The Current State of Refrigerants

ASHRAE Puget Sound Chapter

September 14, 2017

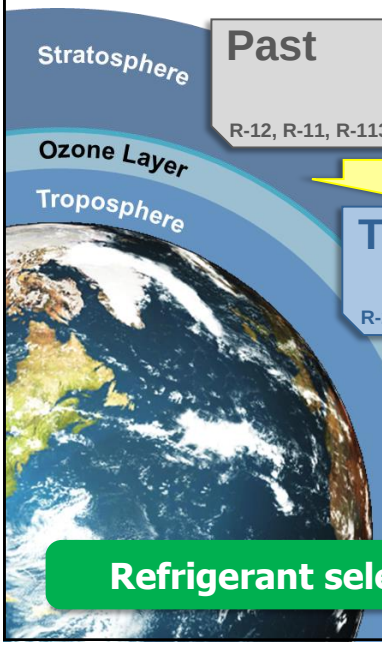
History of HVAC/R Refrigerants

1st Generation "What Ever Worked"	2nd Generation "Safety & Stability"	3rd Generation "Ozone Protection"	4th Generation "Global Warming"
1830's – 1930's	1930's – 1990's	1990's – 2010's	2010 – NOW
• Limited applications mainly industrial • Poor safety & High cost	• Innovation enabled exponential societal improvements	• Preserved 2nd gen. innovations, safety, stability and efficiency	• Fewer optimal choices • Safety & design challenges

• Carbon Dioxide (CO_2)
• Water (H_2O)
• Ammonia (NH_3)
• Various HCs
• Sulfur Dioxide (SO_2)
• Methyl Chloride (CH_3Cl)
	• Sulfur Dioxide (SO_2)
	• CFCs & HCFCs
	  • R-11, R-12, R-22, R-502
	  • R-113, R-114, Many more blends….
		• Sulfur Dioxide (SO_2)
		• HCFCs & HFCs
		  • R-123, R-134a, R-407C, R-410A
		  • R-404A, Many more blends….
			• Sulfur Dioxide (SO_2)
			• HFOs & HFC/HFO Blends
			  • R-1234yf, R-1234ze
			  • R-1233zd, Blends….
			• Renewed Interest "Natural"
			  • CO_2, HCs

Societal Demands Continue to Drive Refrigerant Innovations

Refrigerant Transitions



Past
CFCs
R-12, R-11, R-113, R-500, R-502 more…

Transitional
HFCs & HCFCs
R-22, R-134a, R-410A, R-123 more…

Next-Generation
HFOs & Blends
R-1234ze, R-1233zd, R- 513A, R-514A…

Atmospheric Life

ODP

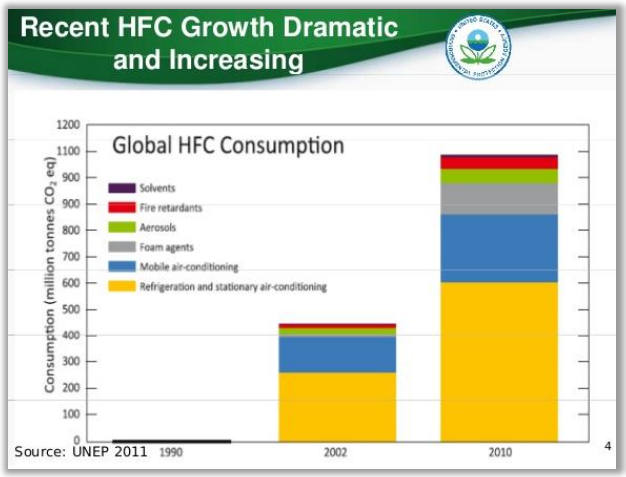
GWP

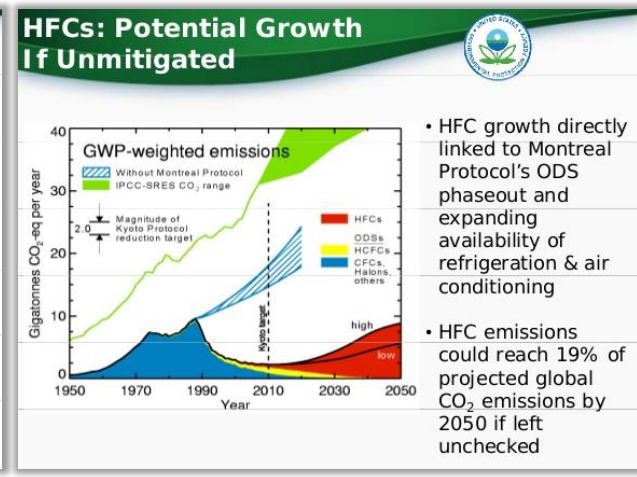
Half-life in DAYS

Refrigerant selection focused on minimizing overall impacts

What is Driving Action?

