The Changing Refrigerant Landscape (Minefield?!)

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Today's Topics

- Drivers for Change
- Regulatory Actions
  - EU F-gas Laws
  - US EPA SNAP Rules
  - SNAP Determinations of Acceptability
  - Section 608 Refrigerant Management
  - Montreal Protocol Amendment
- The Alternatives
  - HFO's and Blends
  - Hydrocarbons
- Future Trends
- Refrigerant Roadmap

Drivers for Change

- #1 Concern: HCFCs deplete atmospheric ozone, HCFCs & HFCs have high Global Warming Potential (GWP)
  - Baseline for GWP is CO_2, set at 1
  - Example GWPs: R404A=3922, R410A=2088, R134a=1430
  - For R22, ODP=0.055 (5.5% of R12), GWP=1810
- Aggressive F-gas regulation now law in Europe
- US EPA SNAP actions
  - Pending de-listing of many HFCs
  - Recent or pending approval of new refrigerants
- Montreal Protocol
  - Treaty ratified by all UN member nations that established phase-outs of CFCs, then HCFCs
  - Now amended to include HFCs
- "Green" sells!

EU F-gas Regulation:
HFC Phasedown, other new requirements begin

- Now law, per Regulation (EU) No. 517/2014 of the European Parliament.
- “Political agreement” in late 2013, final ratification in May 2014, became law in October 2014
- Began phasing into effect 1/1/2015
- Establishes GWP limits and timelines to meet those limits for several different classes of equipment. *(summary table next slide)*
- Establishes categories of equipment based on tons equivalent CO_2 charge, sets requirements for labeling, periodic leak checks, repair, record keeping, and reporting.
- Requires leak monitoring systems on systems larger than 500 tons-equivalent CO_2 charge (~300 lbs R404A, ~600 lbs R407F)
- Requires certified personnel and companies for service and end-of-life recovery.

EU F-gas GWP Limits/Timeline

- 2020/2022 GWP 2500 and 150 Hermetically sealed systems (Refrigerators and Freezer
- 2020 GWP 2500 Stationary refrigeration equipment
- 2022 GWP 150 and 1500 Large commercial refrigeration systems
- 2020 GWP 150 Movable room a/c appliances
- 2025 GWP 750 Small split a/c systems

11. Refrigerators and freezers […] for commercial use (hermetically sealed systems)	**that contain HFCs with GWP of 2500 or more**	**1 January 2020**
	that contain HFCs with GWP of 150 or more	**1 January 2022**
11a. Stationary refrigeration equipment, that contains, or that relies upon for its functioning HFCs with GWP of 2500 or more except equipment intended for application designed to cool products to temperatures below -50°C		**1 January 2020**
11b. Multipack centralised refrigeration systems for commercial use with a capacity of 40kW or more that contain, or that rely upon for their functioning, fluorinated greenhouse gases with GWP of 150 or more, except in the primary refrigerant circuit of cascade systems where fluorinated greenhouse gases with a GWP of less than 1500 may be used		**1 January 2022**
12. Movable room air-conditioning appliances (hermetically sealed equipment which is movable between rooms by the end user) that contain HFCs with GWP of 150 or more		**1 January 2020**
12a. Single split air-conditioning systems containing less than 3kg of fluorinated greenhouse gases, that contain, or that rely upon for their functioning, fluorinated greenhouse gases with GWP of 750 or more		**1 January 2025**

Recent US EPA Actions

Focus turns from HCFCs to HFCs

- SNAP changes – 3 final rules
  - Final (effective 5/11/2015) – adds R32, R170, R290, R441A, & R600a for home & light commercial A/C, stand-alone food retail, vending, others, implements charge limits for A2L & A3 refrigerants.
  - Final (effective 7/20/2015) – eliminates R404A & R507 from most commercial applications, R134a & others from limited applications
  - Final (published 9/26/2016) – lists R290 for new applications; formally eliminates several highly flammable R22 alternates from auto, residential, & chillers; sets timetable for phase-out of R134a, R407C, R410A & others from chillers; R404A, R507, & others from some industrial & domestic refrigeration applications
- US EPA SNAP website:

  http://www.epa.gov/snap/

US EPA Final rule to SNAP list HCs & R32

- New rule opens more applications, including home/light commercial air conditioning, food retail, & vending machines
  - HCs first allowed in a few applications in 2011
  - New rule effective 5/11/2015
  - Hydrocarbons are ASHRAE A3 safety classified – non-toxic, highly flammable
  - R32 is an A2L HFC – non-toxic, mildly flammable, low burn-rate
  - *New equipment only, no retrofits*

Application	R32 (HFC) difluoromethane	R170 (HC) ethane	R290 (HC) propane	R441A (HC) azeotropic blend	R600A (HC) isobutane
New stand-alone retail food refrigeration	---	---	X	X	---
Very low temperature refrigeration (a)	---	X	---	---	---
Household refrigerators and freezers	---	---	X	X (b)	X (b)
Vending Machines	---	---	X	X	X
Residential and Light Commercial A/C and heat pumps	X	---	X	X	---

