TRANE BEYOND TOMORROW

Technology and development of refrigerant for HVAC

Trane environmental perspective

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Trane Pacific

1 December 2017

Ingersoll Rand

TRANE

1938	World's first direct-drive, hermetic, multi-stage, centrifugal water chiller with first generation refrigerant R-113.
1981	The first three-stage, direct-drive centrifugal chiller with the most efficient refrigerant R-11.
1992	Stratospheric Ozone Protection Award for R-123 CenTraVac.
1993	EarthWise™ CenTraVac™, the world's most efficient lowest-emissions chiller.
1995	Wisconsin Society of Professional Engineers Award for New Products.
1998	Climate Protection Award.
2000	Energy Star® Gold Award.
2002	S-series oil-free EarthWise™ CenTraVac™.
2007	Best-of-the-Best Stratospheric Ozone Protection Award.
2012	First (and only) commercial chiller to earn Environmental Product Declaration.
2013	S-series oil-free, AdaptiSpeed EarthWise™ CenTraVac™.
2015	***E-series CenTraVac™, first chiller with R-1233zd(E)***
2017	***CenTraVac™ with low GWP refrigerant R-514A***

TRANE

A Commitment to Technology and Environment…

that is proven by time

that you can trust

Environmental terminology

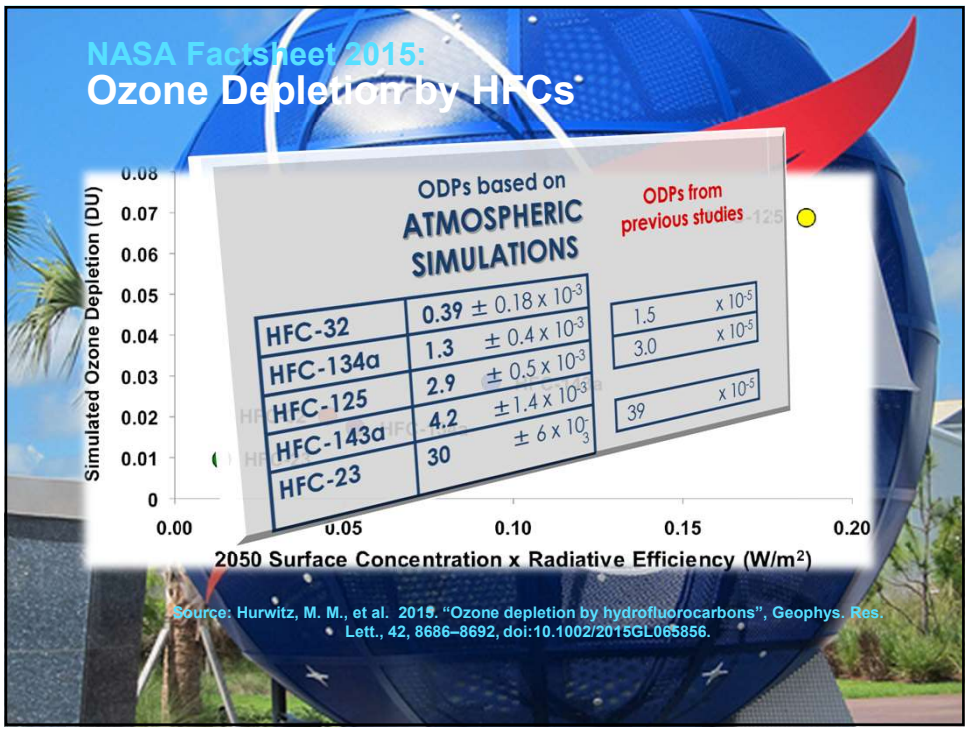
TRANE

- **ODP** – ozone depletion potential – degree to which a substance can degrade the ozone layer; all measurements relative to a similar mass of CFC-11, which is indexed at 1.0.
- **GWP** – global warming potential – degree to which a greenhouse gas (GHG) traps heat in the atmosphere; all measurements relative to a similar mass of carbon dioxide (CO_2), which is indexed at 1.0. The buildup of GHGs can cause climate change.

Environmental terminology

- **CFCs** – chlorofluorocarbons (e.g. R-11, R-12) – phased out by the Montreal Protocol because of their very high ODPs. Significant impact on both ozone depletion and global warming due to the chlorine and fluorine atoms and very long atmospheric lives.
- **HCFCs** – hydrochlorofluorocarbons (e.g. R-22, R-123) – also ozone-depleting substances(**ODS**), but contribute less to ozone depletion and climate change due to shorter atmospheric lives. Still in use globally, but have phase-out dates scheduled under the Montreal Protocol.
- **HFCs** – hydrofluorocarbons (e.g. R-134a, R-245fa, R-125, R-32) – **non-ODS**, but they do have high GWPs given their fluorine content. Currently targeted for global phase down under the Montreal Protocol and phase-out by the U.S.A., Canada, Japan and other countries for use in certain applications.

