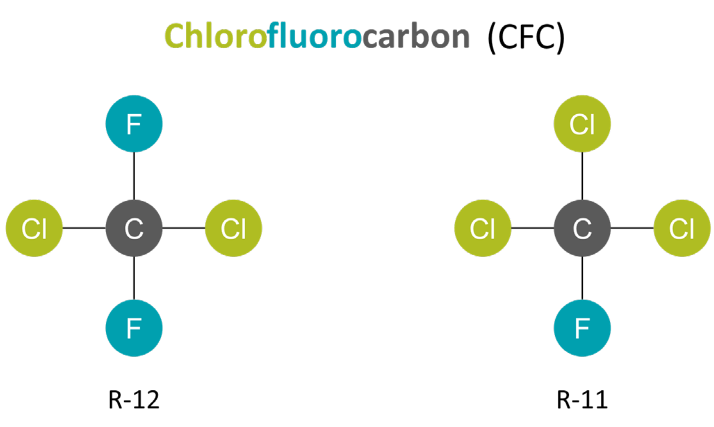

Figure 1: The First CFC Refrigerants

[3] www.williscarrier.com/1876-1902.php
[4] http://acshist.scs.illinois.edu/bulletin_open_access/v31-2/v31-2%20p66-74.pdf

CFCs were so much safer than earlier alternatives that they became the dominant refrigerants for decades. When Midgley introduced Freon to the public at a meeting of the American Chemical Society in 1930, he took the stage, lit a candle, took a deep breath of R-12, and blew out the flame.[5] His demonstration—while ill-advised by modern standards—proved his point. CFCs are so stable, in fact, that R-12 lasts for 100 years in the atmosphere, and R-11 lasts for 45 years.[6]

The Ozone Hole

In the 1970s, a clear link was established between CFCs and the destruction of the earth's ozone layer.[7] The ozone layer is located between 65,000 feet and 100,000 feet in the stratosphere and acts as a shield around our planet. When ultraviolet light from the sun shines on the ozone layer, most of the UVA goes through, most of the UVB is absorbed, and all of the UVC is absorbed. That's good news, because UVB can cause skin cancer and cataracts, and UVC is powerful enough to fry the ocean's phytoplankton that are the foundation of the food chain for life on earth. CFCs last for so long in the atmosphere that they are carried by the prevailing winds to the South Pole, where they are trapped in the polar vortex and float around in the ozone layer. When CFCs finally break down, their chlorine atoms destroy ozone molecules by bonding with one of the oxygen atoms. A chain reaction starts when another nearby oxygen atom joins the first to create diatomic oxygen, releasing the chlorine atom to destroy more ozone. Governments responded in 1987 by drafting the Montreal Protocol, the most widely adopted environmental treaty in history, which was ratified by 197 countries. Negotiators from around the world all agreed to phase out the use of CFCs.

The Montreal Protocol

Under the Montreal Protocol, each refrigerant was assigned an Ozone Depletion Potential (ODP) rating relative to R-11, which was given an ozone depletion potential of 1. Production of all CFCs, including R-11 and R-12, was banned starting in 1996.

Refrigerants that break down faster, before they can travel up to the ozone layer, have a lower atmospheric life, and therefore a lower ozone depletion potential. The formula for R-22 substitutes a hydrogen atom for a chlorine atom, creating a hydrochlorofluorocarbon (HCFC) and reducing both its atmospheric life and the effect of ozone-destroying chlorine atoms. R-22 has an atmospheric life of 12 years, and an ozone depletion potential of 0.04.[8] Its phase-out period was longer than that of R-11 and R-12: new equipment was banned starting in 2010, and production was banned starting in 2020.

HCFC R-123 was given the longest phase-out period with no new equipment allowed beginning in 2020, and no new production starting in 2030. R-123 has an atmospheric life of 1.3 years, and an ozone depletion potential of just 0.01.

To get to an ozone depletion potential of zero, one solution was to remove the chlorine entirely, creating a hydrofluorocarbon (HFC). R-134a is one popular HFC, and R-410A is a popular HFC blend. The lowercase letter

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[5] https://www.smithsonianmag.com/smart-news/one-man-two-deadly-substances-20th-century-180963269/
[6] https://www.epa.gov/ozone-layer-protection/ozone-depleting-substances
[7] Stratospheric Ozone Protection, 30 Years of Progress and Achievements, EPA, https://www.epa.gov/sites/production/files/2017-12/documents/mp30_report_final_508v3.pdf

[8] Ozone Depletion Potentials updated per ODP2 (WMO 2011) https://www.epa.gov/ozone-layer-protection/ozone-depleting-substances

“a” denotes an isomer, a particular molecular formation, whereas the uppercase letter “A” denotes a particular blend.