(a) Designed to maintain temps lower than -170°F

(b) SNAP-listed for this application 12/2011

Please refer to details in final rule, published here:

http://www.gpo.gov/fdsys/pkg/FR-2015-04-10/pdf/2015-07895.pdf

US EPA Final rule to SNAP list HCs & R32 (continued)

- New rule applies charge limits in accordance with UL484
  - Appliances limited to 57 grams
  - Self contained retail & vending limited to 150 grams
  - A/C & heat pumps limited based on refrigerant, unit capacity, size of space unit is intended for, and lower flammability limit of refrigerant/air mixture – up to ~8kg for R32 (A2L HFC)
  - Requires red marking on piping and flammable warning labels on units
- Exempts hydrocarbons from CAA Section 608 prohibition on venting refrigerants
  - Okay to vent R170, R290, R441A, R600a only when servicing the listed applications – not considered hazardous to environment
  - Still required to recover R32, because it is an HFC

Final Rule to de-list HFCs

- US EPA released final SNAP status change on 7/2/2015 affecting HFCs, primarily in commercial refrigeration.
- Air conditioning applications (except autos) unaffected, other areas affected are aerosols and foam blowing.
- Originally published proposed rule on 8/6/2014 with effective dates for most were 1/1/2016
- Comment period closed 10/20/2014 – around 200 formal letters, over 7000 total submitted.
- Many commenter's asked for 2020-21 instead of 2016
- Final dates rolled back some, but prohibitions still began one year after publication in Federal Register - July 20, 2016 for retrofits
- Very aggressive timeline – years quicker than Europe
- Canada is following EPA on HFC bans, though their regulations more closely resemble Europe's

Final Rule to de-list HFCs

Summary of de-listing

EPA Final Rule de-listing Current HFC's

Protection of Stratospheric Ozone: Change of Listing Status for Certain Substitutes under the Significant New Alternatives Policy Program

Application	Refrigerants to be Unacceptable	Effective
Retrofitted supermarket systems	**R-404A**, R-407B, R-421B, R-422A, R-422C, R-422D, R-428A, R-434A, **R-507A**	**July 20, 2016**
New supermarket systems	HFC-227ea, **R-404A**, R-407B, R-421B, R-422A, R-422C, R- 422D, R-428A, R-434A, **R-507A**	**January 1, 2017**
Retrofitted remote condensing units	**R-404A**, R-407B, R-421B, R-422A, R-422C, R- 422D, R-428A, R-434A, **R-507A**	**July 20, 2016**
New remote condensing units	**R-404A**, R-407B, R-421B, R-422A, R-422C, R-422D, R-428A, R-434A, **R-507A**	**January 1, 2018**
Retrofitted vending machines	**R-404A, R-507A**	**July 20, 2016**
New vending machines	FOR12A, FOR12B, **HFC-134a**, KDD6, R-125/290/134a/600a (55.0/1.0/42.5/1.5), **R-404A, R-407C, R-410A**, R-410B, R-417A, R-421A, R-422B, R- 422C, R-422D, R-426A, R-437A, R-438A, **R-507A**, RS-24 (2002 formulation), SP34E	**January 1, 2019**

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Final Rule to de-list HFCs

Summary of de-listing (continued)

EPA Final Rule de-listing Current HFC's

Protection of Stratospheric Ozone: Change of Listing Status for Certain Substitutes under the Significant New Alternatives Policy Program

Application	Refrigerants to be Unacceptable	Effective
Retrofitted stand-alone retail food refrigeration equipment	**R-404A, R-507A**	**July 20, 2016**
New stand-alone medium-temperature units with a compressor capacity below 2,200 Btu/hr and not containing a flooded evaporator	FOR12A, FOR12B, **HFC-134a**, HFC- 227ea, KDD6, R-125/290/134a/600a (55.0/1.0/42.5/1.5), **R-404A, R-407A**, R-407B, **R- 407C, R-407F, R-410A**, R-410B, R-417A, R-421A, R-421B, R-422A, R-422B, R-422C, R-422D, R-424A, R-426A, R-428A, R-434A, R-437A, R-438A, **R-507A**, RS-24 (2002 formulation), RS-44 (2003 formulation), SP34E, THR-03	**January 1, 2019**
New stand-alone medium-temperature units with a compressor capacity equal to or greater than 2,200 Btu/hr and stand-alone medium-temperature units containing a flooded evaporator	FOR12A, FOR12B, **HFC-134a**, HFC-227ea, KDD6, R-125/290/134a/600a (55.0/1.0/42.5/1.5), **R-404A, R-407A,** R-407B, **R-407C, R-407F, R-410A**, R-410B, R- 417A, R-421A, R-421B, R-422A, R-422B, R-422C, R-422D, R-424A, R-426A, R-428A, R-434A, R-437A, R-438A, **R-507A**, RS-24 (2002 formulation), RS-44 (2003 formulation), SP34E, THR-03	**January 1, 2020**
New stand-alone low-temperature units	HFC-227ea, KDD6, R-25/290/134a/600a (55.0/1.0/42.5/1.5), **R-404A, R-407A**, R-407B, **R-407C, R-407F, R-410A,** R-410B, R-417A, R-421A, R-421B, R-422A, R-422B, R-422C, R-422D, R-424A, R-428A, R-434A, R-437A, R-438A, **R-507A,** and RS-44 (2003 formulation)	**January 1, 2020**