Dramatic global growth of high-GWP HFCs

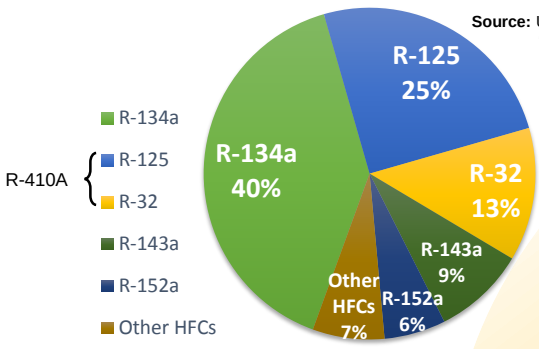




Alignment with Support to Sign Montreal Protocol Amendment

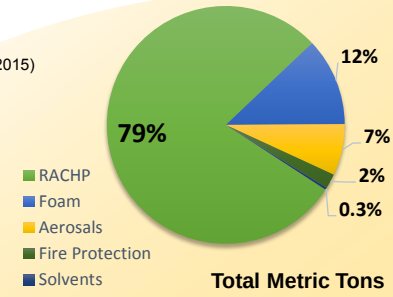
Global Consumption of HFCs

Source: UNEP Ozone Secretariat Fact Sheet 2
"Overview of HFC Market Sectors" (Oct 2015)

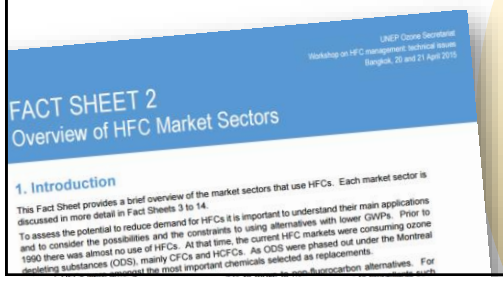


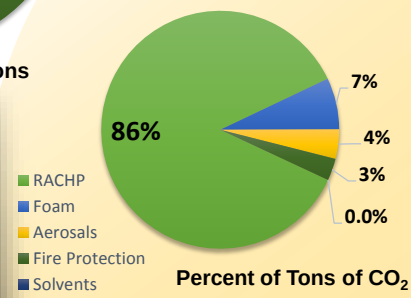
Total Metric Tons

Markets Using HFCs



Total Metric Tons



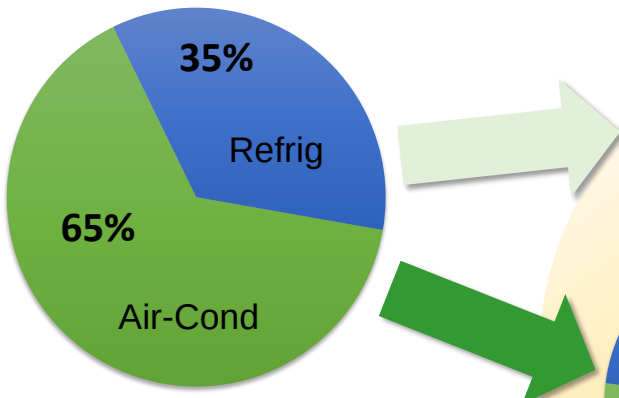


Percent of Tons of CO_2

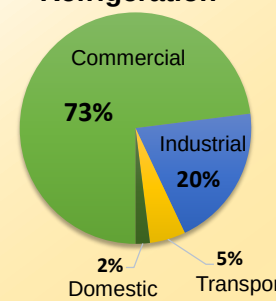
Market	Key HFCs	GWP
RACHP	R-404A R-410A R-407C HFC-134a	3922 2088 1774 1430
Aerosols	HFC-134a HFC-152a HFC-227ea	1430 124 3220
Foams	HFC-134a HFC-245fa HFC-365mfc / HFC-227ea	1430 1030 960 - 1100
Fire protection	HFC-227ea HFC-125 HFC-23	3220 3500 14800
Solvents	HFC-4310mee	1640

Global HFC use of Refrigerants in RACHP

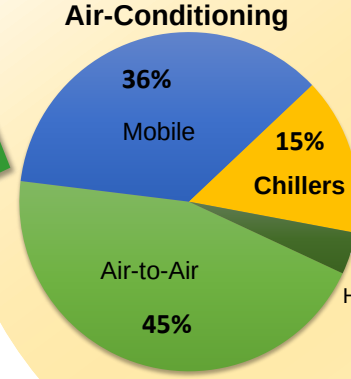
Refrigeration, Air-Conditioning, Heat Pump



Refrigeration



Air-Conditioning



Source: UNEP Ozone Secretariat Fact Sheet 2
"Overview of HFC Market Sectors" (Oct 2015)

Actions Taken in Mobile Air Conditioning

European Environment Agency

European Union F-Gas Regulations

1-1-2013 de facto ban on R-134a in newly type-approved vehicles per Directive 2006/40/EC on mobile air conditioning

R-1234yf in 7 million cars by 2016

Cooling Post

Corporate Average Fuel Economy (CAFE)

The 2012-2016 Standards offer credits for using low-GWP refrigerants other than R-134a:

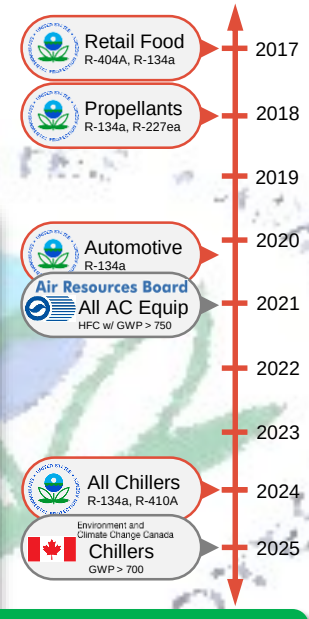
- ~ 3-4 MPG for changing refrigerant
- ~ 5 MPG for overall system changes

