Published on *BuildingGreen* (https://www.buildinggreen.com (https://www.buildinggreen.com))

The Cost of Comfort: Climate Change and Refrigerants

FEATURE ARTICLE

Refrigerants with very high global warming potential can negate the energy-efficiency benefits of many HVAC systems, including popular heat pumps.

by Brent Ehrlich (https://www.buildinggreen.com/author/brent-ehrlich) [1]

November 6, 2017

What is the number-one action we can take to reverse anthropogenic global warming?

Eliminate coal-fired power plants? Drive electric cars? Install solar panels? Paul Hawken's new book, *Drawdown* (http://www.drawdown.org/the-book) [2], calculates and rates the environmental and financial impacts of addressing carbon output across various sectors. According to *Drawdown*, the number one action we can take to fix our greenhouse gas problem is…to reduce the impact of high-global-warming-potential (GWP) refrigerants.

Reducing those impacts won't be easy. Refrigerants are the lifeblood of modern society. Refrigerators, freezers, and displays use them to keep our food at a safe temperature. Commercial chillers, air conditioners, mini- and multi-split heat pumps, and variable-refrigerant-flow (VRF) systems use refrigerants for space cooling and heating. They're even used in vending machines, water coolers, ice machines, dehumidifiers, residential clothes dryers, and water heaters.

It's not just that refrigerants are everywhere. Many systems use refrigerants with thousands of times the impact on global warming of carbon dioxide. These refrigerants can escape during installation, servicing, accidents, and disposal. For HVAC systems, the energy and carbon savings from their use usually outweighs the potential greenhouse gas emissions of the refrigerants over the equipment's lifespan, but not if these systems are improperly installed, commissioned, or disposed of.

As we try to minimize energy use and move away from consuming fossil fuels toward more energy-efficient equipment, we are using more electricity for heating and cooling—and that means using more refrigerants than ever. Heat pumps and VRF systems (heat pumps that serve multiple rooms and can provide cooling to one part of a building while heating another), for instance, have become the go-to heating and cooling method for high-performance homes and many commercial spaces. These systems often use long lines of refrigerant that both increase the volume of refrigerant used, and expose it to the risk of release.

In this article, we'll explore:

- how refrigerants work

- data comparing the carbon footprint of mini-split heat pumps and standard high-performance HVAC systems
- ways of reducing refrigerant leaks throughout the appliance life cycle
- alternative refrigerants and their limitations
- some steps we can take to minimize the environmental impact of these important fluids

What Are Refrigerants?

We feel the effect of refrigerants every time we sweat. As water evaporates off our skin, turning from a liquid to a vapor, it expands, pulling heat from our bodies. Commercial chillers, heat pumps, and refrigerators use this same principle but in a closed loop called a vapor-compression cycle (see image), where the following steps occur:

1. A liquid refrigerant flows through an expansion valve or similar device, where it turns into a vapor in an evaporator.
2. Heat moves from the room or refrigerator through the walls of the evaporator piping/tubes to the vapor, cooling the room and warming the vapor.
3. The superheated vapor flows to a compressor, where it is compressed, adding some additional heat from mechanical action in the process.
4. The compressed, superheated vapor flows to a condenser where the heat is removed by either air or water (such as radiators on air conditioners), cooling the vapor and transforming it back into a liquid. The heat energy is either vented or in some cases captured for reuse.
5. The cooled, liquid refrigerant is pumped back through the system and the loop repeats.

With many HVAC systems, ducts connect to a central air-conditioning unit to provide cooling and are hooked into a fresh air supply, but split-system heat pumps (https://www.buildinggreen.com/feature/ductless-mini-splits-and-their-kin-revolution-variable-refrigerant-flow-air-conditioning) [3] are usually ductless and do not provide fresh air. Instead, an outdoor compressor pumps refrigerant via tubing to indoor units that can heat or cool rooms, depending on the direction of refrigerant flow. VRF systems have long tubing runs that require addition refrigerant.

HVAC systems use different types of compressors, ranging from old piston-driven, reciprocating models to centrifugal units that spin and use magnetic levitation instead of bearings (see Magnetic-Bearing Chillers: Cooling without Friction (https://www.buildinggreen.com/product-review/magnetic-bearing-chillers-cooling-without-friction) [4]). These systems typically use different amounts and types of refrigerant.

Short- vs. Long-Term Carbon Emissions

To get a better idea of the impact refrigerants have on carbon emissions and energy use, Robin Neri and Marc Zuluaga, mechanical engineers at Steven Winter Associates, recently presented some theoretical calculations. They calculated the carbon output of two theoretical residential HVAC systems: a single-room mini-split air-source heat pump versus a best-in-class efficient gas hydronic baseboard system.