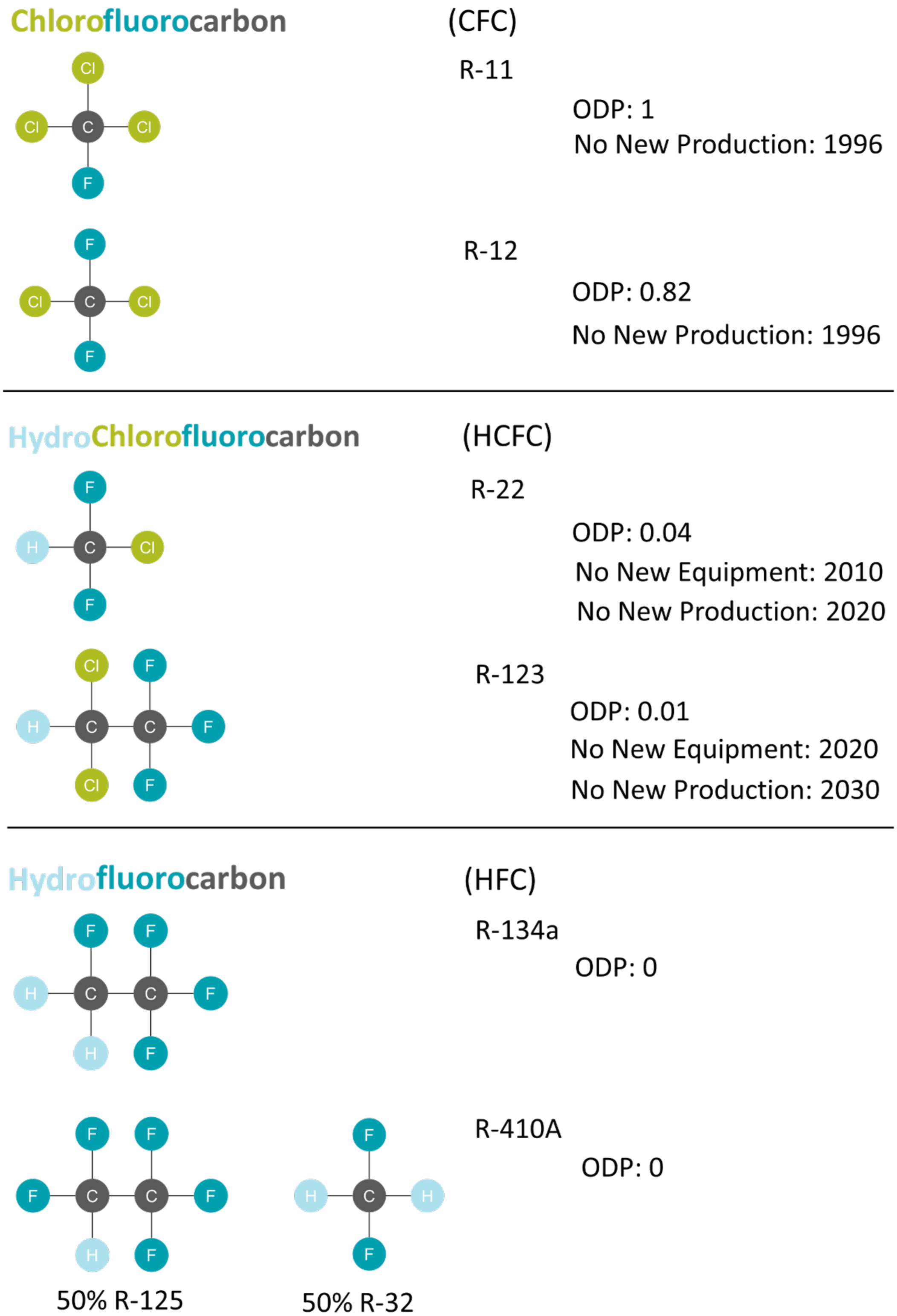

Figure 2: Refrigerant Formulas, Ozone Depletion Potential, and Montreal Protocol Phase-out Dates

Global Warming and the Kyoto Protocol

In the 1990s, actions taken following the Montreal Protocol successfully reduced the damage to the ozone layer, and the scientific community shifted its focus to the issue of global warming. Although HFCs contain no chlorine atom, and therefore have no ODP, they were found to contribute to the greenhouse effect. The greenhouse effect occurs when gasses blanketing the Earth hold and reflect heat back to the Earth's surface, causing global warming. These concerns led the international community to create the Kyoto Protocol, an international treaty, in 1997. HFCs were reevaluated based on a rating system that measures Global Warming Potential (GWP). Greenhouse gasses including HFCs were measured against CO_2, which was given a global warming potential of 1. The popular HFC R-134a, by comparison, has a global warming potential of 1,300. Another popular HFC, R-410A, has a global warming potential of 1,924.[9] The Kyoto Protocol set reduction targets for greenhouse gasses in developed countries, and was signed, but not ratified, by the United States.

The Kigali Amendment to the Montreal Protocol

In October 2016, the Montreal Protocol was further revised by the Kigali Amendment, signed in Kigali, Rwanda, with the goal of cutting production and consumption of HFCs by 80 percent over 30 years to avoid up to 0.5° Celsius warming by 2100. The European Union and other highly developed countries led the way with the most ambitious commitments under the amendment, which were scaled down for developing countries with the hottest climates. Like the Kyoto Protocol, the Kigali Amendment was signed, but not ratified, by the United States.[10]

EPA Significant New Alternatives Policy (SNAP)

The Environmental Protection Agency (U.S. EPA) also attempted to regulate HFCs, releasing Final Rule 21 for its Significant New Alternatives Policy (SNAP) program in December of 2016, provided for under Section 612 of the Clean Air Act. The program expands the list of acceptable refrigerant substitutes and prohibits the use of previously acceptable substitutes as new refrigerants that pose less overall risk to human health and the environment become available. Three industrial sectors were included: refrigeration & air conditioning, fire suppression & explosion protection, and foam blowing.[11] Notably for HVAC, new chillers using certain HFCs, including R-134a and R-410A, were declared unacceptable except as otherwise allowed under a narrowed use limit, as of January 1, 2024.

In response to the new regulations, Mexichem Fluor, a Mexican chemical manufacturer, and Arkema, a French chemical manufacturer, sued the U.S. EPA. Despite support from Chemours and Honeywell, chemical manufacturers headquartered in the U.S., the Washington D.C. Circuit Court of Appeals ruled against the U.S. EPA in August of 2017. In its decision, the Appeals court wrote that Section 612 of the Clean Air Act "does not require (or give U.S. EPA authority to require) manufacturers to replace non-ozone-depleting substances such as HFCs."[12] According to decision, the U.S. EPA had misunderstood its mandate; Section 612 applies only to ozone

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[9] 100-year GWP values taken from the IPCC Fifth Assessment Report: https://www.theclimateregistry.org/wp-content/uploads/2019/02/Draft-PC-Appendix_A_Global-Warming-Potentials.pdf
[10] Recent International Developments under the Montreal Protocol, EPA, https://www.epa.gov/ozone-layer-protection/recent-international-developments-under-montreal-protocol
[11] https://www.epa.gov/snap/fact-sheet-final-rule-21-protection-stratospheric-ozone-significant-new-alternatives-policy
[12] http://blogs2.law.columbia.edu/climate-change-litigation/wp-content/uploads/sites/16/case-documents/2017/20170808_docket-15-1328_opinion.pdf

depletion, not global warming. The court left it up to the U.S. EPA and others to lobby for new laws. Petitions for rehearing were denied, and on October 9, 2018, the Supreme Court declined to hear the case.[13]