Vehicles using **R-1234yf** refrigerant (North America)

Auto Industry, shipping cars with R-1234yf starting in 2011

Need for Refrigerant Choice

Government Action on Setting Phase-Outs on HFCs



More to come…

Montreal Protocol HFC Amendment Agreement

Kigali Amendment – Dubai Pathway on HFCs – Global Transitions Based on GWP

October 15, 2016

Nations, Fighting Powerful Refrigerant That Warms Planet, Reach Landmark Deal

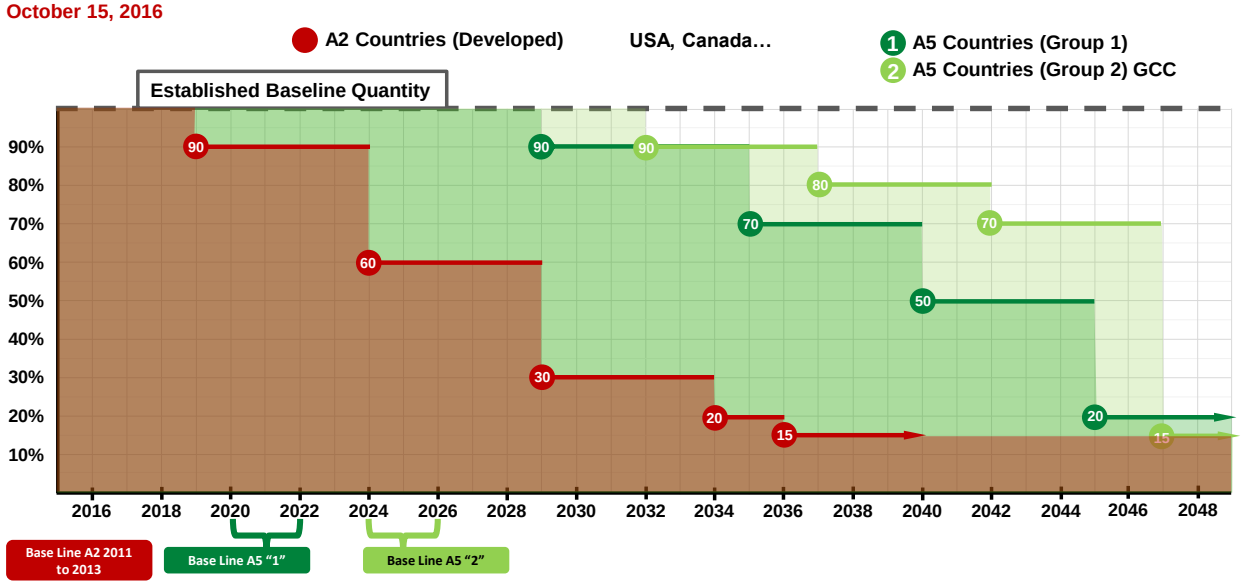
KIGALI, Rwanda — Negotiators from more than 170 countries on Saturday reached a legally binding accord to counter climate change by cutting the worldwide use of a powerful planet-warming chemical used in air-conditioners and refrigerators.

The World has Spoken… Phase Down HFCs

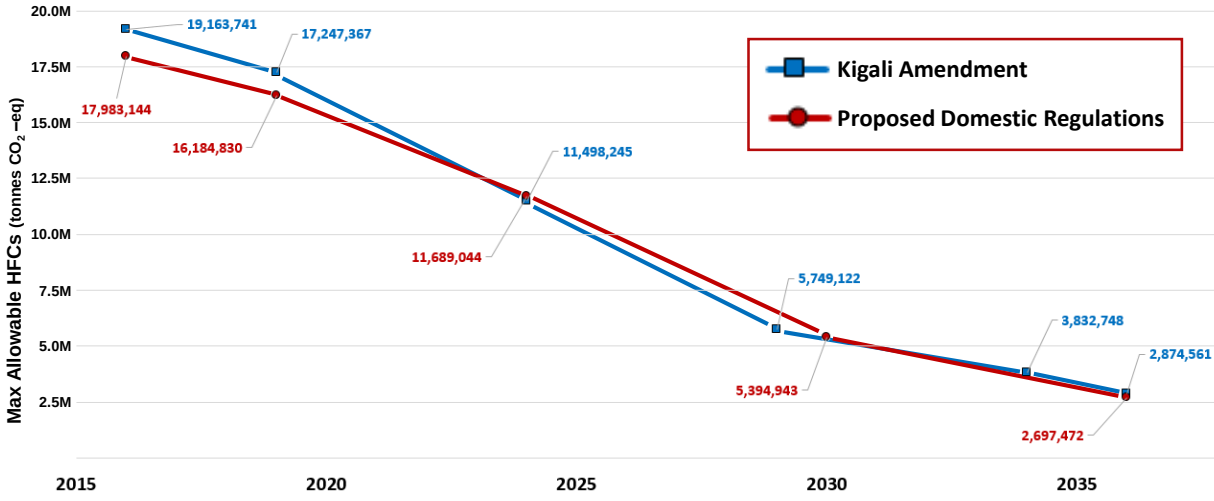
Montreal Protocol HFC Amendment Agreement