“We looked at heating use and carbon emissions per square foot of floor area based on the typical size system to serve that floor area apartment (500 square feet),” says Neri. The calculations are based on energy and climate data specific to New York City and assumed an annual heating coefficient of performance (COP) of 2.5 (2.5 kilowatt hours of heat energy are produced for every 1 kWh consumed) for a

12,000 Btu/hour (1 ton) heat pump.

They estimated the amount of refrigerant in the system, or “charge,” to be about 2.9 pounds of refrigerant, including that contained in the tubing connecting the indoor and outdoor units.

And, importantly, they also incorporated refrigerant leakage in their calculations, which changes the environmental impact of the system.

Neri and Zuluaga reported the following key findings:

- The heat pump’s electricity consumption equals annual CO_2 equivalent (CO_2e) emissions of approximately 1.0 pound per square foot (1.0 lb/sf/yr), based on the New York City electrical grid.
- The hydronic system would generate CO_2e emissions twice that: about 2.0 lb/sf/yr.
- If all of the refrigerant (R410a) were to escape from the heat pump, it would result in approximately 12 lb/sf of CO_2e emissions, or 6,000 pounds CO_2e. For reference, burning a ton of coal releases 3,740 pounds of CO_2, according to the U.S. Energy Information Administration, so 6,000 pounds of CO_2e equates to burning 1.6 tons of coal.

The table provides a detailed summary of the team’s data.

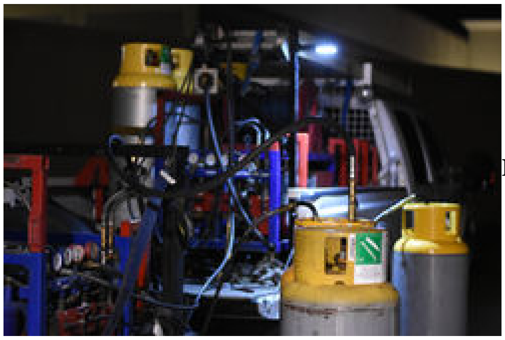
Impact of Refrigerant Leakage per Year on Heating CO_2 Intensity

Refrigerant leakage rate per year	Pounds CO_2e per square foot per year due to building emissions and refrigerant leakage
0%	1.0
1%	1.2
5%	1.6
10%	2.2 (comparable to a gas hydronic system = approximately 2.0)
25%	3.8 (comparable to a median electric baseboard = approximately 4.2)
40%	5.8 (comparable to a median steam building = approximately 6.2)

Zuluaga says that they were looking at refrigerants from the application side within the context of the electrification of larger buildings in New York City. “We wanted to raise industry awareness around the (leakage) issue. We can’t realize 80 x 50 carbon reduction goals (80% 2005 greenhouse gas emission levels by 2050) without figuring out how to responsibly scale up heat pumps.” But the leakage rate problem could be extrapolated to larger heat pumps. “There are a lot of reasons to do VRFs,” he says, “but if a primary reason to retrofit a building with VRF is carbon, then you really can’t ignore leakage.” According to Neri and Zuluaga, at 10% leakage per year, the carbon benefit of a small residential heat pump disappears compared to a top-tier gas-fired hydronic system. In commercial applications, VRF systems require approximately four to six pounds of refrigerant for every ton of cooling to account for longer tubing runs and larger equipment. In these cases, the leakage and long-term carbon emissions become even more important.

How much do these systems actually leak? Clearly, that’s critical to understanding their actual CO_2e impact. We’ll get into that later in the article.

How Concerned Should We Be?



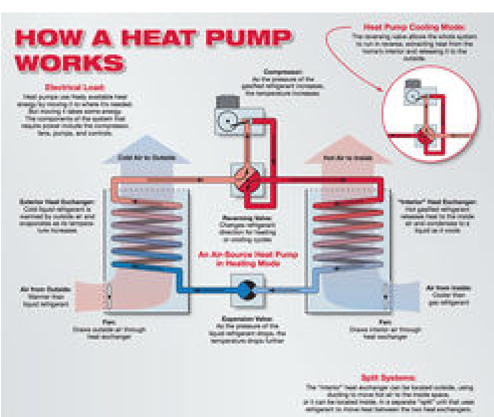
Reducing the greenhouse gas emissions from our homes and businesses is a priority, and *Drawdown* puts a surprising focus on refrigerants. But only about 35% of hydrofluorocarbon (HFC) refrigerants are used for HVAC (http://ozone.unep.org/sites/ozone/files/Meeting_Documents/HFCs/FS_2_Overview_of_HFC_Markets_Oct_2015.pdf) [5]. This is a significant percentage, but far more refrigerants (including hydrochlorofluorocarbons, or HCFCs, found in grandfathered systems) are used in commercial food preparation and storage, supermarket displays, industrial and petroleum refining, and cars, and all have worse records in terms of accidental leakage. So, looking across various industries, HVAC in homes and offices isn't the most critical sector. However, data like Neri and Zuluaga's show that refrigerant use in HVAC has to be considered.