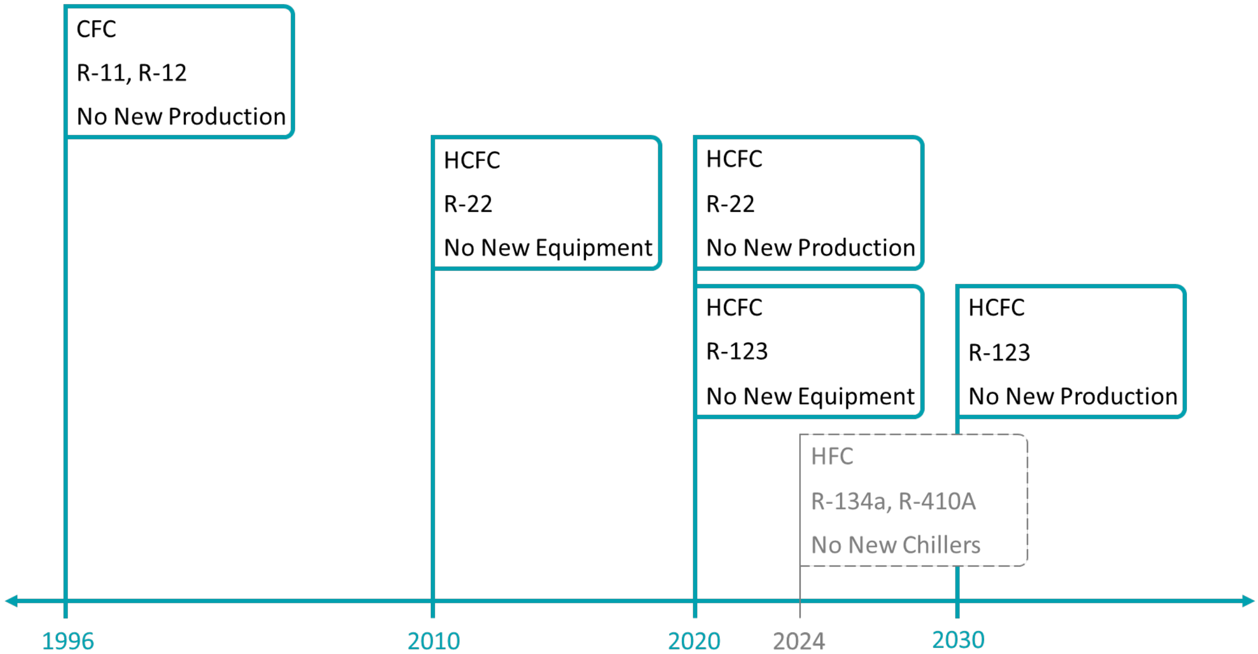

Figure 3: United States CFC and HCFC Phase-out Dates

Low GWP Refrigerants

Low Global Warming Potential (GWP) refrigerants are already available in many HVAC systems. The key differentiator in systems which use lower GWP refrigerants is operating pressure (see Figure 4). Manufacturers have readily available replacement options for low and medium pressure systems, but replacement options for high-pressure systems tend to be flammable, and therefore are not yet acceptable in building codes. Lower pressure refrigerants are used in larger compressors, which are more efficient because they spin more slowly and require less energy to reach their operating pressure. For high capacity systems with large, easily accessible mechanical rooms, larger equipment is not an issue. If smaller size is required, compressors can spin faster to achieve the required compression. Magnetic bearing compressors were developed to operate at the necessary speed. Lower capacity equipment typically uses small compressors with high-pressure refrigerants.

Compressor Type:	Scroll	Helical Rotary (Screw)	Centrifugal
Operating Pressure:	High	Medium	Low
Efficiency:	Low	Medium	High
Size:	Small	Medium	Big

[13] http://climatecasechart.com/case/mexichem-fluor-inc-v-epa/?cn-reloaded=1

Typical tonnage (each):	0 - 30	70 - 120	100 - 2,000
Typical Equipment:	Packaged and Split DX Unitary Systems (most air conditioners and heat pumps)	Chillers	Chillers

Figure 4: Typical Compressors by Operating Pressure

Transitions by manufacturers to lower GWP refrigerants include switching from R-123 (global warming potential 79) to R-514A (global warming potential 2) for low pressure systems, and from R-134a (global warming potential 1,300) to R-513A (global warming potential 573) for medium pressure systems. These hydrofluoroolefin (HFO) blends break down quickly if leaked, virtually eliminating any chance of reaching the ozone layer.

The olefinic double carbon bond also breaks down quickly in single component refrigerants such as hydrochlorofluoroolefin (HCFO) R-1233zd, a low pressure refrigerant with a global warming potential of 1, and insignificant, or "de minimis," ozone depletion potential.

High-pressure refrigerants such as R-410A have proven to be the most difficult to replace. A blend of 50 percent R-32 (slightly flammable) and 50 percent R-125 (a fire suppressant), R-410A is a non-flammable refrigerant. Many good candidates to replace high-pressure refrigerants are slightly flammable, a problem that is being remedied by relaxing the standard of flammability.[14]

[14] https://web.archive.org/web/20200717152527/https://www.ashrae.org/about/news/2015/addition-of-subclass-2l-refrigerants-proposed-for-ashrae-refrigerant-safety-standard