Kigali Amendment - Global Transitions Based on GWP

October 15, 2016



Montreal Protocol HFC Amendment Agreement



Comparison of Max Allowable HFC Consumption

AHRI Letter to Executive Branch

Support of Congressional Action

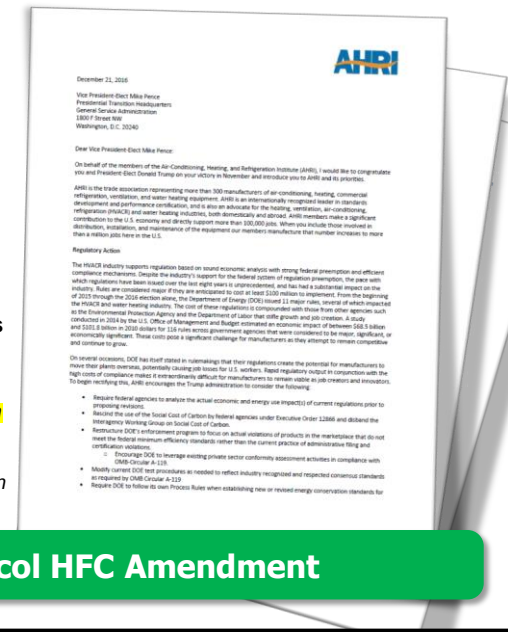
Vice President-Elect Mike Pence **December 21, 2016**

… action should be taken to enable U.S. industry to solidify its position as the global leader of innovation, job creation, and production of energy efficient products and equipment. The industry encourages the following actions in pursuit of that goal.

- *Submit the Kigali Amendment on the usage of hydrofluorocarbons to the Montreal Protocol to the Senate for ratification.*

AHRI, firmly support a number of current programs and regulations that bring predictability and consistency to our marketplace.

- *Maintain the Environmental Protection Agency (EPA) Significant New Alternatives Program (SNAP) as established under Section 612 of the Clean Air Act. The EPA's ability to list alternative refrigerants by issuing new rules and maintaining previous rules continues to allow for flexibility in our members' product designs while pursuing health and safety for consumers in the marketplace.*


AHRI

December 21, 2016

Vice President-Elect Mike Pence
Presidential Transition Headquarters
General Service Administration
1800 F Street NW
Washington, D.C. 20240

Dear Vice President-Elect Mike Pence:

On behalf of the members of the Air-Conditioning, Heating, and Refrigeration Institute (AHRI), I would like to congratulate you and President-Elect Donald Trump on your victory in November and introduce you to AHRI and its priorities.

AHRI is the trade association representing more than 300 manufacturers of air-conditioning, heating, commercial refrigeration, ventilation, and water heating equipment. AHRI is an internationally recognized leader in standards development and performance certification, and is also an advocate for the heating, ventilation, air-conditioning, refrigeration (HVACR) and water heating industries, both domestically and abroad. AHRI members make a significant contribution to the U.S. economy and directly support more than 330,000 jobs. When you include those involved in distribution, installation, and maintenance of the equipment our members manufacture that number increases to more than a million jobs here in the U.S.

Regulatory Action

The HVACR industry supports regulation based on sound economic analysis with strong federal preemption and efficient compliance mechanisms. Despite the industry's support for the federal system of regulation preemption, the pace with which regulations have been issued over the last eight years is unprecedented, and has had a substantial impact on the industry. Rules are considered major if they are anticipated to cost at least $100 million to implement. From the beginning of 2015 through the 2016 election alone, the Department of Energy (DOE) issued 11 major rules, several of which impacted the HVACR and water heating industry. The cost of these regulations is compounded with those from other agencies such as the Environmental Protection Agency and the Department of Labor that stifle growth and job creation. A study conducted in 2014 by the U.S. Office of Management and Budget estimated an economic impact of between $68.5 billion and $101.8 billion in 2010 dollars for 116 rules across government agencies that were considered to be major, significant, or economically significant. These costs pose a significant challenge for manufacturers as they attempt to remain competitive and continue to grow.

On several occasions, DOE has itself stated in rulemakings that their regulations create the potential for manufacturers to move their plants overseas, potentially causing job losses for U.S. workers. Rapid regulatory output in conjunction with the high costs of compliance makes it extraordinarily difficult for manufacturers to remain viable as job creators and innovators. To begin rectifying this, AHRI encourages the Trump administration to consider the following:

- Require federal agencies to analyze the actual economic and energy use impact(s) of current regulations prior to proposing revisions.
- Rescind the use of the Social Cost of Carbon by federal agencies under Executive Order 12866 and disband the Interagency Working Group on Social Cost of Carbon.
- Restructure DOE's enforcement program to focus on actual violations of products in the marketplace that do not meet the federal minimum efficiency standards rather than the current practice of administrative filing and certification violations.
  - Encourage DOE to leverage existing private sector conformity assessment activities in compliance with OMB Circular A-119.
- Modify current DOE test procedures as needed to reflect industry recognized and respected consensus standards as required by OMB Circular A-119.
- Require DOE to follow its own Process Rules when establishing new or revised energy conservation standards for