ODP=0?

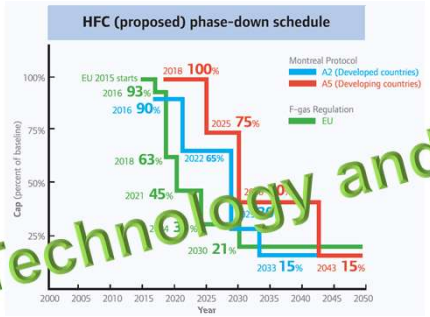


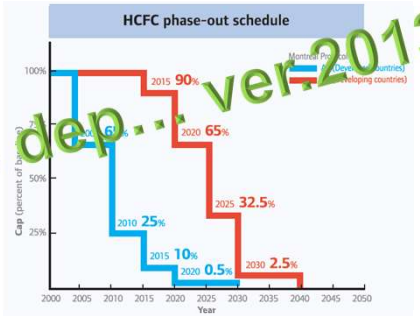
Environmental terminology

- **Montreal Protocol** – international treaty signed in 1987, originally designed to protect the ozone layer by phasing out the production and consumption of ODSs. The **Kigali Amendment** was signed on 15 October 15 2016, extending the scope of the Montreal Protocol to phase down the global production and consumption of HFCs.

Phase out by a Clean List of chemicals in the Annex

Global environmental regulation





Technology and dep... ver. 2013

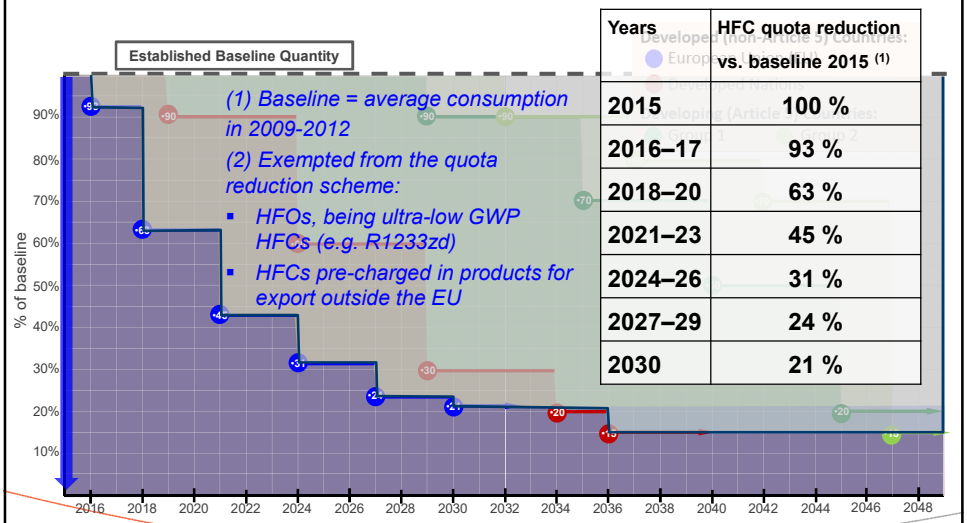
HFC baseline: (2008 - 2010 average)
•A2 = HFC + 85% x HCFC
•A5 = 90% x HCFC

HCFC baseline:
•A2 = 2.8% x 1989 CFC+100% x 1989 HCFC
•A5 = (2009 HCFC + 2010 HCFC) / 2

A2: Australia/NZ, Hong Kong, Japan, Taiwan
A5: China, Indonesia, Malaysia, Philippines, Singapore, South Korea, Thailand, Vietnam