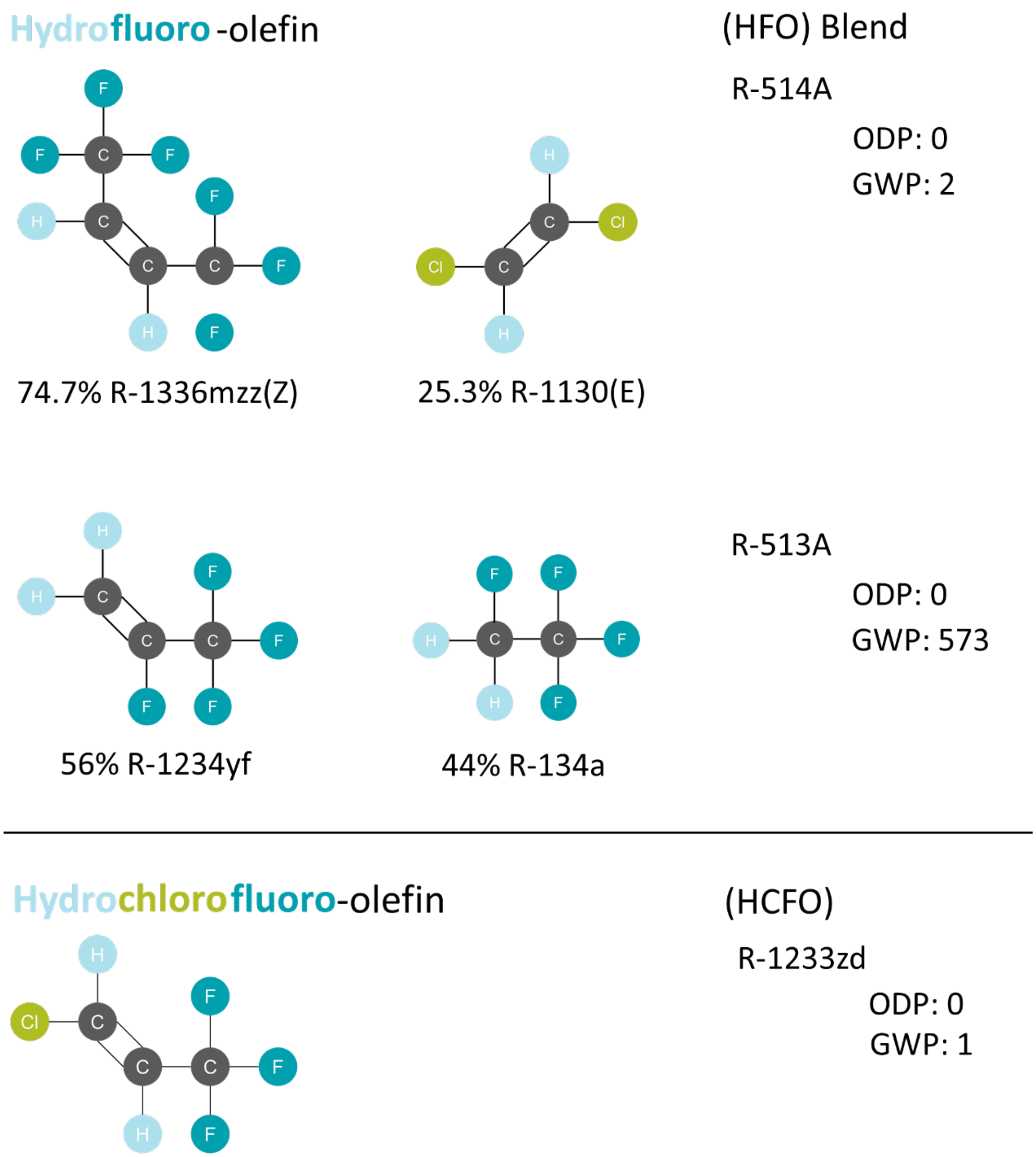

Figure 5: Low GWP Refrigerants

Natural Refrigerants

As their name suggests, natural refrigerants can occur naturally but are nevertheless industrially processed chemicals, such as ammonia. They are attractive for their low environmental impact, but have the most extreme characteristics among common refrigerants: toxicity (ammonia), flammability (propane), and very high pressure (CO_2).Technicians must be specially trained for safe handling, presenting a challenge for wider adoption.

ASHRAE projects that ammonia's use in commercial refrigeration will increase as regulatory and code officials become informed of its relative safety.[15] Ammonia has zero ozone depletion potential and zero global warming potential, and is well suited for commercial refrigeration and other low temperature applications. The self-alarming smell and fact that it is lighter than air makes leak detection faster and safer than other refrigerants.

Propane and CO_2 are also attractive low GWP solutions for commercial refrigeration and select applications. CO_2 heat pump water heaters offer an excellent opportunity to replace fossil fuel and electric boilers. First commercialized in Japan in 2001, they are expected to gain popularity in the U.S. soon.[16] CO_2 refrigeration circuits are typically factory sealed, significantly reducing the likelihood of leakage. In supermarket applications, technicians are becoming comfortable with this higher pressure refrigerant.[17]

ASHRAE 15 – Safety

The most pressing concern with refrigerant safety in buildings is the risk of asphyxiation. Leaked refrigerants are typically gasses, heavier than air, and therefore displace oxygen in an enclosed space. The American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE) Standard 15, Safety Standard for Refrigeration Systems, provides requirements to protect nearby people and property. Refrigerant monitors in mechanical rooms are one common requirement to detect and alarm in the event of a leak. Systems with the most refrigerant piping spread throughout occupied areas, such as variable refrigerant flow (VRF), are subject to requirements accounting for the entire system charge leaking into the smallest enclosed area, and may require additional refrigerant monitors. Typical considerations in system design include placing units over hallways instead of smaller rooms, providing pass-throughs between rooms, and using a separate mini or multi-split for a certain area. In the event a system cannot be designed to meet ASHRAE 15 with traditional VRF, hybrid systems using water in the pipes to the indoor units are available, albeit at lower efficiency due to the additional heat exchange between refrigerant and water.

ASHRAE 34 – Toxicity

ASHRAE Standard 34, Designation and Safety Classification of Refrigerants, designates a Refrigerant Concentration Limit (RCL) for each refrigerant, and a two-part safety classification.[18] The RCL is measured in pounds of potentially leaked refrigerant per cubic foot of occupied space, and is based on the lowest of either the Acute Toxicity Exposure Limit (ATEL), oxygen deprivation limit (asphyxiation), or flammability hazard.