According to the U.S. Department of Energy (https://www.researchgate.net/profile/Zoubair_Boulahia/post/Is_there_any_earlier_studies_on_how_can_we_recycle_heat_emitted_from_out-building_parts_of_air_condition/attachment/59d63cfb79197b8077999e24/AS:417917561786369@1476650719466/download/The+Future+of+AC+Report+-+Full+Report_0.pdf) [6] (DOE), globally, air-conditioning accounts for 700 million metric tons of CO_2e annually. Direct emissions of refrigerants from comfort cooling accounts for about 21% of this output. The majority comes from indirect emissions generated by power plants and other sources that provide energy to the system. Though not a panacea, using low-GWP refrigerants would reduce CO_2e emissions from HVAC significantly.

These reductions will be particularly important since the number of air-conditioners (mostly heat pumps) is growing worldwide and is expanding rapidly in developing countries. The International Energy Agency projects that by 2050, developing countries will use 4.5 times more air-conditioning than in 2010. Data from the National Sample Survey Organization (https://www.iea.org/media/workshops/2016/egrdspacecooling/5.NiharShah.pdf) [7] bears this out. Of those surveyed, air-conditioner ownership in urban China went from almost 0% in 1990s to 100% in 15 years.

To reduce climate impacts of our HVAC systems we will have to move toward low-GWP refrigerants, along with other measures. *Drawdown* calculates that in 30 years, capturing 87% of refrigerants from equipment leaks and at the end of equipment life would avoid emissions equivalent to 89.7 gigatons (89.7 billion tons) of CO_2. Getting there will be the challenge.

Refrigerant Basics



The various refrigerants that run through comfort cooling systems are not one-size-fits-all. A window-mounted air-conditioner has a few ounces of refrigerant, whereas a supermarket refrigeration system can contain more than 40,000 pounds. Each system typically requires different refrigerants. That's because refrigerants store heat at different rates, become a vapor at different temperatures, require different pressures in the compressor, and work in tandem with different lubricants. Cooling systems (and heating in the case of heat pumps and VRF systems) are optimized to take advantage of the mechanical properties of the fluids and compressors to operate as efficiently, and inexpensively, as possible.

The evolution of refrigerants

Early refrigerants—such as methyl chloride or sulfur dioxide—were often toxic, flammable, or both. (Ammonia, propane, and CO_2 were also used—and still are—but are not ideal for all applications; more on this later.) So in the 1920s, the industry turned to safer and more stable compounds based on chlorine, fluorine, and carbon chemistries.

The first generation of refrigerants were known as chlorofluorocarbons (CFCs). They became the refrigerant standard and ushered in the modern era of air conditioning. There was a heavy price to pay for our newfound comfort, however. CFCs destroy the ozone layer that protects the planet from ultraviolet radiation (see the Primer (https://www.buildinggreen.com/primer/ozone-depletion-global-warming-kigali-amendment) [8] article on the Montreal Protocol). They also have a very high global warming potential—the major CFC refrigerant R-12 has a GWP 10,000 times that of CO_2.

The international community adopted the Montreal Protocol on Substances that Deplete the Ozone Layer in 1989 to stop the use of these ozone-depleting substances worldwide. Seven years later the U.S. banned CFCs under the Clean Air Act.

The second generation of refrigerants, hydrochlorofluorcarbons (HCFCs), have lower ozone-depletion potential (ODP), but still have very high GWP. They are scheduled to be phased out by the Montreal Protocol, and Clean Air Act as well, with 99.5% gone by 2020 and 100% by 2030. This phase out includes the HCFC R-22, one of the most versatile and widely used refrigerants.

Concern over ozone depletion led to the adoption of the third generation of refrigerants: chlorine-free HFCs. But there has been an environmental price to be paid for these as well. As research piled up over the decades, scientists found that HFCs have a high global warming potential. The Kigali Amendment to the Montreal Protocol, ratified in 2016, is intended to begin the phaseout of these refrigerants worldwide, but its adoption has stalled in the U.S.

The fourth generation of refrigerants, hydrofluoroolefins (HFOs), do not contain chlorine or carbon. They offer zero ODP and very low GWP. Natural refrigerants such as CO_2, propane, and ammonia also have a niche in refrigeration and cooling, and are exempt from Montreal-related regulations due to their low OWP and GWP.