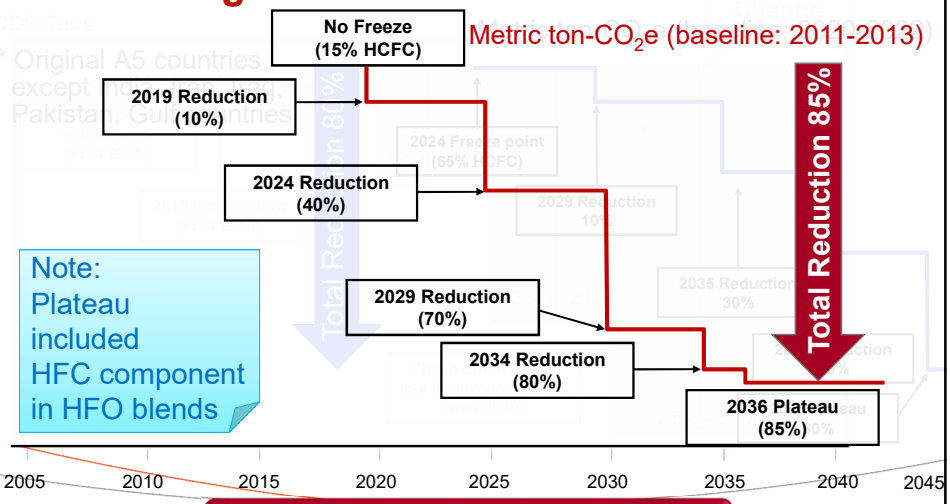
Technology and development... ver.2017

Europe: F-gas Regulation (2014)



Years	HFC quota reduction vs. baseline 2015 (1)
2015	100 %
2016–17	93 %
2018–20	63 %
2021–23	45 %
2024–26	31 %
2027–29	24 %
2030	21 %

Article 2 Country (developed)
Montreal Protocol HFC Cap & Reduction
2016 Kigali Amendment



85% Global Reduction by 2046

US places bans on R404A and R134a

Posted on Tuesday, September 27, 2016 · Leave a Comment

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USA: The US EPA is to ban a host of high GWP refrigerants including R404A, R134a, R407C and R410A in certain new products from as early as January 1, 2021.

The bans are part of wide ranging new rules finalised by the US Environmental Protection Agency yesterday, that will see bans on a number of existing refrigerants and a tightening of leak rate rules to reduce HFC emissions.

Commonly-used high GWP refrigerants R404A and R507A are among a number of refrigerants to be banned in new retail food refrigeration from as early as January 1, 2021, with both also being banned in new cold storage warehouses from January 1, 2023. Also included in the bans are many of the so-called retrofit blends including R407A and R407B.

R134a is one of a number of common refrigerants that will be banned from use in new centrifugal and positive displacement chillers as of January 1, 2024. Others include R407C and R410A, as well as a number of interim "drop-in" blends.

The new rules will also see R134a being banned in new domestic fridges and freezers from January 1, 2021.

Japan: HFC Reduction Policy

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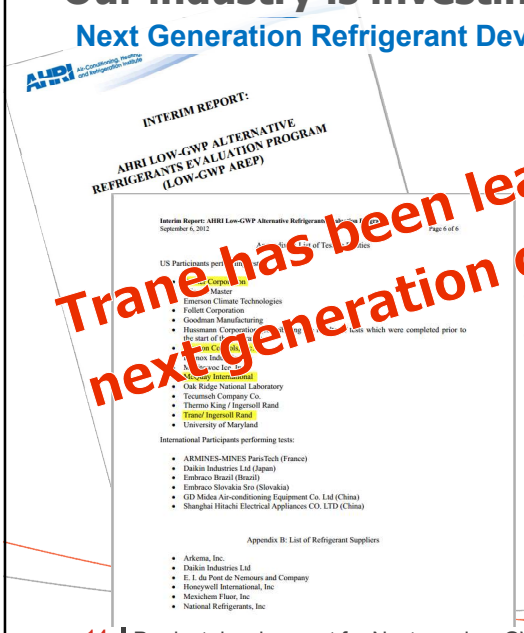
Designated products ※	Present refrigerant (GWP)	Target value (GWP)	Target year
Room air-conditioning	R410A(2090) R32(675)	750	2018
Commercial air-conditioning (for offices and stores)	R410A(2090)	750	2020
Condensing unit and refrigerating unit (for separate type showcases etc	R404A(3920) R410A(2090) R407C(1774) CO_2(1)	1500	2025
Cold storage warehouse （for more than 50000 ㎥）	R404A(3920) Ammonia (single digit)	100	2019
Mobile air-conditioner	R134a(1430)	150	2023
Urethane foam (for House building materials)	HFC-245fa(1030) HFC-365mfc(795)	100	2020
Dust blowers	HFC-134a(1430) HFC-152a(124) CO_2(1), DME(1)	10	2019

13 | Product d

Our industry is investing…

Next Generation Refrigerant Development


INTERIM REPORT:

AHRI LOW-GWP ALTERNATIVE REFRIGERANTS EVALUATION PROGRAM (LOW-GWP AREP)