The safety classification begins with a letter "A" or "B" to indicate the toxicity class based on chronic exposure. Refrigerants with no identified toxicity at 400 ppm or less are assigned to Class A, and those with identified toxicity at 400 ppm or less are assigned to Class B. Although well intentioned, this classification system is not particularly helpful in rating how safe these chemicals actually are, because no humans experience chronic exposure to refrigerants as defined in Standard 34 – an Occupational Exposure Limit (OEL) based on eight hours/day and 40 hours/week. The U.S. EPA attempted to alleviate concerns with refrigerant toxicity, stating, "Concerns with refrigerant safety have been heightened by negative marketing by competing equipment and

[15] https://www.ashrae.org/File%20Library/About/Position%20Documents/Ammonia-as-a-Refrigerant-PD-2017.pdf
[16] https://www.bpa.gov/EE/Technology/EE-emerging-technologies/Projects-Reports-Archives/Pages/Split-system-CO2-heat-pump-water-heaters-.aspx
[17] https://www.r744.com/articles/8780/vermont_to_test_co2_condensing_unit_in_store
[18] https://www.daikinac.com/content/assets/DOC/White-papers-/TAVRVUSE13-05C-ASHRAE-Standard-15-Article-May-2013.pdf

refrigerant vendors. Frequent overstatement (to influence customer perceptions) coupled with contradictions have fueled discomfort in refrigerant choices for some alternative refrigerants."[19]

ASHRAE 34 – Flammability

The second half of the ASHRAE 34 safety classification originally included three flammability classes: Class 1 for no flame propagation, Class 2 for lower flammability, and Class 3 for higher flammability. Flammability is defined in the English language as the ability to support combustion, which depends on the ambient temperature. Standard 34 flame propagation testing is done per ASTM Standard E681 at an ambient temperature of 140°F. It is important to note that almost anything will burn at a high enough temperature. For example, R-1234ze is classified as flammable, but like a puddle of diesel, won't ignite at room temperature. In a building fire, even Class 1 refrigerants can combust. The most common flammable gasses that are piped into buildings, natural gas (methane) and propane, are Class 3. In 2010, Class 2 was given a subclass 2L in an effort to commercialize lower GWP high-pressure refrigerants by treating them more like Class 1.[20] The rate of flame propagation was defined as one requirement, with a burning velocity (BV) limit of 10 centimeters per second at room temperature and atmospheric pressure.[21] Subclass 2L refrigerants are difficult to ignite and sustain a flame. An open flame or high-energy source, more than a spark, is required.[22] Typical household sources like light switches, plugging and unplugging appliances, and butane lighters are not sufficient for ignition.[23]

[19] https://www.epa.gov/snap/refrigerant-safety
[20] https://web.archive.org/web/20200717152527/https://www.ashrae.org/about/news/2015/addition-of-subclass-2l-refrigerants-proposed-for-ashrae-refrigerant-safety-standard
[21] https://web.archive.org/web/20200717152527/https://www.ashrae.org/about/news/2015/addition-of-subclass-2l-refrigerants-proposed-for-ashrae-refrigerant-safety-standard
[22] http://www.ahrinet.org/App_Content/ahri/files/Resources/AHRI_SRTTF_Low_GWP_Refrigerants_FAQs.pdf
[23] https://www.ahrinet.org/App_Content/ahri/files/RESEARCH/Technical%20Results/AHRI_8018_Final_Report.pdf

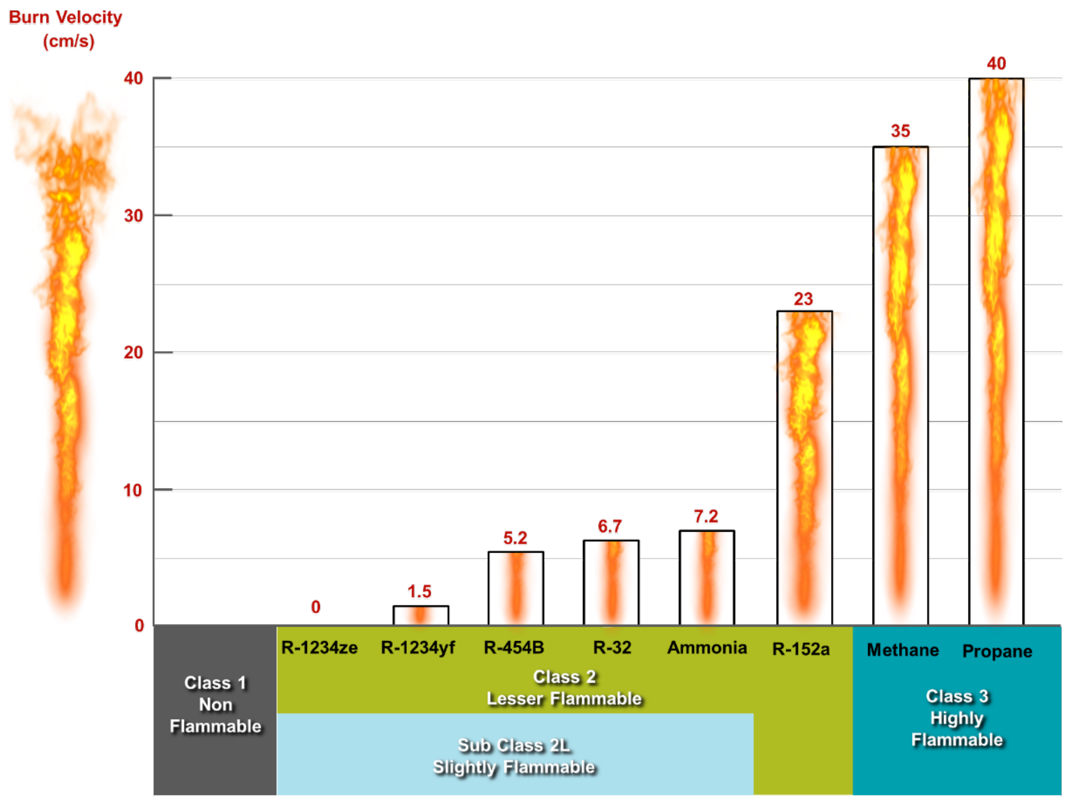

Figure 6: Refrigerant Flammability Classes and Burn Velocities

In 2019, ASHRAE Standard 34 was revised to make subclass 2L a separate flammability class.[24] In June 2020, the U.S. EPA proposed SNAP Rule 23 to list as acceptable a number of Class 2L refrigerants including R-32, R-454B, and Arkema's R-457A.[25] Already common outside the U.S., Class 2L refrigerants will need to be accepted by building codes in the U.S. to reach mass adoption. Worldwide, over 100 million R-32 systems have been installed without report of safety incident.[26] To catch up, the United States must be willing to accept some degree of flammability in the tradeoff with Global Warming Potential.