Industry Supports Montreal Protocol HFC Amendment

US EPA to Tighten HFC Regulations

Changes to Section 608 Refrigerant Management Regulations

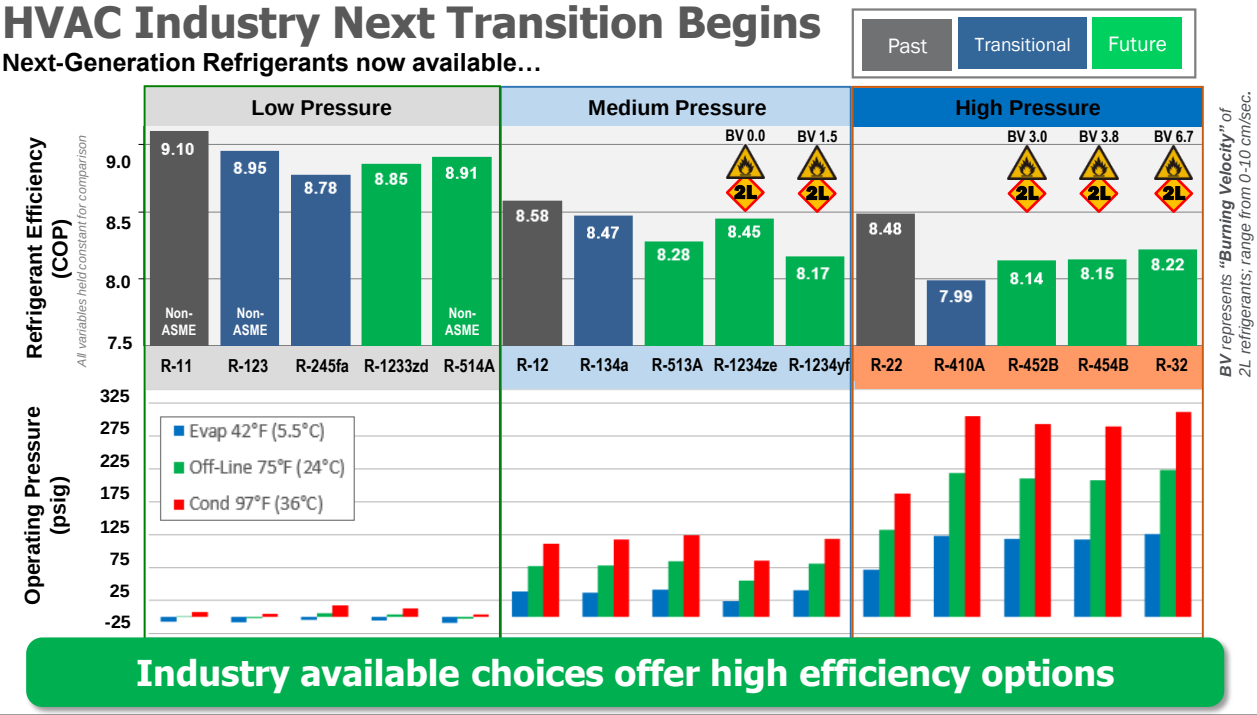
	Current	EPA Final Ruling
Covered	CFCs & HCFCs	CFCs, HCFCs, HFCs & HFOs *(Including all blends)*
Recordkeeping	> 50 lbs.	> 5 lbs. for disposal > 50 lbs. for service/repair
Allowable Leak Rates (systems >50 lbs.)	Industrial Process Ref: 35% Commercial Ref: 35% Comfort Cooling: 15%	Industrial Process Ref: 30% Commercial Ref: 20% Comfort Cooling: 10%
Leak Inspections	None Required	If allowable leak rate is exceeded, then 50-500 lbs. – annual inspections > 500 lbs. – quarterly inspections
Chronic Leaks	None Required	≥ 125% charge loss (in a calendar year), detailed reports must be filled (find & repair equipment)

https://www.epa.gov/section608/revised-section-608-refrigerant-management-regulations