12/1/2016 Final SNAP Rule:
Affecting A/C, Chillers, Refrigeration

- US EPA published a proposed SNAP status change on 4/18/2016 dealing with several refrigerants and applications.
  - Lists as “acceptable with use conditions” R290 for new equipment.
  - Lists as “unacceptable” several class 3 flammable refrigerants in new and existing air conditioning and chiller applications
  - Sets a timeline for delisting more HFCs from current chiller and refrigeration applications.
- The public comment period ended 6/3/2016
- Final rule officially released 12/1/2016
  - Advanced copy was published 9/26/2016

Full text of the final rule:

https://www.gpo.gov/fdsys/pkg/FR-2016-12-01/pdf/2016-25167.pdf

12/1/2016 Final Rule:

Acceptable with Use Conditions, Unacceptable Alternatives

ACCEPTABLE ALTERNATIVES, WITH USE CONDITIONS

End-Uses	Substitutes	Effective Date
Refrigeration		
Self-contained commercial ice machines (new)	Propane (R-290)	30 days after publication of final rule
Water coolers (new)	Propane (R-290)	30 days after publication of final rule
Very low temperature refrigeration equipment (new)	Propane (R-290)	30 days after publication of final rule
Motor Vehicle Air Conditioning (MVAC)		
MDPVs, HD pickup trucks, and complete HD vans (newly manufactured)	HFO-1234yf	30 days after publication of final rule

UNACCEPTABLE ALTERNATIVES

End-Uses	Substitutes	Effective Date
Air Conditioning (AC)		
Residential and light commercial AC and heat pumps – unitary split AC systems and heat pumps (retrofit)	All ASHRAE Flammability Class 3 Refrigerants[a]	30 days after publication of final rule
Residential and light commercial AC and heat pumps (new)	Propylene (R-1270), R-443A	30 days after publication of final rule
Centrifugal chillers and positive displacement chillers (new)	Propylene (R-1270), R-443A	30 days after publication of final rule
Refrigeration		
Cold storage warehouses (new)	Propylene (R-1270), R-443A	30 days after publication of final rule

[a] All refrigerants identified as or otherwise meeting the criteria for flammability Class 3 in American National Standards Institute (ANSI)/American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 34–2013. All refrigerants meeting the criteria for flammability Class 3 include, but are not limited to, R-170 (ethane), R-290 (propane), R-600a (isobutane), R-1270 (propylene), R-441A, R-443A and refrigerant products sold under the names R-22a, 22a, Blue Sky 22a refrigerant, Coolant Express 22a, DURACOOL-22a, EC-22, Ecofreeez EF-22a, Envirosafe 22a, ES-22a, Frost 22a, HC-22a, Maxi-Fridge, MX-22a, Oz-Chill 22a, Priority Cool, and RED TEK 22a.

12/1/2016 Final Rule:

Timeline to Phase Out HFCs in Chiller Applications

End-Uses	Substitutes	Date of Change of Status
Air Conditioning		
Centrifugal chillers (new)	FOR12A, FOR12B, HFC-134a, HFC-227ea, HFC-236fa, HFC-245fa, R-125/134a/600a (28.1/70/1.9), R-125/290/134a/600a (55.0/1.0/42.5/1.5), R-404A, R-407C, R-410A, R-410B, R-417A, R-421A, R-422B, R-422C, R-422D, R-423A, R-424A, R-434A, R-438A, R-507A, RS-44 (2003 composition), and THR-03	Unacceptable, except as otherwise allowed under a narrowed use limit, as of January 1, 2024
Centrifugal chillers (new)	HFC-134a for military marine vessels	Acceptable, subject to narrowed use limits, as of January 1, 2024
Centrifugal chillers (new)	HFC-134a and R-404A for human-rated spacecraft and related support equipment	Acceptable, subject to narrowed use limits, as of January 1, 2024
Positive displacement chillers (new)	FOR12A, FOR12B, HFC-134a, HFC-227ea, KDD6, R-125/134a/600a (28.1/70/1.9), R-125/290/134a/600a (55.0/1.0/42.5/1.5), R-404A, R-407C, R-410A, R-410B, R-417A, R-421A, R-422B, R-422C, R-422D, R-424A, R-434A, R-437A, R-438A, R-507A, RS-44 (2003 composition), SP34E, and THR-03	Unacceptable, except as otherwise allowed under a narrowed use limit, as of January 1, 2024
Positive displacement chillers (new)	HFC-134a for military marine vessels	Acceptable, subject to narrowed use limits, as of January 1, 2024
Positive displacement chillers (new)	HFC-134a and R-404A for human-rated spacecraft and related support equipment	Acceptable, subject to narrowed use limits, as of January 1, 2024