Refrigerants and Their Ozone-Depleting and Global-Warming Potentials

Type	ASHRAE Number	IUPAC Chemical Name	Atmospheric Lifetime (years)	ODP	GWP 100-yr	ASHRAE 34 Safety Group
CFC	R-11	Trichlorofluoromethane	45	1.0	4,750	A1
CFC	R-12	Dichlorodifluoromethane	100	1.0	10,900	A1
HCFC	R-22	Chlorodifluoromethane	12.0	0.05	1,810	A1
HFC	R-32	Difluoromethane	4.9	0	675	A2L
HCFC	R-123	2,2-dichloro-1,1,1-trifluoroethane	1.3	0.02	77	B1
HFC	R-134a	1,1,1,2-tetrafluoroethane	14	0	1,430	A1
HCFC	R-141b	1,1-dichloro-1-fluoroethane	9.3	0.12	725	A2
HC	R-290	Propane	12	0	3.3	A3
HFC	R-410a	R-32/125 (50+.5, −1.5/50+1.5, −.5)	16.95	0	2,088	A1
HFO	R-1234yf	2,3,3,3-tetrafluoropropene	0.03	0	4	A2L

CFCs: chlorofluorocarbons; HCFC: hydrochlorofluorocarbons; HFC: hydrofluorocarbons; HC: hydrocarbons; HFO: hydrofluoroolefins

The GWP of HFCs and other refrigerants can be difficult to calculate. That's because of the way different refrigerants react with the atmosphere. Some linger for years yet do little damage, while others react quickly and dissipate. The Intergovernmental Panel on Climate Change (IPCC) provides GWP in 20-, 100-, and 500-year intervals. The 100-year interval is most often used for comparisons and policy decisions, and will be used here. The IPCC updates its 100-year GWP of refrigerants periodically based on improved data, so it is common to see different values provided in literature. R-410a, for example, was once considered to have a GWP of 1,725, but was updated to 1,975, and is now considered to have a value of 2,088. Whichever number you pick, it's high!

Life-cycle impacts

The GWP of a refrigerant is a snapshot of its potential impacts and only tells part of the story. To try and gain a clearer picture of impacts over time, some experts are turning to life-cycle models that measure both direct and indirect emissions of equipment, and can give a more complete carbon accounting.

Total equivalent warming impact (TEWI), for instance, looks at the refrigerant GWP, the annual leakage rate, equipment run-time, system efficiency, and other metrics, with local utility fuel sources complicating the carbon calculation. Life-cycle climate performance (LCCP) takes TEWI one step further, adding the emissions from refrigerant production and transportation.

These tools are intended to provide more accurate pictures of refrigerant impacts and are useful for comparing theoretical data. In the real world, fuels used by local utilities have different carbon impacts whether using coal or more renewables. Equipment is also application-specific, with different leakage rates that vary from system to system.

For instance, some models run using TEWI as their metric show that CO_2 as a refrigerant can have a greater overall carbon impact than R-410a, mostly due to CO_2 refrigerant system inefficiencies and system type. But end uses of CO_2 systems are usually different than those using R-410a, and CO_2 is an effective refrigerant in the right applications.

The lack of reliable leakage-rate data adds to the complexity of gathering life-cycle data, so some have chosen to omit their use. Patrick Phelan, professor of mechanical and aerospace engineering at Arizona State University and manager of the Emerging Technologies program at the DOE's building technology office from 2012 through 2016, worked with international research experts to judge the impact of refrigerants. "The key part is estimating the leakage rates of refrigerants over their lifetime," he says. "That is the part that is difficult to agree on." In the end, their group chose to use standard refrigerant GWP numbers to avoid ambiguity.

Leakage and Disposal

Karim Amrane, vice president of regulatory and research at the Air-Conditioning, Heating, and Refrigeration Institute (AHRI), estimates that for commercial chillers, almost 95% of the emissions come from creating the energy that powers them. "If you do the math using life-cycle climate performance, the greatest contribution to the climate is not coming from the refrigerant; it comes from the indirect emissions." But extrapolating from the Steven Winter calculations, leakage rates that exceed 10% from VRF systems could potentially result in a system with more direct emissions than indirect.

Leakage

Amrane states, "if it (a refrigerant) doesn't leak, there is no direct impact." But when there are leaks, they are no laughing matter. Leaks reduce system efficiency, capacity, and reliability, as well as add costs for replacement refrigerant, parts, and labor. Refrigerant leaks can come from initial charging (adding refrigerant), defective equipment, installation (even when done well), repairs, corrosion, damage, recharging, and improper disposal.