Interim Report: AHRI Low-GWP Alternative Refrigerants Evaluation Program (Low-GWP AREP)
September 6, 2012 Page 6 of 6

US Participants performing tests:

- Arkema, Inc.
- Carrier Corporation
- Chemours / DuPont
- Daikin Applied
- Emerson Climate Technologies
- Follett Corporation
- Goodman Manufacturing
- Hussmann Corporation
- Lennox International Inc.
- Mexichem Fluor
- Mitsubishi Electric
- Oak Ridge National Laboratory
- Tecumseh Company Co.
- Thermo King / Ingersoll Rand
- Trane/ Ingersoll Rand
- University of Maryland

International Participants performing tests:

- ARMINES-MINES ParisTech (France)
- Daikin Industries Ltd (Japan)
- Embraco Brazil (Brazil)
- Embraco Slovakia Sro (Slovakia)
- GD Midea Air-conditioning Equipment Co. Ltd (China)
- Shanghai Hitachi Electrical Appliances CO. LTD (China)

Appendix B: List of Refrigerant Suppliers

- Arkema, Inc.
- Daikin Industries Ltd
- E. I. du Pont de Nemours and Company
- Honeywell International, Inc
- Mexichem Fluor, Inc
- National Refrigerants, Inc

Trane has been leading in next generation chiller R&D

- *Spent US$2 billion since 2009*
- *Invest US$5 billion in the next 10 years*
- Phase I: 2011-2013
  - Tested 30+ Refrigerants
- Phase II: from 2014
  - Testing 20+ More Refrigerants
  - High Ambient Testing

Ingersoll Rand crowned climate leader

Posted on Wednesday, March 9, 2016 · Leave a Comment

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USA: Ingersoll Rand, with its brands Thermo King transport refrigeration and Trane air conditioners, was today recognised for its refrigerant phase-out efforts by the US EPA.

CLIMATE LEADERSHIP AWARDS

Ingersoll Rand was presented with an Organisational Leadership Award by EPA Administrator Gina McCarthy at the 2016 Climate Leadership Conference in Seattle today. Ingersoll Rand was one of 17 organisations from across America recognised at the event.

Singled out for praise was Ingersoll Rand's greenhouse gas emissions reduction goal of 35% by 2020 and its commitment to reduce the climate impact of the refrigerants used in its products by 50% by 2020. This includes its EcoWise portfolio of products combining low global warming potential refrigerants with high efficiency operation.

Through collaborations with external organisations, Ingersoll Rand also contributed to the 2003 Industry Genius book, the 2007 Adjustment to the Montreal Protocol accelerating the HCFC phase out, and the pending Amendment to the Montreal Protocol to phase down HFCs.

Ingersoll Rand also partnered with the refrigerant manufacturer Chemours to develop R452B a next-generation, low-GWP refrigerant that is design-compatible with R410A.

Ingersoll-Rand Commitment

Reducing Greenhouse Gas Emissions

CLIMATE SUMMIT 2014
CATALYZING ACTION

UN Headquarters • New York
23 September 2014

Our company is helping to solve some of the world's most pressing challenges – including the unsustainable demand for energy resources and impact on greenhouse gas emissions.

Our Products

50% reduction in GHG via:

1) increased energy-efficient products; 2) use of next generation refrigerants with lower GWP in refrigerant-based products by 2020

50%

Our Operations

35% GHG reductions in our office buildings, manufacturing facilities and fleet by 2020

35%

Market Leadership and Convening

$500M in research to promote energy efficiency & solve refrigerant gaps via innovation, research, testing, policy over the next 5 years