12/1/2016 Final Rule:

Timeline to Phase Out HFCs in Refrigeration Applications

End-Uses	Substitutes	Date of Change of Status
Refrigeration		
Cold storage warehouses (new)	HFC-227ea, R-125/290/134a/600a (55.0/1.0/42.5/1.5), R-404A, R-407A, R-407B, R-410A, R-410B, R-417A, R-421A, R-421B, R-422A, R-422B, R-422C, R-422D, R-423A, R-424A, R-428A, R-434A, R-438A, R-507A, and RS-44 (2003 composition)	Unacceptable, as of January 1, 2023
Retail food refrigeration – refrigerated food processing and dispensing equipment (new)	HFC-227ea, KDD6, R-125/290/134a/600a (55.0/1.0/42.5/1.5), R-404A, R-407A, R-407B, R-407C, R-407F, R-410A, R-410B, R-417A, R-421A, R-421B, R-422A, R-422B, R-422C, R-422D, R-424A, R-428A, R-434A, R-437A, R-438A, R-507A, RS-44 (2003 formulation	Unacceptable, as of January 1, 2021
Household refrigerators and freezers (new)	FOR12A, FOR12B, HFC-134a, KDD6, R-125/290/134a/600a (55.0/1.0/42.5/1.5), R-404A, R-407C, R-407F, R-410A, R-410B, R-417A, R-421A, R-421B, R-422A, R-422B, R-422C, R-422D, R-424A, R-426A, R-428A, R-434A, R-437A, R-438A, R-507A, RS-24 (2002 formulation), RS-44 (2003 formulation), SP34E, and THR-03	Unacceptable, as of January 1, 2021

Recent EPA SNAP Approvals

New HFO-blend and CO_2 applications acceptable

- Several refrigerants determined acceptable by technical review
  - 10/21/2014 - R450A for a very wide range of applications, CO2 for transport refrigeration
  - 7/16/2015 - R513A for a very wide range of applications
  - 7/16/2015 - R448A & R449A for supermarket, low-temp stand-alone & others
  - 5/23/2016 – adds new CO2 applications, lists R1336mzz & R514A for A/C & chiller applications
  - 9/26/2016 – R448A & R449A for retail food processing and dispensing, R449B for same applications as R448A & R449A
  - Additional approvals expected, but nothing announced yet

SNAP Determinations of Acceptability

Summary, 2014 - present

Refrigerant	Trade Name	Applications	New	Retrofit
R450A	Honeywell Solstice® N13	• Centrifugal chillers	X	X
R513A	Chemours Opteon® XP10	• Cold storage warehouses	X	X
		• Commercial ice machines	X	X
		• Household refrigerators and freezers	X	X
		• Industrial process air-conditioning	X	X
		• Industrial process refrigeration	X	X
		• Reciprocating, screw and scroll chillers	X	X
		• Refrigerated transport	X	X
		• Retail food refrigeration—low-temp and medium-temp stand-alone equipment	X	X
		• Retail food refrigeration—supermarket systems and remote condensing units	X	X
		• Vending machines	X	X
		• Water coolers	X	X
		• Retail food refrigeration—food processing and dispensing equipment	X	X
R448A	Honeywell Solstice® N40	• Commercial ice machines	X	X
R449A	Chemours Opteon® XP40	• Refrigerated transport	X	X
R449B	Arkema Forane®	• Retail food refrigeration—low-temperature stand-alone equipment *(1)*	X	X
		• Retail food refrigeration—supermarket systems and remote condensing units	X	X
		• Retail food refrigeration—food processing and dispensing equipment	X	X
CO2	Carbon Dioxide	• Refrigerated transport	X	
		• Ice skating rinks	X	
		• Centrifugal chillers	X	
		• Positive displacement chillers	X	
		• Industrial process air-conditioning	X	
R1336mzz	Chemours Opteon® MZ	• Centrifugal chillers	X	
		• Positive displacement chillers	X	
		• Industrial process air-conditioning	X	
		• Non-mechanical heat transfer	X	X
R514A	Chemours Opteon® XP30	• Centrifugal chillers	X	X
		• Positive displacement chillers	X	X