Refrigerant emissions have gained a lot of attention because of the number and volume of leaks from supermarket and large commercial refrigeration. These systems have had reported leakage rates of 35% annually and can use 3,500 pounds or more of refrigerant, according to the U.S. Environmental Protection Agency (EPA). With long piping runs and connections that are subjected to vibration, long hours, and generally rough conditions, large refrigeration systems like these have more opportunities for leaks. The same is true for cars, where vibration, corrosion, and DIY repairs lead to more accidental releases.

Experts are less concerned about leaks from residential and commercial HVAC systems, because they are often factory-built to tighter tolerances and have fewer connections that can leak or fail. Even so, the International Institute of Refrigeration (http://www.iifiir.org/userfiles/file/publications/notes/NoteTech_24_EN.pdf) [9] estimates that commercial chillers have leakage rates of up to 15% and residential and light commercial systems up to 10%, and higher for complicated split systems. Of course, the more connections, the more chance of leakage, so special attention should be paid when installing larger commercial systems such as VRF systems with long refrigerant lines.

For small leaks from residential and light commercial systems, there's not much we can do, according to Keilly Witman, owner of KW Refrigerant Management Strategy and co-chair of the North American Sustainable Refrigeration Council, who says "AC units have very little refrigerant in them, and by the time you find out you have a leak, it is too late to save the refrigerant inside of it. It doesn't take very long for five pounds of refrigerant to leak out." Witman, who used to run the GreenChill Partnership at the EPA covering supermarket refrigerant emissions, said occupants rarely know there is a leak until they notice the system isn't working properly, and by then it is often too late.

End of life

To truly minimize the impact of refrigerants as put forth in *Drawdown*, we need to address the elephant in the room: managing refrigerants at the end of equipment's service life. We can't assume refrigerants will be captured before disposal, and many life-cycle models assume 100% emissions at the end of life.

As with leakage rates, there is little solid data to assess all the losses due to equipment failure or improper disposal of equipment. Witman notes that most equipment is replaced or repaired when it stops working, and that often means it has lost most, if not all, of its refrigerant.

Refrigerant recovery realities

Collecting refrigerant from aging equipment is not a simple matter. Under Section 608 of the Clean Air Act, "You are required to evacuate any piece of equipment that contains an ozone-depleting refrigerant before that equipment is disposed of," according to Witman. "It doesn't matter if it is a home air-conditioner or a supermarket refrigeration rack." You have to account for leakage, and building owners can be fined for not complying. The refrigerant also has to be captured in the case of service calls, where repairing or removing a part would result in a leak, such as replacing a compressor.

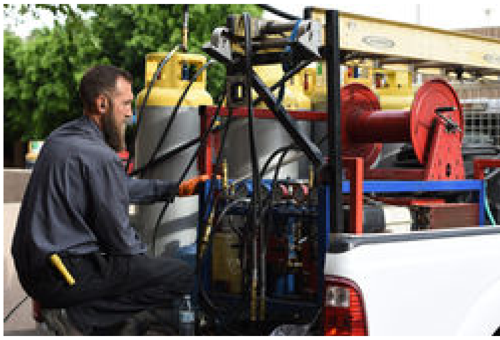
But do people comply? They should. Refrigerants are nearly 100% recyclable, and can be used over and over for years with little loss in performance. Because of this, there are economic and regulatory incentives for recovering refrigerant from large commercial systems, so approximately 80% of those refrigerants are captured at end of service life, according to a report from the California Air Resources Board (https://www.arb.ca.gov/research/rsc/10-28-11/item7dfr07-330.pdf) [10] (CARB). This refrigerant can potentially be reclaimed and recycled, depending on the type and its quality, further lowering costs and the overall carbon footprint. Glenn Rose, vice president of sales and network operations at Rapid Recovery, a national refrigerant recovery company, says recovering 500 pounds of refrigerant at a market rate of $4.80 a pound (for R-22) can more than pay for the cost of recovery.

For smaller equipment, there is little or no economic incentive to collect the amount of refrigerant in these systems. It is cheaper and easier for a service technician to simply vent the refrigerant rather than take the time to set up equipment and capture both the liquid and vapor, said Rose. In fact, if a service technician charges for new refrigerant, then recovering and reusing old refrigerant costs them money and becomes a financial disincentive.

At the end of equipment's life, recovery can be just as much of a challenge. Scrapyards get money for steel and copper from appliances, and can stack those materials, but recovering six ounces of refrigerant from an air conditioner, storing it in a canister, and then selling it is not nearly as easy.