Appeal in having leak-tight machines is a real advantage

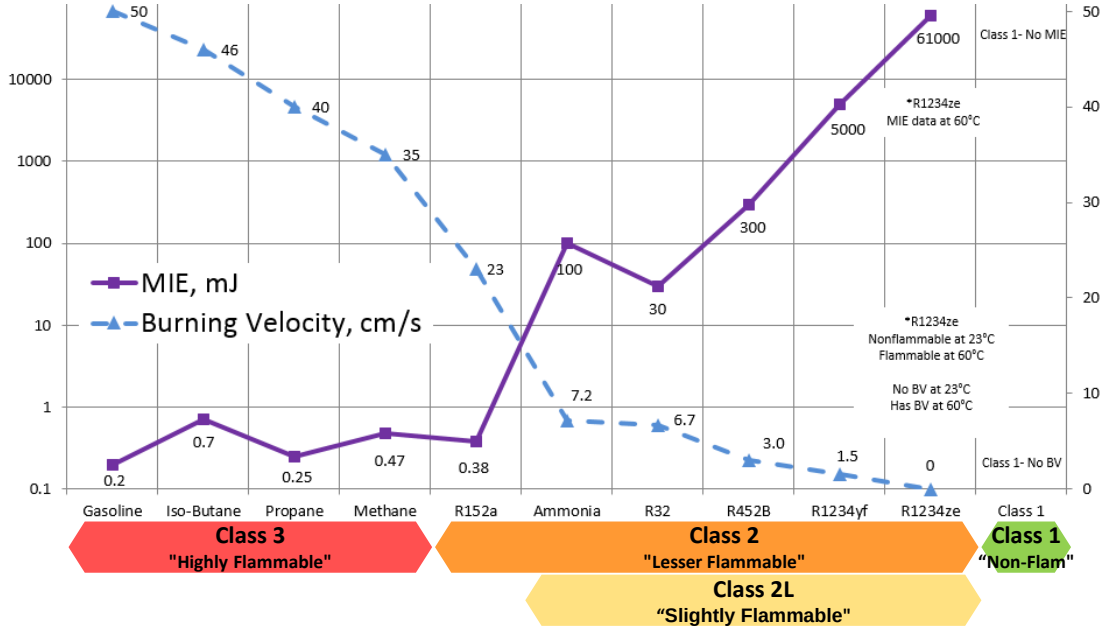
HVAC Industry Next Transition Begins

Next-Generation Refrigerants now available…



Industry available choices offer high efficiency options

Flammability Properties Vary



Visual Examples of Burning Velocity

Differences with 2L Flammable Refrigerants

R-32

Burning Velocity
6.7 cm/sec

Minimum Ignition Energy
>30 mj

R-1234yf

Burning Velocity
1.5 cm/sec

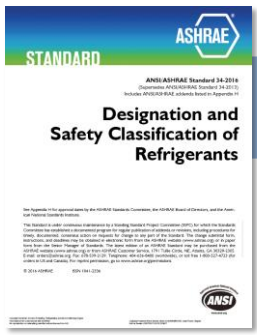
Minimum Ignition Energy
>5000 mj

Burn Velocity Differs Between 2L Refrigerants

ANSI/ASHRAE Refrigerant Standards

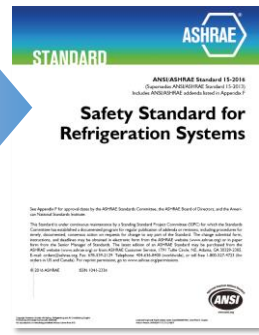
How are they related

Standard 34



Safety Classification

Standard 15



Standard of Care

Model Code

State Law

"enforceable"

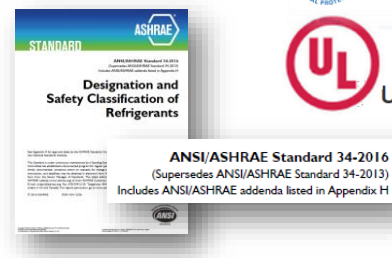
Several Steps Before Code Adoption

Safety Standards and Building Codes

Revisions underway to enable application of next-generation refrigerants

When can we apply these new refrigerants?

1. 2016 ASHRAE 34 ☑
2. SNAP-approved (U.S.) ☑
3. Standards and codes?
   - ❑ **A1/B1 (non-flammable) options… TODAY!** (*no standard or code changes required*)
   - ❑ **A2L/B2L (slightly flammable) options…. *in addition to 1 & 2 above:***



UL 60335-2-40

OUTDOOR INSTALLATION:

- 2017 UL 60335-2-40 Ed. 2
- 2018 model mechanical codes (*e.g. ICC and IAPMO*)
- States, with 2017 UL 60335-2-40 Ed. 2

INDOOR INSTALLATION:

- 2017 UL 60335-2-40 Ed. 2
- 2019 ASHRAE 15
- 2021 model mechanical codes (*e.g. ICC and IAPMO*)
- States, with 2021 model codes

ICC INTERNATIONAL CODE COUNCIL

Non-flammables – today. Outdoor 2L application – with SNAP approval. Indoor 2L application – with 2021 model codes.

Refrigerant Choices & Comparison

Screw & Centrifugal Technology Options

	Low Pressure			Medium Pressure			
	R-123	R-1233zd	R-514A	R-134a	R-513A	R-1234yf	R-1234ze
Flammability	Non (1)	Non (1)	Non (1)	Non (1)	Non (1)	Slight (2L)	Slight (2L)
Toxicity	Higher (B)	Lower (A)	Higher (B)	Lower (A)	Lower (A)	Lower (A)	Lower (A)
Fluid Efficiency	8.95 COP	8.85 COP	8.91 COP	8.47 COP	8.28 COP	8.17 COP	8.45 COP
Capacity Change	1	~35% Gain	~5% Loss	1	Similar	~5% Loss	~25% Loss
GWP	79	1	2	1300	573	1	1

Multiple, Next-Gen Refrigerants available… Today!