(1) Equipment designed to maintain internal temperatures at 32°F (0°C) or below

EPA Rule Changes, non-SNAP

Changes to Section 608 Requirements

- US EPA released changes to Refrigerant Management Requirements under CAA Section 608 on 9/26/2016. Major provisions:
  - Extend the requirements of the Refrigerant Management Program to cover substitute refrigerants, including HFCs.
    - Hydrocarbons already exempted from Section 608 requirements remain exempted
  - Leak rate repair threshold: annual rate above which refrigeration and air conditioning equipment normally containing 50+ lbs. of refrigerant must be repaired:
    - Lower from 35% to 30% for industrial process refrigeration (IPR)
    - Lower from 35% to 20% for commercial refrigeration equipment
    - Lower from 15% to 10% for comfort cooling equipment
  - Require regular leak inspections or continuous monitoring devices for refrigeration or air conditioning systems that have exceeded the above leak limits:
    - Annual inspections for systems normally containing 50+ lbs. of refrigerant
    - Quarterly inspections for commercial refrigeration and IPR systems normally containing 500+ lbs.
  - Systems normally containing 50+ lbs. of refrigerant that have leaked 125% or more of their full charge in a 12 month period must be reported to EPA.
  - Require technicians to keep a record of refrigerant recovered during system disposal from systems with a charge size from 5–50 lbs.

Montreal Protocol Amended to Include HFCs

- First HFC amendment was proposed in 2013 by the US
  - Not well received by several countries, particularly India
- In 2015, there were five additional amendment proposals
  - North American (US, Canada, Mexico), India, European Union, Island States, African Group
- Meeting of the Parties in Dubai, November 1-5, 2015
  - All 197 Parties agreed to begin work on an HFC amendment
  - “Dubai Pathway”
- Several working meetings in 2016
- Meeting of the Parties in Kigali, Rwanda October 8-14, 2016
  - Agreements reached and finalized
  - Signed by all parties
- 2/3 majority of Senate must approve to be ratified by the US
  - AHRI has committed to push for approval

Key Provisions of the Kigali Amendment to the Montreal Protocol

- Lists 18 HFC's as a new Annex F
  - Does not include HFO's, but does include R32
- Phases down to 15% plateau from baseline, on GWP-weighted basis
  - Not a complete phase-out.
- Licensing of HFC imports and exports, and import and export controls for non-Parties.
- Reporting of production, consumption, and byproduct emissions.
- Recognizes three groups of nations, with different timelines
  - Non-Article 5 (developed nations: US, Canada, Australia, Japan, etc.)
    - EU nations already more aggressive phase-down by F-gas laws.
  - Article 5, Group 1 (China, Brazil, Indonesia, etc.)
  - Article 5, Group 2 (Saudi Arabia, Kuwait, Bahrain, Qatar, UAE, Oman, India, Iraq, Iran, Pakistan)

Montreal Protocol HFC Phasedown Timeline

Group		European Union	Non-Article 5	Article 5, Group 1	Article 5, Group 2
Baseline calculation years		2009-12	2011-13	2020-22	2024-26
Baseline HFC component		100% Avg consumption	100% Avg consumption	100% Avg consumption	100% Avg consumption
Baseline HCFC component		---	15% Avg consumption	65% Avg consumption	65% Avg consumption
Freeze at baseline		2015	2018	2024	2028
Steps:	First	90% - 2016	90% - 2019	90% - 2029	90% - 2032
	Second	65% - 2018	55% - 2024	70% - 2035	80% - 2037
	Third	45% - 2021	30% - 2029	50% - 2040	70% - 2042
	Fourth	30% - 2024	20% - 2034	---	---
	Fifth	25% - 2027	---	---	---
	Plateau	20% - 2030	15% - 2036	15% - 2045	15% - 2047

It appears that the EU would have a higher eventual plateau than the rest of the world at 20% versus 15%. However, their baseline calculated using earlier years will likely lead to it being nearly the same as the other non-A5 countries. The F-gas laws carry provisions for regular progress review and revision if necessary, so there is already a mechanism in place for adjustment on the EU's part. There are also slight variances in steps and timeline for a few smaller countries that were negotiated into the amendment.

Alternates: An Overview

- Lower-GWP HFC blends, such as:
  - R407A, GWP = 2107 and R407F, GWP = 1824
  - Commonly used as drop-ins or retrofits for R22 and R404A/R507
  - R32, GWP = 675, showing promise as R410A alternate
- Honeywell/DuPont joint venture to develop HFO's:
  - R1234yf & R1234ze(E) both ODP=0, GWP's recently revised to "below 1" – *synthetics with lower GWP than naturals!*
  - R1234yf adopted for automobile A/C beginning 2013 model year in US & EU - very similar thermodynamically to R134a
  - Low pressure, low volumetric capacity > need to blend with others to match capacity of current HFC blends.
- Natural Refrigerants:
  - Carbon Dioxide (CO_2), Hydrocarbons, Ammonia (NH_3)
  - All GWP's ~3 or less, all with other challenges