Current Refrigerant Considerations

Equipment and refrigerant manufacturers are attempting to navigate and balance a wide variety of factors to provide refrigerants for a broad line up of system types. The table below shows several common refrigerants and pertinent metrics for each. While refrigerant efficiency is not covered in this chart, it is important to note that manufacturers make efficiency improvements in whichever equipment they are researching and developing. With each round of phase-outs, manufacturers have had to develop and choose which refrigerant to use in their equipment going forward. Although the earlier refrigerants were simpler and more efficient, manufacturers have more than made up for the efficiency difference by optimizing their equipment for the new refrigerants.

[24] https://www.ashrae.org/news/esociety/new-refrigerants-higher-flammability-refrigerants-addressed-in-updated-ashrae-standards-15-34
[25] https://www.coolingpost.com/world-news/us-epa-to-list-a2l-refrigerants-for-air-conditioning-use/
[26] https://www.r32reasons.com/

Pressure	Type	Refrigerant	Toxicity	Flammability	ODP	GWP
Low (Chillers)	CFC	R-11	A	1	1	4,660
	HCFC	R-123	B	1	0.01	79
	HFO	R-514A	B	1	0	2
	HCFO	R-1233zd	A	1	0	1
Medium (Chillers)	CFC	R-12	A	1	1	10,200
	HFC	R-134a	A	1	0	1,300
	HFO	R-513A	A	1	0	573
	HFO	R-1234ze	A	2L - BV 0.0	0	1
	HFO	R-1234yf	A	2L - BV 1.5	0	1
High (Packaged and Split DX Unitary Systems, Commercial Refrigeration)	HCFC	R-22	A	1	0.05	1,810
	HFC	R-410A	A	1	0	1,924
	HFC	R-466A	A	1	0	733
	HFC	R-454B	A	2L - BV 5.2	0	467
	HFC	R-32	A	2L - BV 6.7	0	677
	HFC	R-152a	A	2 - BV 23	0	138
	HC	R-50 (Methane)	A	3 - BV 35	0	28
	HC	R-290 (Propane)	A	3 - BV 40	0	5
		R-717 (Ammonia)	B	2L - BV 7.2	0	0
Very High (Packaged DX Unitary Systems, Commercial Refrigeration)		R-744 (Carbon Dioxide)	A	1	0	1

Figure 7: Common HVAC Refrigerants and Metrics

Due to the time and effort required for R&D and building code revisions, consumers are left with relatively few decisions to make regarding refrigerants. One such decision is whether to repair or replace an existing R-22 system. R-410A systems are higher pressure and require a different type of oil. If the outdoor unit is replaced with a new R-410A model (or lower GWP alternative), it is necessary to check that the refrigerant lines and indoor coil can handle the increased pressure, and thoroughly flush the system during installation. "Drop-in" replacements such as R-407C are often not recommended and not supported by manufacturers. The best option is usually to repair systems that are leaking, and replace old equipment as soon as possible with R-410A (or newer) equipment, because it will be much more efficient than the old equipment. R-22, however, is expected to be available for the foreseeable future. Although it is illegal in the U.S. to produce or import R-22 as of 2020, all refrigerants can be reclaimed and recycled indefinitely. Over time, there will be fewer R-22 systems in use, lowering demand. In instances where lower GWP refrigerants are available for new equipment, such as R-513A in place of R-134a, consumers will have an opportunity to specify which refrigerant they want.

Total Equivalent Warming Impact (TEWI) of HVAC Systems

Total Equivalent Warming Impact (TEWI) is used to describe the global warming impacts of energy consumption and refrigerant leakage over the life of an HVAC system.

Total Equivalent Warming Impact	Source of Warming Impact	Contributing Factors	Mitigation Strategies
Indirect Impact:	GHG emissions from electricity generation	GHG footprint of electricity generation	Decrease GHG emissions from electricity generation.
		Energy consumption	Increase system efficiency.
Direct Impact:	GWP of leaked refrigerant	GWP of refrigerant	Decrease GWP of refrigerants through phase-downs and regulations.
		Refrigerant leakage	Reduce leakage through quality design/installation, leak detection, and reclamation.

Figure 8: Total Equivalent Warming Impact (TEWI)

The single most significant factor in the lifetime cost of an HVAC system is energy efficiency. One manufacturer estimates that approximately 88 percent of a chiller's lifetime cost is spent on electricity bills.[27] Energy efficiency

[27] https://www.trane.com/content/dam/Trane/Commercial/global/products-systems/education-training/industry-articles/ENV-APN001A-EN_2015_refrigerants.pdf

and payback calculations are of primary importance in the selection of new equipment. Of course, the entire system should be considered more than any one piece of equipment.