High Pressure Replacements

		High Pressure				
		R-22	R-410A	R-452B	R-454B	R-32
Flammability	ASHRAE Class	Non (1)	Non (1)	Slight (2L)	Slight (2L)	Slight (2L)
	BV (cm/s)			3.0	3.8	6.7
Toxicity		Lower (A)	Lower (A)	Lower (A)	Lower (A)	Lower (A)
Fluid Efficiency	Theoretical		7.99	8.14	8.15	8.22
	Drop-in	*n/a*	*n/a*	*8.39*	*8.40*	*7.83*
Capacity Change	Theoretical		1	~2% loss	~3% loss	~9% gain
	Drop-in	*n/a*	*n/a*	*same*	*same*	*same*
GWP		1810	1924	675	466	677
ODP		0.05	0.00	0.00	0.00	0.00

Driving Factors
- Performance
- Safety
- Cost

Blend
26% R-1234yf
7% R-125
67% R-32

Blend
31% R-1234yf
69% R-32

All Current High Pressure Alternatives are 2L

What refrigerant do I select?

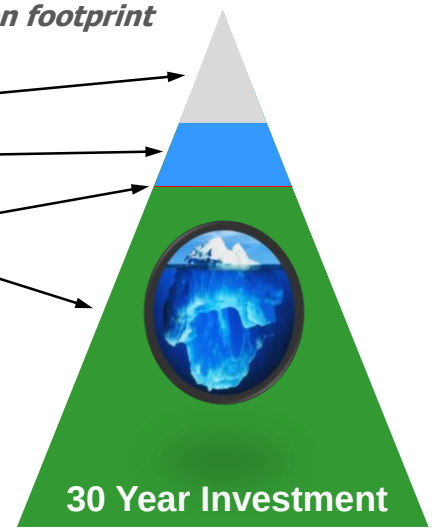
- There are **no** perfect refrigerants
- Take a balanced approach:
  Safety, Environmental Impact, Efficiency
- R-123, R-134a, R-410A, R-404A, R-407C are all responsible HVAC refrigerant choices… *today*
- Leak tightness is key!
  Means lower emissions, higher efficiencies, lower cost, safer
- Next-generation alternatives are available; only A1/B1 refrigerants offer clear and immediate solutions… *it's time to evaluate your options*

Understand your choices… plan for tomorrow

How Can I Protect My Investment?

Total cost of ownership encompasses total carbon footprint

"First Cost" (chiller + refrigerant)	**4.92%**
Lifetime Service Costs*	**6.53%**
Lifetime Refrigerant Supply*	**0.04%**
Lifetime Electrical Costs	**88.51%**



All refrigerants used today are and will be – available for the life of the equipment.

Focus on reliable, efficient designs!

** Based on low-pressure, hermetic design*

A Balanced Approach, with a Focus on Efficiency

Thank you for your time and attention!

Support Documentation & Sources

AHRI Discusses HFC Phasedown with E&ETV

Following AHRI's agreement with ASHRAE and the Department of Energy to help fund flammable refrigerant research, AHRI President and CEO Stephen Yurek spoke with E&ETV's OnPoint to discuss the growing global momentum to phase down HFCs, specifically focusing on how the HVACR industry will work to comply with proposed amendments to the Montreal Protocol. Yurek highlighted AHRI's extensive and proactive research effort to identify suitable alternatives for many different applications in an effort to reduce the use of high-global warming potential refrigerants. Watch the full interview here. Contact: Francis Dietz.

AHRI's Yurek says global momentum building to phase down HFCs

OnPoint: Wednesday, June 8, 2016

http://www.eenews.net/videos/2138?platform=hootsuite

References & Additional Information

How do I Find Out More?

THE MONTREAL PROTOCOL ON SUBSTANCES THAT DEPLETE THE OZONE LAYER

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…and industry support:
http://www.racplus.com/newsletter/news/usa-focus/ahri-applauds-hfc-phase-down-decision/8691735.article
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http://www.epa.gov/climatechange/ghgemissions/gases/fgases.html
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Rule 20 (July 2015) – Prohibition on the use of certain high-GWP HFCs as alternatives
Final Rule: https://www.gpo.gov/fdsys/pkg/FR-2015-07-20/pdf/2015-17066.pdf
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http://www.coolingpost.com/world-news/r134a-faces-chiller-ban-from-2025/
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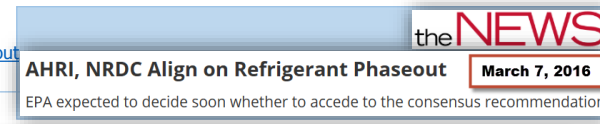

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How do I Find Out More? (cont.)

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AHRI's Low-GWP Alternative Refrigerants Evaluation Program
http://www.ahrinet.org/site/514/Resources/Research/AHRI-Low-GWP-Alternative-Refrigerants-Evaluation

Kujak S., Thompson, M. "Future of refrigeration and air conditioning in 2032; insights into design and market challenges with lower global warming potential (GWP) refrigerant candidates." Cryogenics and Refrigeration-Proceedings of ICCR2013. Paper ID: B-4-10.