HFO's and blends, R134a-like

R134a	R1234yf	R1234ze	R450A	R513A
Replaced	Replaces	Replaces	Replaces	Replaces
R12	R134a	R134a	R134a	R134a
Compound Type	Compound Type	Compound Type	Compound Type	Compound Type
HFC	HFO	HFO	HFO zeotropic blend	HFO azeotropic blend
Components	Components	Components	Components	Components
Pure	Pure	Pure	42% R134a 58% R1234ze	44% R134a 56% R1234yf
Common Mfg's/Brands	Common Mfg's/Brands	Common Mfg's/Brands	Common Mfg's/Brands	Common Mfg's/Brands
DuPont SUVA 134A Arkema Forane 134a	Honeywell Solstice yf DuPont Opteon YF	Honeywell Solstice ze	Honeywell Solstice N13	DuPont Opteon XP10
ASHRAE Safety Class	ASHRAE Safety Class	ASHRAE Safety Class	ASHRAE Safety Class	ASHRAE Safety Class
A1	A2L	A2L	A1	A1
Global Warming Potential	Global Warming Potential	Global Warming Potential	Global Warming Potential	Global Warming Potential
1430	<1	<1	601	631
GWP vs R134a	GWP vs R134a	GWP vs R134a	GWP vs R134a	GWP vs R134a
0.0%	-99.9%	-99.9%	-58.0%	-55.8%
Normal Boiling Point	Normal Boiling Point	Normal Boiling Point	Normal Boiling Point	Normal Boiling Point
-14.9°F	-21.0°F	-2.2°F	-10.1°F	-20.6°F
Critical Point	Critical Point	Critical Point	Critical Point	Critical Point
213.9°F, 588.8 psia	202.5°F, 490.6 psia	228.9°F, 527.2 psia	222.2°F, 567.5 psia	205.8°F, 546.2 psia
Temperature Glide	Temperature Glide	Temperature Glide	Temperature Glide	Temperature Glide
0.0°F	0.0°F	0.0°F	1.1°F	0.0°F
EPA SNAP Status	EPA SNAP Status	EPA SNAP Status	EPA SNAP Status	EPA SNAP Status
Approved, de-listing for several apps 2019-24	Approved (Auto A/C)	Approved (Chillers)	Approved	Approved

R134a-like HFO's & blends

Notes & Observations

- Pure HFO's:
  - R1234yf very similar to R134a, both P-T and thermodynamically
  - R1234ze is lower pressure and capacity than yf & R134a, but is a good choice in chillers (good efficiency)
  - Both still high cost, but ze is less costly to produce than yf – new production capacity for both online recently or in near future
- Blends:
  - R513A is an azeotrope, R450A glide is very low
  - R450A and R513A EPA SNAP-approved for a wide range of applications
  - Bitzer and Copeland support both R450A and R513A
  - Commercially available in EU, Canada, and US.
  - Manufacturers focusing on promoting these, rather than developing additional R134a alternatives

R404a-like Blends

R404A	R407A	R407F	R448A	R449A	R449B
Replaced	Replaces	Replaces	Replaces	Replaces	Replaces
R502	R22, R404A, R507	R404A, R507	R404A, R507	R404A, R507	R404A, R507
Compound Type	Compound Type	Compound Type	Compound Type	Compound Type	Compound Type
HFC zeotropic blend	HFC zeotropic blend	HFC zeotropic blend	HFO zeotropic blend	HFO zeotropic blend	HFO zeotropic blend
Components	Components	Components	Components	Components	Components
44% R125 4% R134a 52% R143a	20% R32 40% R125 40% R134a	30% R32 30% R125 40% R134a	26% R32 26% R125 21% R134a 20% R1234yf 7% R1234ze	24.3% R32 24.7% R125 25.7% R134a 25.3% R1234yf	25.2% R32 24.3% R125 27.3% R134a 23.2% R1234yf
Common Mfg's/Brands	Common Mfg's/Brands	Common Mfg's/Brands	Common Mfg's/Brands	Common Mfg's/Brands	Common Mfg's/Brands
DuPont SUVA 404A	Mexichem KLEA 60, KLEA 407A Arkema FORANE 407A	Honeywell Genetron Performax LT	Honeywell Solstice N40	DuPont Opteon XP40	Arkema
ASHRAE Safety Class	ASHRAE Safety Class	ASHRAE Safety Class	ASHRAE Safety Class	ASHRAE Safety Class	ASHRAE Safety Class
A1	A1	A1	A1	A1	A1
Global Warming Potential	Global Warming Potential	Global Warming Potential	Global Warming Potential	Global Warming Potential	Global Warming Potential
3922	2107	1824	1387	1397	1411
GWP vs R404A	GWP vs R404A	GWP vs R404A	GWP vs R404A	GWP vs R404A	GWP vs R404A
0.0%	-46.3%	-53.5%	-64.6%	-64.3%	-64.0%
Normal Boiling Point	Normal Boiling Point	Normal Boiling Point	Normal Boiling Point	Normal Boiling Point	Normal Boiling Point
-51.2°F	-49.0°F	-50.9°F	-50.7°F	-50.8°F	-50.4°F
Critical Point	Critical Point	Critical Point	Critical Point	Critical Point	Critical Point
161.9°F, 540.8 psia	180.1°F, 654.9 psia	180.8°F, 689.6 psia	182.6°F, 675.4 psia	178.7°F, 645.0 psia	180.0°F, 657.0 psia
Temperature Glide	Temperature Glide	Temperature Glide	Temperature Glide	Temperature Glide	Temperature Glide
1.0°F	10.2°F	10.3°F	10.3°F	10.2°F	10.2°F
EPA SNAP Status	EPA SNAP Status	EPA SNAP Status	EPA SNAP Status	EPA SNAP Status	EPA SNAP Status
Approved, de-listing for many apps 2016 - 2020	Approved, de-listing for some apps 2016 - 2020	Approved, de-listing for some apps 2016 - 2020	Approved - Supermarket, LT S-C, Transport, Ice	Approved - Supermarket, LT S-C, Transport, Ice	Approved - Supermarket, LT S-C, Transport, Ice