$500M

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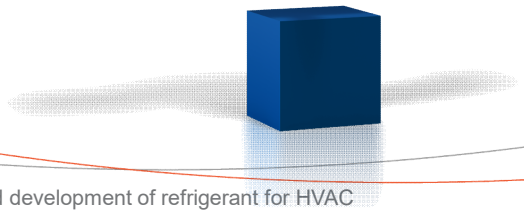
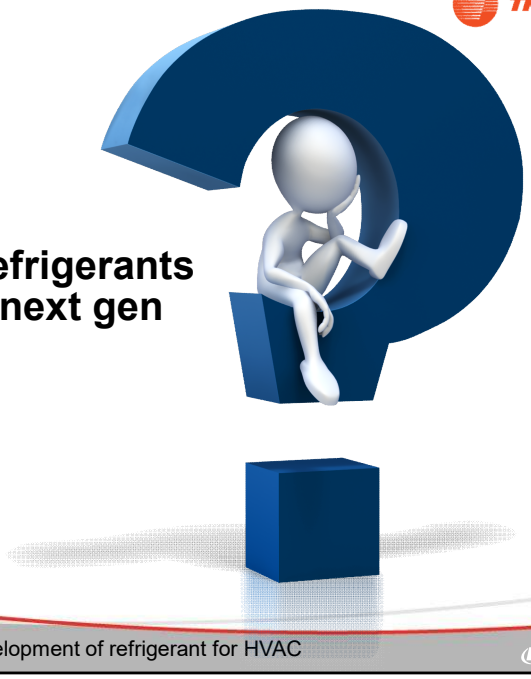
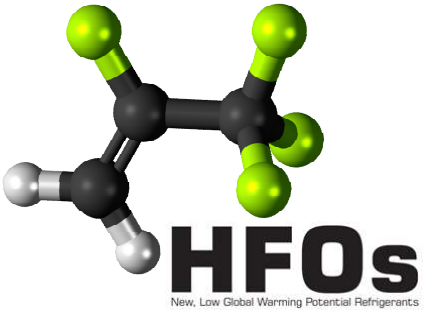
Alternative refrigerants available for next gen products



Alternative refrigerants available for next gen products



Next Generation Refrigerants



- Unsaturated fluorinated fluid:
  - Performance characteristics similar to HFC/HCFC
  - Very short atmospheric life
  - GWP vs flammability

- Commercialized products:
  - R1234yf, GWP <1
    - Automotive "drop-in"
    - Atmospheric life = 14 days
    - Slightly flammable (A2L)
  - R1234ze(E), GWP <1
    - Not a drop-in replacement
    - Atmospheric life = 14 days
    - Slightly flammable (A2L)
  - R1233zd(E), GWP ~1
    - Foam blowing
    - Atmospheric life = 26 days
    - Non-flammable (A1)
  - R1336mzz(Z), GWP 8.9
    - Foam expansion
    - Atmospheric life = 24 days
    - Non-flammable (A1)

Refrigerant Number

ASHRAE Standard 34

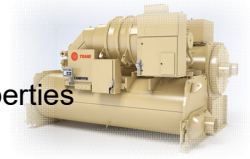
- 000 Series Methane Based, e.g. R-11, -12, -22, -32
- 100 Series Ethane Based, e.g. R-123, -125, -134a,
- 200 Series Propane Based, e.g. R-227ea, -245fa, -290
- 300 Series Cyclic Organic Compounds
- 400 Series Zeotrope, e.g. R-404A, -410A, -452A, -452B
- 500 Series Azeotrope, e.g. R-513A, -514A, -515A
- 600 Series Organic Compounds, e.g. R-600
- 700 Series Inorganic Compounds, e.g. R-717, -744
- 1000 Series Unsaturated Organic Compounds, e.g. R-1234yf, -1234ze(E), -1233zd(E), -1336mzz(Z), -1130(E)

Application Considerations

Major Product Categories

- Scroll and reciprocating compressors
  - Smaller equipment, 100 tons and below

- Screw compressors
  - Medium size equipment, 100-450 tons
  - Used on medium and large commercial applications
- Centrifugal Compressors
  - Large equipment, 300+ tons
  - Used on large commercial/industrial properties



Application Considerations

Scroll and Recip Compressors

Current Offering

- **R-22**
  - GWP 1810
  - ODP 0.055
  - Non-flammable
- **R-410A**
  - GWP 2100
  - Non-flammable

Next Generation

R-452B (HFO blend)
- GWP 676
- R410A "drop-in"
- 2L, BV 3.0 cm/s, MIE 200 mJ

R-32
- GWP 675
- New design
- 2L, BV 6.7 cm/s, MIE 29 mJ

R-290
- GWP ~3
- New design
- Highly flammable

Comments:
- Cost sensitive segment
- No non-flammable alternative, safety concerns
- GWP level consensus

Application Considerations

Screw Compressors

Current Offering

- **R-22**
  - GWP 1810
  - ODP 0.055
  - Non-flammable
- **R-134a**
  - GWP 1430
  - Non-flammable

Next Generation

- **R-513A** (HFO blend)
  - GWP 573, non-flammable
  - Performance similar to R134a

R-1234ze (medium pressure HFO)
- GWP <1, 2L flammability
- Efficiency same as R134a
- Capacity loss 10~20%

R-1234yf (medium pressure HFO)
- GWP <1, 2L flammability
- Efficiency loss 4%
- Same capacity as R134a