Energy efficiency is also the most important factor in determining the environmental impact of an HVAC system. The U.S. EPA, ASHRAE, and manufacturers agree:

- "Energy efficiency is the main environmental consideration in the selection of a chiller as long as the equipment is carefully maintained and refrigerant emissions are kept near zero." – U.S. EPA[28]

- "For chillers, the vast majority of impact on climate change will come from generating electricity to run the equipment, versus refrigerant emissions." – Daikin[29]

- "Efficiency is essential to a chiller's environmental impact. About 95 percent of a chiller's lifetime carbon footprint comes from indirect emissions." – York[30]

- "Over the operating life of the equipment, this indirect effect, which occurs as a result of the CO_2 produced by fossil fuel power plants, is usually much greater than the direct effect due to the GWP of the refrigerant itself." – ASHRAE[31]

- "For hermetic systems, up to 95 percent of the total environmental impact is the indirect impact—the energy used to power HVAC systems." – Trane[32]

One study of the TEWI found that a 10 percent increase in energy consumption was equivalent to a doubling of the refrigerant charge and leakage. [33] Because leaks are pressure dependent, manufacturers typically only guarantee leakage rates for low-pressure equipment, for example, offering to replace any lost refrigerant volume exceeding 0.5 percent annually.[34] VRF systems and other "split" systems with field-installed piping are more prone to leaks than factory sealed systems. One UK study estimated the average leakage for heat pumps to be approximately 3.5 percent per year.[35] On the high end of the spectrum, the average U.S. supermarket's commercial refrigeration leakage rate is 25 percent per year.[36]

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[28] Building Owners Save Money, Save The Earth, US EPA
[29] Myths and Facts of HVAC Refrigerants, Daikin, https://daikinapplied-us-stage.azurewebsites.net/o365/GetDocument/Doc100/Daikin_Chiller_Refrigerant_Myth-Fact_White_Paper.pdf

[30] Chiller Refrigerants: A Time to Stay the Course, Johnson Controls, https://www.johnsoncontrols.com/insights/2015/building-efficiency/feature/chiller-refrigerants-a-time-to-stay-the-course
[31] https://www.ashrae.org/file%20library/about/position%20documents/refrigerants-and-their-responsible-use.pdf
[32] HVAC Refrigerants: A Balanced Approach, Trane, https://www.trane.com/commercial/uploads/pdf/11612/related_literature/refrigerant/hvac_refrigerants.pdf
[33] Refrigeration, Air Conditioning and Heat Pumps, by G F Hundy, https://books.google.com/books?id=ujQdCAAAQBAJ&lpg=PA48&dq=upper%20or%20lowercase%20letter%20in%20refrigerant&pg=PA48#v=onepage&q&f=false
[34] https://www.trane.com/Commercial/Uploads/PDF/11612/Related_Literature/Refrigerant/Leak_Tight_Guarantee.pdf
[35] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/303689/Eunomia_-_DECC_Refrigerants_in_Heat_Pumps_Final_Report.pdf
[36] https://www.epa.gov/sites/production/files/documents/gc_averagestoreprofile_final_june_2011_revised_1.pdf

The industry has long been aware that direct effects from refrigerant emissions are much smaller than indirect effects from generating electricity. A 1997 Oak Ridge National Laboratory study, *Energy and Global Warming Impacts of HFC Refrigerants and Emerging Technologies*, concluded:

> TEWIs for HFC mixtures proposed as HCFC-22 alternatives are not significantly different from those calculated for HCFC-22, and with optimization of equipment design efficiency should continue to improve. Refrigerant leakage, and the corresponding global warming impact of the refrigerant, from hermetic unitary equipment is very small and future service losses will be low because maintenance and replacement practices mandating refrigerant recovery and recycling are in place or under consideration in many countries.
>
> The direct contributions to TEWI for all vapor compression systems presented are small fractions of the total in each case. These contributions should not be ignored, however. Procedures for handling refrigerants and accounting for refrigerant usage currently being adopted should be effective in reducing the direct effect from [the results shown].[37]

Little has changed in U.S. refrigerant handling and reclaim practices since 1997, compared to extensive "F-gas regulations" introduced in Europe. For the U.S. to catch up, more attention should be placed on reducing direct emissions.

GWP Regulatory Landscape

Many states have taken regulatory actions for HFC and GWP refrigerants. California led the way by adopting California SNAP, composed of two parts: the California Air Resource Board (CARB) HFC regulation, and the California Cooling Act (Senate Bill 1013), which both took effect on January 1, 2019.[38] Together, the regulations cover all the end-use specific HFC prohibitions of SNAP Rules 20 and 21, with the exception of motor vehicles. The California Cooling Act also directs CARB to establish the Fluorinated Gases Emission Reduction Incentive Program to increase the adoption of low-GWP refrigerants in the supermarket and industrial sector, the first state law incentivizing funding for that purpose.

CARB has currently proposed a 750 GWP limit for all new stationary air conditioning systems in the state beginning January 1, 2025. For commercial refrigeration, there is a proposed 150 GWP limit for new systems containing more than 50 pounds of refrigerant, effective January 1, 2022. Extensions to the deadlines are being considered, especially for systems in which Class 2L refrigerants are not yet allowed by building codes.

SNAP Rule adoption by Northeast States

To date, several Northeast states have followed California's lead and adopted U.S. EPA SNAP Rules 20 and 21, as shown in Appendix A. Because the U.S. EPA rules did not cover residential heat pump or VRF end uses, states also do not. Maine is the notable exception and has included heat pumps as an end use. States that have taken action are all members of the Short Lived Climate Pollutant (SLCP) working group within the U.S. Climate Alliance.[39] Regulations proposed or adopted by Northeast states are highlighted in Appendix A.

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[37] https://www.epa.gov/sites/production/files/documents/Energy_and_Global_Warming_Impacts_of_HFC_Refrigerants.pdf
[38] https://ww2.arb.ca.gov/our-work/programs/california-significant-new-alternatives-policy-snap/about
[39] http://hydrocarbons21.com/articles/9036/states_coalition_making_progress_on_hfc_reduction

Federal Regulations

Refrigerant regulations at the federal level include actions by the legislature and judiciary. In December 2020, Congress passed the American Innovation and Manufacturing Leadership (AIM) Act, which included a bipartisan effort to phase down HFC use similar to the Kigali Amendment, without calling for a vote to ratify the international treaty itself. It was composed of two bills that progressed in parallel through the House of Representatives (H.R. 5544[40]) and the Senate (S. 2754[41]). The result was Congress' first time targeting specific molecules based on Global Warming Potential, which could lead to similar measures imposed on CO_2 emissions from fossil fuels.[42] The onus is now on the U.S. EPA to lead an HFC phase-down.[43,44] Given that past plaintiffs are producing their own low GWP refrigerants, SNAP rules are not expected to face new challenges in court.