R404A-like Blends

Notes & Observations

- R407A & F primarily for supermarket – eliminated by EPA for stand-alone
- Capacity and efficiency of R407F higher than R404A and R407A in many published tests, but also higher discharge temp and cost
- R448A and R449A approved for supermarket, low-temp stand-alone food retail, transport refrigeration, and ice machine applications
- R448A & R449A higher discharge temps, but also higher capacity and efficiency vs R404A per most published tests
- Several successful field trials of both
- Bitzer and Copeland support both R448A and R449A
- Significantly increasing retrofit activity from both R22 and R404A
- On a per-unit-capacity basis, for R448A or R449A:
  - ~25% lower mass flow than R404A, liquid volumetric flow is ~30% lower
  - ~10% higher mass flow than R22, liquid volumetric flow is ~15% higher
  - Existing R404A TEVs may be oversized, Existing R22 TEVs may be OK
- Suction volumetric flow is 5 – 15% higher for R448A or R449A vs R22 or R404A
  - Existing suction side valves (EPR, EEPR, Solenoid, etc.) probably OK

Hydrocarbon Refrigerants

Compared with similar existing HCFC's/HFC's

Medium Pressure

R22	R290	R1270
Replaces: N/A	Replaces: R22	Replaces: R22
Compound Type: HCFC	Compound Type: Hydrocarbon (Propane)	Compound Type: Hydrocarbon (Propylene)
Components: Pure	Components: Pure	Components: Pure
Common Mfg's/Brands: All refrigerant sources	Common Mfg's/Brands: Linde, Intergas, etc.	Common Mfg's/Brands: Linde, Intergas, etc.
ASHRAE Safety Class: A1	ASHRAE Safety Class: A3	ASHRAE Safety Class: A3
Global Warming Potential: 1810	Global Warming Potential: 3.3	Global Warming Potential: 1.8
GWP vs R22: 0.0%	GWP vs R22: -99.8%	GWP vs R22: -99.9%
Normal Boiling Point: -41.3°F	Normal Boiling Point: -43.8°F	Normal Boiling Point: -53.7°F
Critical Point: 205.1°F, 723.7 psia	Critical Point: 206.1°F, 616.6 psia	Critical Point: 198.4°F, 676.6 psia
Temperature Glide: 0.0°F	Temperature Glide: 0.0°F	Temperature Glide: 0.0°F
EPA SNAP Status: De-listed for all new applications	EPA SNAP Status: Approved (limited)	EPA SNAP Status: No Approvals at this time

Low Pressure

R134a	R600a
Replaced: R12	Replaces: R134a
Compound Type: HFC	Compound Type: Hydrocarbon (Isobutane)
Components: Pure	Components: Pure
Common Mfg's/Brands: DuPont SUVA 134A, Arkema Forane 134a	Common Mfg's/Brands: Linde, Intergas, etc.
ASHRAE Safety Class: A1	ASHRAE Safety Class: A3
Global Warming Potential: 1430	Global Warming Potential: 3
GWP vs R134a: 0.0%	GWP vs R134a: -99.8%
Normal Boiling Point: -14.9°F	Normal Boiling Point: 10.9°F
Critical Point: 213.9°F, 588.8 psia	Critical Point: 274.4°F, 526.3 psia
Temperature Glide: 0.0°F	Temperature Glide: 0.0°F
EPA SNAP Status: Approved, de-listing for some apps 2019-21	EPA SNAP Status: Approved (limited)