Comments:
- Low GWP option with flammability concerns
- Higher GWP easy transition

Application Considerations

Centrifugal Compressors

Current Offering

- **R-123**
  - GWP 77
  - ODP 0.02
  - Non-flammable
- **R-134a**
  - GWP 1430
  - Non-flammable

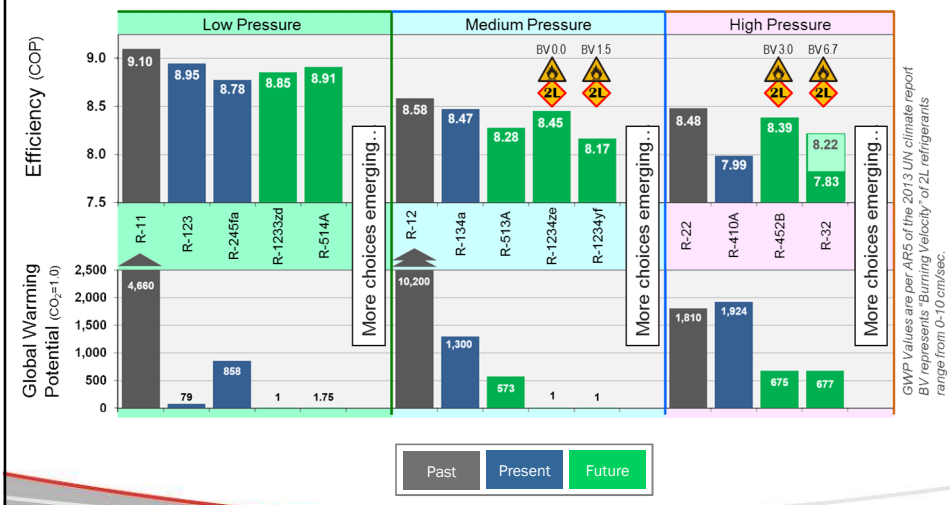
Next Generation

- **R-514A** (low pressure HFO blend)
  - GWP <2, non-flammable
  - Performance similar to R123
- **R-1233zd** (low pressure HFO)
  - GWP 1, non-flammable
  - 10% more efficient than R134a
- **R-1234ze**
  - GWP <1, 2L flammability
  - Efficiency same as R134a
  - Capacity loss 10~20%

Comments:
- Most efficient market segment
- Widespread options by 2020

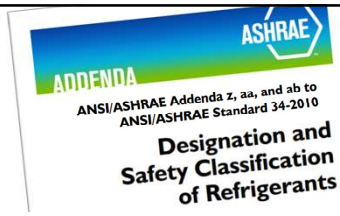
Efficiency impacted by Refrigerant Choice…

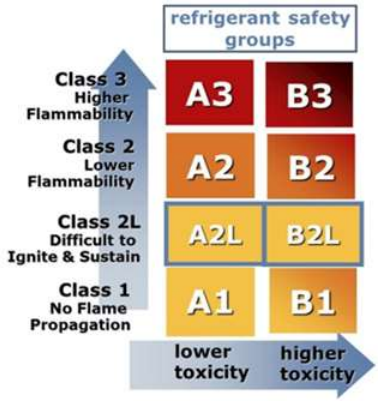
Centrifugal & Screw Chillers in particular



Refrigerant Flammability

- ASHRAE 2L Flammability Class
  - Created in 2010
  - "Difficult to Ignite & Sustain"
  - Key for Many New Refrigerants
- Current 2L Refrigerants:
  - R-1234yf
  - R-1234ze(E)
  - R-32
  - R-717 (Ammonia)
- 2L Definition Being Evaluated
  - Not all 2L fluids are created equally
  - Burning Velocities of R-32/R-717 higher than the proposed limit of <5 cm/s





Refrigerant Flammability

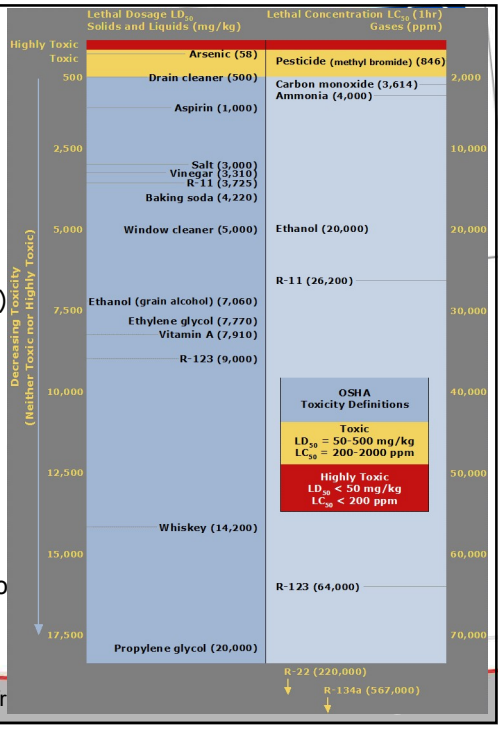
People can be very creative!