Conclusion

The HVAC industry is in the midst of its fourth refrigerant phase down, now focused on reducing Global Warming Potential. The previous transitions to R-12, to R-22, and to R-410A show how the industry has handled phase outs/downs successfully three times before. Low GWP refrigerants are already available for many applications, and are becoming available for split systems in the U.S. Uniformity in regulation helps everyone from manufacturers to fire marshals plan appropriately for a smooth transition. States must update applicable UL and model mechanical codes to allow Class 2L refrigerants in high pressure applications. So far, only Washington State has completed the necessary changes. It will require a much larger critical mass of states for manufacturers to take the leap of selling Class 2L systems in the United States. For commercial refrigeration, the largest source of leaks, CO_2 and other natural refrigerants are one solution to reduce direct emissions. Congress has created an orderly path for HFC and GWP reduction in line with the Kigali Amendment to the Montreal Protocol, led by the EPA. While efforts should be taken to mitigate the direct impacts of refrigerants, more significant reductions in both the cost and environmental impact of HVAC systems will come from improved system efficiency and cleaner power sources. Energy efficiency is a goal that can unite stakeholders around the world in reducing Total Equivalent Warming Impact and saving consumers money. Perhaps the most exciting transition for refrigerants will be their role in enabling heat pumps to replace fossil fuels as a key climate solution. The future is bright for HVAC refrigerants, heat pumps, and the planet.

[40] https://www.congress.gov/116/bills/hr5544/BILLS-116hr5544ih.pdf
[41] https://www.congress.gov/116/bills/s2754/BILLS-116s2754is.pdf
[42] https://cei.org/studies/the-american-innovation-and-manufacturing-aim-act-myth-vs-fact/
[43] https://www.achrnews.com/articles/144236-congress-approves-hfc-phasedown-plan-in-omnibus-bill
[44] https://tonko.house.gov/uploadedfiles/hfc_tonko-olson_fact_sheet.pdf

Appendix A

Refrigerant Regulation and Legislation by Northeast States

Northeast State	Legislation, Regulation or Consideration	Date Proposed or Passed	Description and latest updates
States with Existing Legislation/Regulation			
New Jersey	An Act concerning the reduction of greenhouse gas emissions from hydrofluorocarbons and supplementing Title 26 and Title 52 of the Revised Statutes.	Passed January 21, 2020	This bill adopts SNAP rules, prohibiting the sale or installation of any product that uses hydrofluorocarbons (HFCs). It provides a timeline for prohibition of different types of equipment ranging from 2020 to 2024.
Vermont	Act S.30: An act relating to the regulation of Hydrofluorocarbons.	Passed May 21, 2019	This act limits the use of HFCs in new equipment. Specifically, it stipulates that products containing certain high-GWP HFCs prohibited by SNAP Rules 20 and 21 would not be allowed in Vermont in new equipment for specific applications as of specific dates.
States with Proposed Legislation/Regulation			
Delaware	Proposed Regulation: Code 1151 Prohibitions on Use of Certain Hydrofluorocarbons in Specific End-Uses	Proposed April 2020	This regulation would adopt SNAP rules, prohibiting the manufacturing, sale, and use of many products that use refrigerants. It would not require people to stop using refrigerants or servicing existing systems that use refrigerants. A public hearing was held in April 2020 and the regulations are expected to go into effect in 2021-2025.
Maine	HP1505/LD 2112: An Act To Limit the Use of Hydrofluorocarbons To Fight Climate Change	Proposed February 20, 2020	This bill would prohibit hydrofluorocarbon use in many cases, not including in heat pumps. The timeline for implementation is 2021-2025. In March, this bill was carried over to any Special Session of the 129th Legislature pursuant to Joint Order SP 788.
Maryland	COMAR 26.11.33 Prohibitions on Use of Certain Hydrofluorocarbons (HFC) in Aerosol Propellants, Chillers, Foam, and Stationary Refrigeration End-Uses	Proposed text will be published July 17, 2020 in the Maryland Register	This regulation would adopt SNAP prohibitions for air conditioning and refrigeration equipment, aerosol propellants, and foam-end uses. A public hearing was held on August 17, 2020.
New York	Proposed Regulation: 6 NYCRR Part 494, Hydrofluorocarbon Standards and Reporting	Proposed September 2018	This regulation would adopt SNAP prohibitions on refrigerants and defines prohibited and acceptable uses. A public hearing was held in March 2020 and the regulations are expected to go into effect in 2021-2024

States in Early stage Legislation/Regulation Planning			
Connecticut	Connecticut joins 3 states in reducing HFCs / Connecticut to finalize HFC regs next year	Announced start of regulation development September 17, 2018	The governor directed the Department of Energy and Environmental Protection to develop regulations to adopt SNAP rules. In June 2019, it announced that the regulations would be ready in about a year.
Massachusetts	Massachusetts Joins Other New England States to Propose Regulations Prohibiting Use of HFC Pollutants	Announced plans to propose regulations on February 18, 2020	The governor's office announced plans to propose regulations to prohibit hydrofluorocarbons. The Executive Office and Energy and Environmental Affairs and the Department of Environmental Protection expected a draft to be available in Spring 2020.
Pennsylvania	Requirements for the Control of Hydrofluorocarbons (HFCs) in the New or Retrofit Equipment and New Consumer Products	Announced plans to join U.S. Climate Alliance, which is supporting state adoption of SNAP rules, on April 29, 2019	A regulatory amendment to PA code chapters 121, 129, and 130 *Air Pollution Control Act* is – as of July 10, 2020 – in the pre-draft proposed stage. The rulemaking will prohibit use of certain HFC-using equipment.
Rhode Island	Rhode Island Joins Massachusetts and Maine in Plan to Regulate Hydrofluorocarbons	Announced plan to regulate HCFs on February 18, 2020	The Department of Environmental Management announced that it will be working with stakeholders to develop new regulation, which will be consistent with what is being developed in MA and ME.