Trane / Ingersoll Rand:
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Considerations for Next-Generation HVAC Refrigerants (February 2015)
http://www.trane.com/content/dam/Trane/Commercial/global/products-systems/education-training/industry-articles/ENV-APN001A-EN_2015_refrigerants.pdf

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http://www.trane.com/content/dam/Trane/Commercial/global/products-systems/education-training/engineers-newsletters/energy-environment/adm-apn041-en_0711.pdf

CenTraVac™ Chiller Environmental Product Declaration (EPD) – UL Environment Sustainable Products Guide
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(Overview of HFC Market Sectors, April 2015)

http://www.epa.gov/ozone/downloads/HFC_Amendment_2013-Summary.pdf
(Nice summary of North American proposal to Montreal Protocol)

http://www.achrnews.com/articles/122923-the-future-of-hfcs-in-montreal-protocol
(April 2013, quotes from other HVAC companies)

http://www.epa.gov/ozone/intpol/mpagreement.html
(Sept 2013, fact sheets on the right side of page – focuses on refrigeration, but shows next refrigerants)

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(Sep 2013, G20 nations sign agreement to curtail HFCs)

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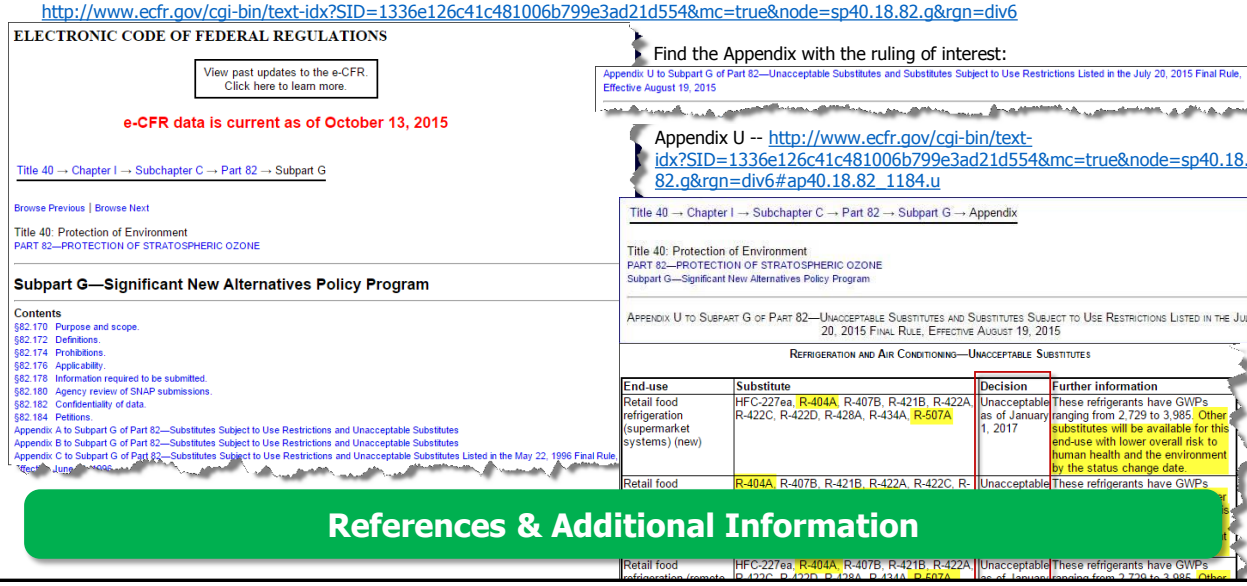
(Unacceptable Refrigerants & Those Subject to Restrictions)

U.S. Government Publishing Office/Electronic Code of Federal Regulations
Title 40 > Chapter I > Subchapter C > Part 82 > Subpart G
http://www.ecfr.gov/cgi-bin/text-idx?SID=1336e126c41c481006b799e3ad21d554&mc=true&node=sp40.18.82.g&rgn=div6



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Appendix U -- http://www.ecfr.gov/cgi-bin/text-idx?SID=1336e126c41c481006b799e3ad21d554&mc=true&node=sp40.18.82.g&rgn=div6#ap40.18.82_1184.u

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Title 40: Protection of Environment
PART 82—PROTECTION OF STRATOSPHERIC OZONE
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APPENDIX U TO SUBPART G OF PART 82—UNACCEPTABLE SUBSTITUTES AND SUBSTITUTES SUBJECT TO USE RESTRICTIONS LISTED IN THE JULY 20, 2015 FINAL RULE, EFFECTIVE AUGUST 19, 2015

REFRIGERATION AND AIR CONDITIONING—UNACCEPTABLE SUBSTITUTES

End-use	Substitute	Decision	Further information
Retail food refrigeration (supermarket systems) (new)	HFC-227ea, R-404A, R-407B, R-421B, R-422A, R-422C, R-422D, R-428A, R-434A, R-507A	Unacceptable as of January 1, 2017	These refrigerants have GWPs ranging from 2,729 to 3,985. Other substitutes will be available for this end-use with lower overall risk to human health and the environment by the status change date.
Retail food	R-404A, R-407B, R-421B, R-422A, R-422C, R-	Unacceptable	These refrigerants have GWPs
Retail food	HFC-227ea, R-404A, R-407B, R-421B, R-422A, R-422C, R-422D, R-428A, R-434A, R-507A	Unacceptable as of January	These refrigerants have GWPs ranging from 2,729 to 3,985. Other

References & Additional Information