Installation/application can be uncontrollable…

Follow safety standards:
1. IEC 60335-2-40 ☑
2. ISO 5149 ☑
3. UL 484 ☑
4. ASHRAE 34 ☑
5. GB 9237

Refrigerant Toxicity

- ASHRAE 34 Classification
  - Class A: OEL ≥ 400 ppm
  - Class B: OEL < 400 ppm
  - OEL: repeatedly exposed without adverse effect throughout lifetime hour workday, 40-hour workweek)
- ASHRAE 34 added
  - Highly toxic: LC50 ≤200 ppm
  - Toxic: 200< LC50 ≤2000 ppm
  - Neither: lesser toxicity than either those groups
- ASHRAE 15 – ALL refrigerants
  - Leak detector
  - Alarm in and outside equipment ro
  - Mechanical ventilation



Refrigerant Toxicity

TRANE

Table 4-1 Refrigerant Data and Safety Classifications

Refrigerant Number	Chemical Name[a,b]	Chemical Formula[a]	OEL[f], ppm v/v	Safety Group	RCL[c] (ppm v/v)	RCL[c] (lb/Mcf)	RCL[c] (g/m³)	Highly Toxic or Toxic[d] Under Code Classification
Methane Series								
11	trichlorofluoromethane	CCl_3F	C1000	A1	1100	0.39	6.2	Neither
12	dichlorodifluoromethane	CCl_2F_2	1000	A1	18,000	5.6	90	Neither
12B1	bromochlorodifluoromethane	$CBrClF_2$						Neither
13	chlorotrifluoromethane	$CClF_3$	1000	A1				Neither
13B1	bromotrifluoromethane	$CBrF_3$	1000	A1				Neither
14[e]	tetrafluoromethane (carbon tetrafluoride)	CF_4	1000	A1	110,000	25	400	Neither
21	dichlorofluoromethane	$CHCl_2F$		B1				Toxic
22	chlorodifluoromethane	$CHClF_2$	1000	A1	59,000	13	210	Neither
23	trifluoromethane	CHF_3	1000	A1	41,000	7.3	120	Neither
30	dichloromethane (methylene chloride)	CH_2Cl_2		B1				Neither

d. *Highly toxic*, *toxic*, or *neither*, where *highly toxic* and *toxic* are as defined in the *International Fire Code*, *Uniform Fire Code*, and OSHA regulations, and *neither* identifies those refrigerants having lesser toxicity than either of those groups[1,2,3].

e. At locations with altitudes higher than 4920 ft (1500 m), the ODL and RCL shall be 69 100 ppm