Accidental losses during equipment removal and transport are also common. The end result? CARB estimates that only 2% or less of refrigerant is recovered from smaller air-conditioning units—and this is in California, which has the best recovery and enforcement in the country. In the rest of the U.S. and other areas with lax enforcement, refrigerant recovery is probably far less.

Enforcement, motivation, and carbon credits



The amount of refrigerant a system is allowed to leak before requiring service under the Clean Air Act is an astounding 35% for commercial refrigeration and 15% for heating and cooling, well beyond the point where optimum performance is compromised. So the environmental bar is not very high, and those who release refrigerants into the atmosphere are unlikely to be caught—or punished. That's because the EPA is in charge of enforcing the entire Clean Air Act, including refrigerant releases, but there are far too few EPA offices and staff throughout the country for effective refrigerant enforcement. "Even when they do decide to enforce them, they go after companies that will really make an impression (such as large food warehouse chains)," Witman says. "It is very unlikely they will go after any kind of air-conditioning."

In California, refrigerant regulations are taken more seriously under CARB's Refrigerant Management Program (RMP), which requires both refrigerant recovery and record keeping. California's RMP is intended for systems using more than 50 pounds of refrigerant. But those who recover and process refrigerants also have to comply with the regulations. And this is important because these are the companies handling the refrigerants. According to Rose, you can do every part of the process (recovery and processing), but you still need to document it. And to enforce the regulations, the state inspects companies for compliance, including paperwork.

Still, Rose says, "When you look at enforcement, the spirit of the law is right but compliance is minimal." The economic disincentives for recovering substances that evaporate out of site and out of mind are powerful for smaller HVAC systems. Many people who work in the industry still don't fully understand the impact of venting high-GWP refrigerants, he says. But that is starting to change. He claims, "Just by educating people and talking with them, they will do the right thing." He notes that some companies are now touting their refrigerant recovery as part their sustainability message.

Rose's Rapid Recovery is one of those companies. He says he "evangelizes" about refrigerant recovery because recovery is the right thing to do. He also recognizes the need for others to make it worth their while. He claims his company uses equipment that recovers refrigerant faster than standard systems, and provides them with support and documentation help, among other services. They also work with scrap dealers and others to educated them and increase their incentive to recover refrigerants. "We are going to go out there and make it as easy as possible for people to make the right choice, he said. "If we can save a third to a half, we've done a great job."

In 2016, Rapid Recovery recovered 7 billion pounds of CO_2e in refrigerants and is up to over 14 billion in 2017, and climbing.

The only way refrigerant recovery becomes viable is if there is a financial motivation, and California is using carbon credits as incentive. Under the state's Global Warming Solutions Act of 2006 (AB32) (http://www.arb.ca.gov/cc/ab32/ab32.htm) [11], the state created a cap-and-trade program that establishes a market for CO_2e. Though cap-and-trade has its challenges, such as opposition from industry, in a system like this, high-GWP refrigerants become a potentially valuable commodity. As of September 2017, a metric ton of CO_2e was worth nearly $13.00, according to the California Carbon Dashboard (http://calcarbondash.org) [12], and was more than $20.00/metric ton in 2011.

Regulatory Shenanigans

Under President Obama, the U.S. amended the Clean Air Act to include high-GWP HFCs. These updated requirements would have gone into effect in 2019, decreasing annual greenhouse gas emissions by an estimated 7.3 million metric tons. That's the equivalent of annual emissions of 1.5 million cars, according to the EPA.

U.S. refrigerant manufacturers Honeywell and DuPont, as well as Daikin and others, were in favor of the new regulations, but two refrigerant manufacturers—Arkema from France and Mexichem Fluor from Mexico—sued the EPA, contending that the Clean Air Act only covered ozone-depleting chemicals. In August 2017, the courts sided with Arkema and Mexichem, throwing regulation of HFC refrigerants in the U.S. into question. According to Witman, if the ruling stands, more than refrigerants are at risk, and the EPA's Stratospheric Protection Division will no longer address global warming.

Low-GWP Alternatives

Despite the current regulatory setback in the U.S., replacing high-GWP refrigerants with low-GWP alternatives is a key component for maximizing the environmental performance of heat pumps and other energy-saving HVAC. And there is ongoing research into replacements for high-GWP refrigerants. Phelan says that viable new refrigerants fall into two categories, HFOs and natural refrigerants, such as ammonia, CO_2, and propane.

The AHRI Low-GWP Alternate Refrigerant Evaluation Program began testing these alternatives in 2011, taking into account GWP, toxicity, flammability, stability, performance, temperature changes from liquid to vapor (critical temperature), and other factors. AHRI is independent and only tests refrigerants and does not endorse one over another (refrigerants are often patented, branded, and sold at a profit), but according to Amrane, two of the most promising drop-in replacements are the low-GWP HFCs R-32 (GWP 675) and R-452b (GWP 676) for residential and light commercial; CO_2, propane, and some HFO blends for refrigeration; and blends of HFOs for chillers.