Hydrocarbons

Notes & Observations

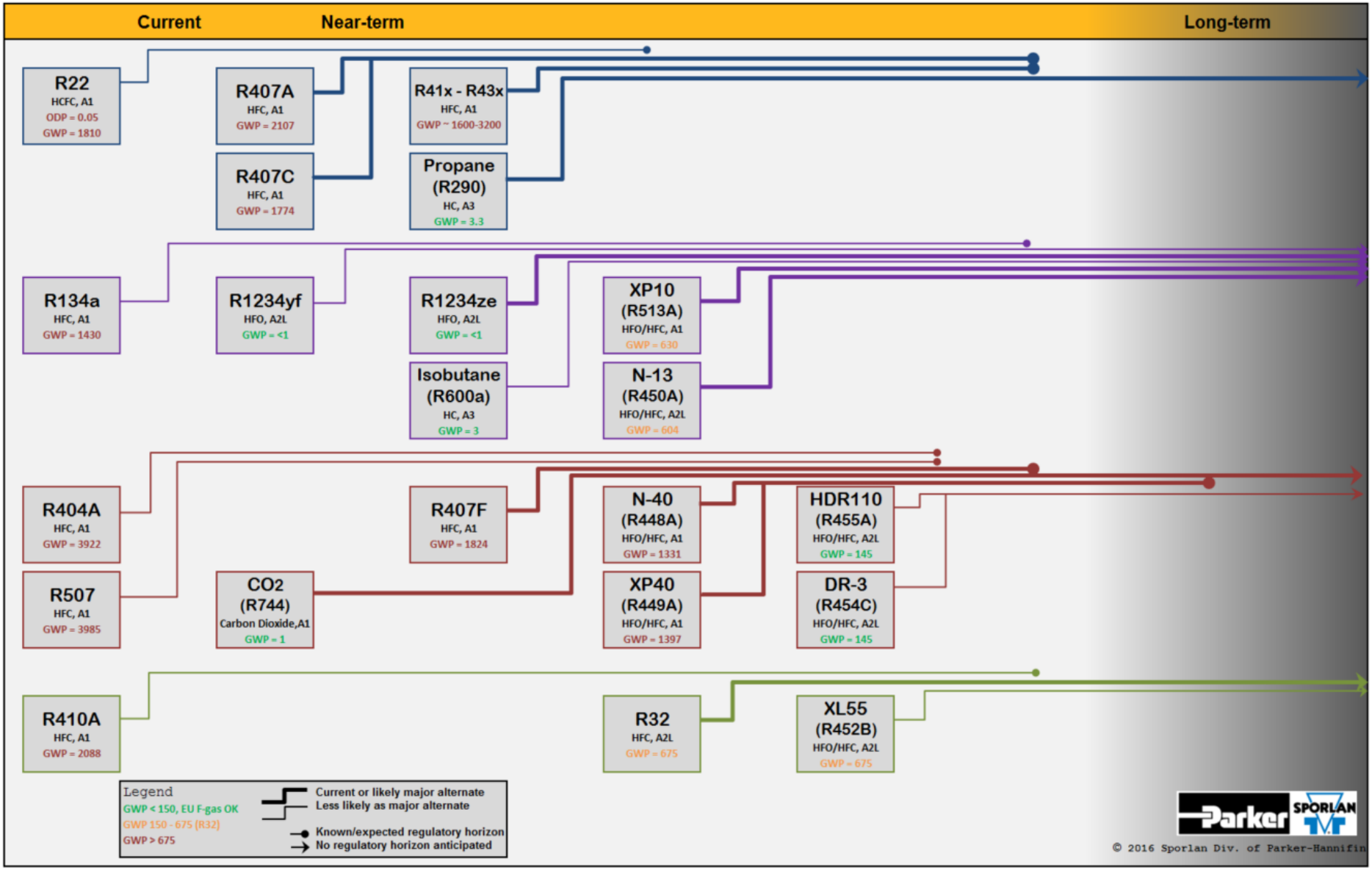
- R600a (isobutane) widely used in place of R134a in EU home appliances, increasing use in US as well
  - Low pressures, but very good capacity and efficiency
- R290 (propane) is a very good replacement for R22
  - *However, retrofits of existing systems not allowed – serious safety issue!*
- Compatible with mineral oil – synthetic not required
- R290 has much higher capacity, slightly higher COP than R22 – enables:
  - Small charges
  - Highly efficient systems
- All are A3 (highly flammable), thus restricted to very small charges in US
- Propylene has good thermodynamic properties, but:
  - Some material & oil compatibility difficulties
  - Air quality concerns - may not be approved in the US

Future Trends

Refrigeration

- Non-flammable replacements for R404A important in the near term. R407A, R407F are in widespread use
- R448A and R449A are both rapidly gaining momentum for both new equipment and retrofits
- R449B now an option as well
- R450A and R513A are lowest GWP that remain A1 safety classified, but are less suitable for low temp
- Some A2L, <150 GWP blends to replace R404A (R454C, R455A, R457A) are coming onto the scene.
- R290 in stand-alone (self contained)
- R600a in home appliances
- CO2 will continue to become more important

Refrigerant Roadmap



Thank You!