Source: ASHRAE Standard 34-2016

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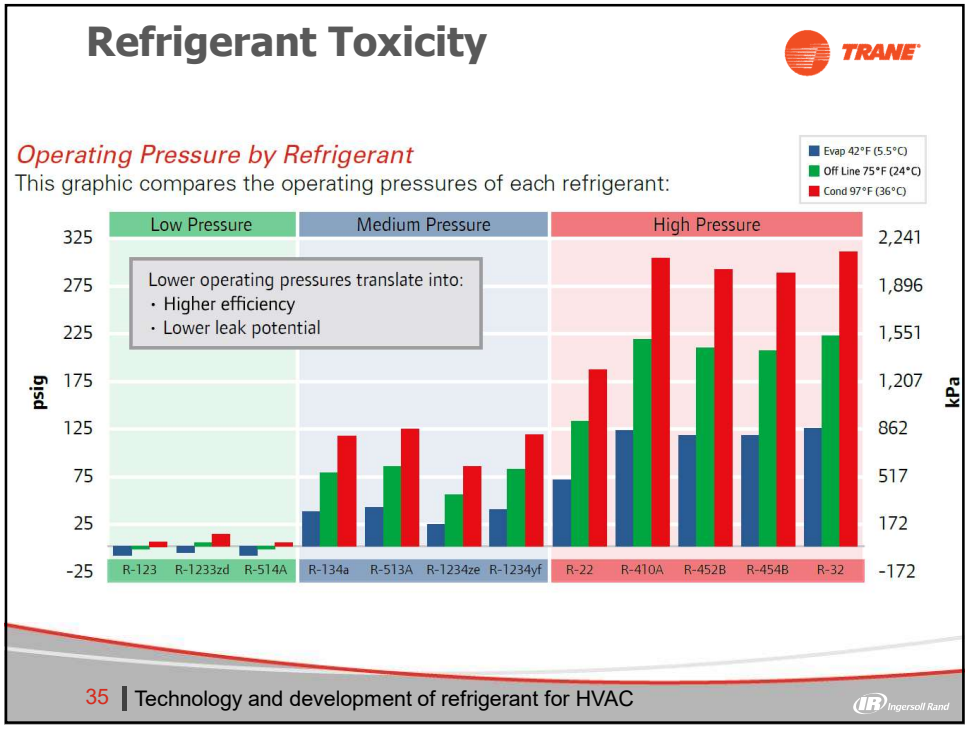
OF BUSINESS NEWS PUBLISHING CO.
Week
Contractor stops leak
R-22 LEAK AT ICE RINK
KILLS ONE, INJURES 34
by B. Checket-Hanks
What Happened at Dimond Mall
Detail of Lower Section of Mall
Pool
Women's Locker Room
Arby's
Bowling Center
Athletic Club
Men's Locker Room
Skating Rink
Food Court
Compressor Room
Escalator
Court
Safety Risk with refrigerants
-- Asphyxiation, not Toxicity


Refrigerant Toxicity
TRANE
Operating Pressure by Refrigerant
This graphic compares the operating pressures of each refrigerant:
Evap 42°F (5.5°C)
Off Line 75°F (24°C)
Cond 97°F (36°C)
Low Pressure
Medium Pressure
High Pressure
Lower operating pressures translate into:
• Higher efficiency
• Lower leak potential
psig
325
275
225
175
125
75
25
-25
kPa
2,241
1,896
1,551
1,207
862
517
172
-172
R-123
R-1233zd
R-514A
R-134a
R-513A
R-1234ze
R-1234yf
R-22
R-410A
R-452B
R-454B
R-32
35
Technology and development of refrigerant for HVAC
Ingersoll Rand

Refrigerant Toxicity

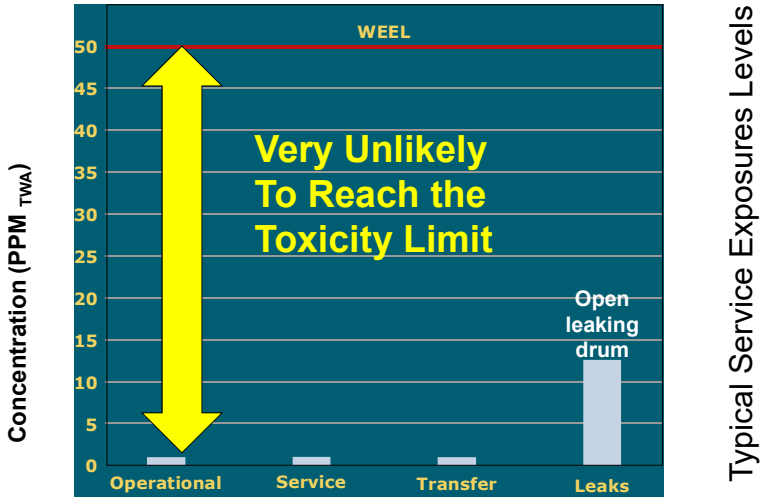
Refrigerant	ASHRAE 34		OEL, ppm	Normal Boiling Point, °C
R-514A	B1	ALL Neither toxic nor highly toxic	320	29.0
R-123	B1		50	27.0
R-1233zd	A1		800	18.1
R-134a	A1		1000	-26.0
R-513A	A1		650	-29.2
R-1234ze	A2L		800	-19.0
R-410A	A1		1000	-51.6
R-32	A2L		1000	-52.0
R-452B	A2L		870	-51.0

Room Temp.

Liquid

Gas

Refrigerant Toxicity



* All measured sites are Trane R-123 centrifugal chillers

Closing Remarks

- R-123, R-134a, R-410A… are giving way to the next generation refrigerants R-1233zd, R-514A, R-513A, etc.
  And more being commercialized before 2020
- Refrigerant must be safe for HVAC application
  Consider both flammability and toxicity
- Sustainable throughout product lifetime
  Lifetime investment, carbon emission, refrigerant availability, etc.