Natural refrigerants

Current Refrigerants and Low-GWP Alternatives

Refrigerant Application	Current Refrigerant	Alternate Refrigerant
Water-Cooled Chiller	R-123	R-1233zd(E) and R-514a
Air-Cooled, Evaporatively Cooled	R-134a	R-513A and R-1234ze
Residential/Commercial Comfort Cooling	R-410a	R-32, R-452b (drop-in replacement)
Commercial Refrigeration	R-404a	R-407a, R-407f, R-448a, R-449a, R-449b
	R-134a	R-450a, R-513a; R-744/CO_2 (supermarkets and other applications); R-290/propane (for charge limited systems as permitted by codes in different regions)

As mentioned, propane is an old refrigerant good for a variety of end uses if flammability concerns can be addressed, and ammonia is also useful in larger industrial and commercial applications, where toxicity can be managed. CO_2 as a refrigerant has had a lot of interest because of its low toxicity, low cost, and low GWP. BuildingGreen has kept an eye on CO_2-based heat pumps over the years, including a commercial system from Mayekawa (https://www.buildinggreen.com/product-review/next-heat-pump-refrigerants-carbon-dioxide) [13] and Sanden's residential split heat-pump water heater, a 2016 BuildingGreen Top 10 product (https://www.buildinggreen.com/product-review/buildinggreen-announces-top-10-products-2016) [14].

Systems using CO_2 do not use vapor compression. They operate at high temperatures and require cooling instead of compression to change from liquid to vapor, known as a transcritical process. These systems require more robust components and piping to handle higher pressures, but they work well in cold temperatures, and they can generate much higher temperatures than standard heat pumps, so they are well suited for water heating and larger systems. Mayekawa, for instance, is used as a boiler replacement in commercial applications, and

CO_2 systems are being adopted for supermarket use.

John Miles, general manager at Sanden, says, “We went to CO_2 in the early 2000s. We looked at the opportunity to use a natural refrigerant that wasn’t flammable or toxic.” Though Mayekawa offers heat pumps in Japan that provide cooling as well, CO_2 is not considered an ideal refrigerant for smaller comfort cooling applications, according to Miles. “It is not very efficient at that format from a thermodynamic point of view, and certain refrigerants (such as R-410a) are really good at doing that.” Instead, Sanden’s systems are solely for heating water. But he notes, “CO_2 is also good at pulling heat away from food. That’s why supermarket chains are beginning to adopt it,” he says.

Coming to appliances in the not-so-distant future

So when can we see these low-GWP refrigerants in products? You’ll have to be patient, because it is going to take some time. To achieve the right combination of performance and low GWP, “refrigerants are going to be flammable one way or the other,” Amrane says. “There is always a tradeoff.”

On the performance side, one refrigerant cannot just be substituted for another without it usually requiring changes to the equipment. Amrane says R-452b will require minimal changes to equipment, but other refrigerants, such as R-32, require higher-pressures and higher discharge temperatures, so you have to redesign the product for that refrigerant. But redesigning equipment could turn out be a positive thing. According to David Calabrese, senior vice president, government affairs at Daikin U.S., "Studies we’ve done show it (using R-32) can improve efficiency by about 10%."

Daikin has been promoting the use of R-32 for years, and has sold millions of air-conditioning products using R-32 in Europe and Asia, he says. The company manufactures both R-32 and air-conditioning units that use it, but Daikin has released its patents on equipment to encourage wider adoption of the refrigerant.

Both R-32 and R452b are considered mildly flammable, and that is a problem. Refrigerants are classified based on flammability, from A1 being least flammable to A3 being most flammable (toxicity is rated B1–B3). Most new refrigerants are classified as mildly flammable at class A2 (the exception is Honeywell’s HFO R1233zd). The most viable low-GWP alternatives, such as R-32 and R-452b, are classified at the even less flammable A2L classification. Getting the lowest flammability and best performance out of these refrigerants is critical for making the transition away from high-GWP options.

Safety is a major concern with refrigerants, and flammability standards are written into codes. ASHRAE 15 limits the use of A2 (HFOs) and A3 refrigerants. “That is what is holding up manufacturers,” says Amrane. For highly flammable refrigerants like propane, there are also restrictions on how much you can use, limiting their availability for larger applications.

According to Amrane, ASHRAE is catching up, and has two addenda out for review that would allow the use of these class A2L refrigerants. The IEC is planning to increase the amount of propane allowed in refrigeration systems from 150 to 500 grams. And the International Code Council will likely adopt the requirements in ASHRAE 15 when finalized.

It takes time for regulations to be approved, adopted, and implemented, and equipment manufacturers are waiting to see how it shakes out. Once approved, they have to optimize equipment to take advantage of the new refrigerants. And then testing and UL approval will be required for some products. It is going to take some time, and Amrane does not expect to see widespread use of new refrigerants for a few years. Of course, early adopters can petition local officials to use new equipment if they can find it and install it safely. When new products do come out, they will likely be far more advanced and efficient than today’s products, further reducing the overall environmental impact of these systems.

In the Meantime

While we wait for technology and codes to catch up, there are a number of common-sense steps that can be taken to lower the GWP of current comfort cooling products. Reducing the cooling load and working with mechanical engineers to "right-size" HVAC systems is critical. John Weale, Engineer Fellow at Integral Group, reaffirms that power consumption is the primary engine of carbon emissions. He recommends the usual steps. "If you use smaller windows and less glass and use more insulation, you can install less refrigerant of any type. Once we get the system size reduced as much as possible, we go for the most efficient unit," Weale says.

Weale acknowledges that HVAC is a challenging field for design teams and engineers. There are only a few options for equipment and refrigerants. And "there is no monetary assessment to get global warming potential down," he says. "Efficiency is what shows up in the monthly pocketbook and reaches beyond preaching to the choir."

Zuluaga also focuses on efficiency and reducing indirect impacts. To bring the overall GWP down, he recommends addressing both energy efficiency and behavioral opportunities. "While more data is needed on the actual field leakage of heat pump systems," he says, "there are some practical things we can do now to minimize impacts, such as proper system commissioning and retro-commissioning. And where possible, packaged equipment that has fewer field joints and less refrigerants per ton should be evaluated."

Finally, in water heating applications, Zuluaga says that heat pumps utilizing CO_2 as a refrigerant are particularly promising from building performance and emissions standpoints.

Reaching the goals set forth in *Drawdown* will require a larger commitment:

1. Create a cap-and-trade system for CO2e that would put a monetary value on high-GWP refrigerants, providing incentive to capture them during equipment commissioning and disposal.
2. Strengthen national regulations to include HFCs.
3. Reduce leaks through improved equipment, monitoring, better fittings that can be used with flammable refrigerants, commissioning, and training.
4. Focus on end-of-life refrigerant management, potentially charging end users for refrigerant management costs up front so there is less incentive to ignore regulations.
5. Use reclaimed HFCs to encourage reclamation and recycling.
6. Select future low-GWP refrigerants based on system efficiency and impacts.
7. Promote education and training programs to improve compliance with regulation.
8. Work with regulators to enforce those regulations.

Source URL: https://www.buildinggreen.com/feature/cost-comfort-climate-change-and-refrigerants?share-code=8f15f67d2c7269da08aa3b9e3e883fdd

Links
[1] https://www.buildinggreen.com/author/brent-ehrlich
[2] http://www.drawdown.org/the-book
[3] https://www.buildinggreen.com/feature/ductless-mini-splits-and-their-kin-revolution-variable-refrigerant-flow-air-conditioning
[4] https://www.buildinggreen.com/product-review/magnetic-bearing-chillers-cooling-without-friction
[5] http://ozone.unep.org/sites/ozone/files/Meeting_Documents/HFCs/FS_2_Overview_of_HFC_Markets_Oct_2015.pdf

[6] https://www.researchgate.net/profile/Zoubair_Boulahia
/post/Is_there_any_earlier_studies_on_how_can_we_recycle_heat_emitted_from_out-building_parts_of_air_condition
/attachment/59d63cfb79197b8077999e24/AS:417917561786369@1476650719466/download
/The+Future+of+AC+Report+-+Full+Report_0.pdf
[7] https://www.iea.org/media/workshops/2016/egrdspacecooling/5.NiharShah.pdf
[8] https://www.buildinggreen.com/primer/ozone-depletion-global-warming-kigali-amendment
[9] http://www.iifiir.org/userfiles/file/publications/notes/NoteTech_24_EN.pdf
[10] https://www.arb.ca.gov/research/rsc/10-28-11/item7dfr07-330.pdf
[11] http://www.arb.ca.gov/cc/ab32/ab32.htm
[12] http://calcarbondash.org
[13] https://www.buildinggreen.com/product-review/next-heat-pump-refrigerants-carbon-dioxide
[14] https://www.buildinggreen.com/product-review/buildinggreen-announces-top-10-products-2016
[15] https://www.buildinggreen.com/avoiding-toxic-chemicals
[16] https://www.buildinggreen.com/heating-cooling