A VISUAL REPRESENTATION OF REFRIGERANT CHARACTERISTICS – WHAT DO HFOs LOOK LIKE?

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The road so far.....

Organic Refrigerants

- 1980s: CFC&HCFC
- 1990s: HCFC&HFC
- 2000s: HCFC&HFC
- 2010s: HFC&HFO

Natural Refrigerants

- 1980s: NH_3&HC
- 1990s: NH_3,CO_2&HC
- 2000s: NH_3,CO_2&HC
- 2010s: NH_3,H_2O,CO_2&HC

This has been difficult to explain to business leaders, who are understandably upset at the thought of having to pay again for another round of refrigerant changes not long after the last time. In addition the changes are becoming more difficult and the time allowed to implement them is getting shorter.

We need a better way of explaining ourselves to non-technical people…

Refrigerant Choices

- Cost of the refrigerant (or system)
- Efficiency
- Operating Pressure
- Cooling Capacity
- Ozone Depletion Potential
- Global Warming Potential
- Toxicity
- Flammability

Creating a rating methodology

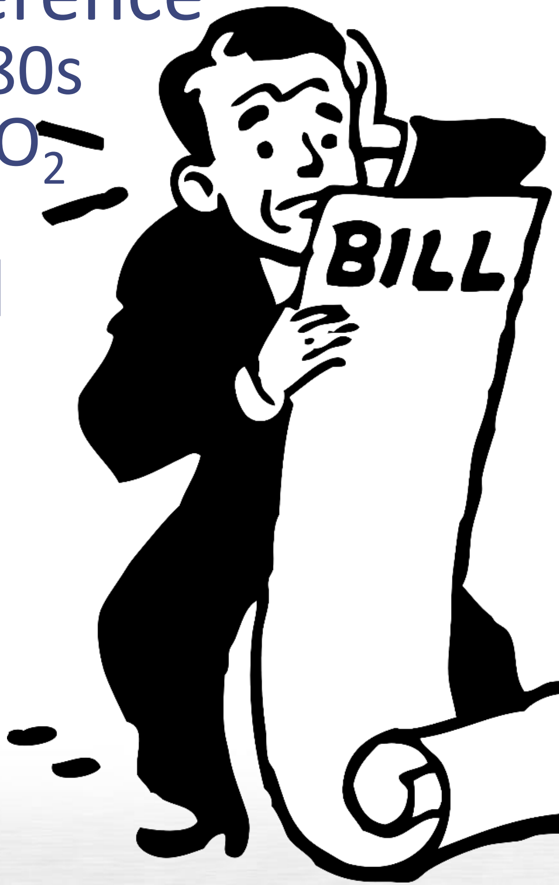
- Consider 8 characteristics that affect choice
- Rank each refrigerant from 1 (bad) to 10 (good)
- Consider each refrigerant in relation to the others
- Make sure that all relevant factors are weighted

	R-12	R-22	NH3	CO2	HC	R-134a	R-32	R-1234yf
Cost	6	5	8	9	6	4	3	1
Capacity	5	7	7	9	7	5	8	5
Flammability	9	7	5	10	3	7	5	5
ODP	1	3	10	10	10	10	10	10
Efficiency	7	6	7	6	7	5	7	4
GWP	1	3	9	9	9	3	5	7
Toxicity	7	7	3	5	7	7	9	8
Pressure	7	6	6	4	6	7	5	7

Creating a rating methodology - Cost

	R-12	R-22	NH3	CO2	HC	R-134a	R-32	R-1234yf
Cost	6	5	8	9*	6	4	3	1

- Purchase price of refrigerant for contractors
- Adjusted to present day values
- Historic factors are included for reference
  - R-12 is relative to ammonia in the 1980s
  - R-22 is level with commercial grade CO_2
  - Industrial grade CO_2 is much cheaper
- Recent HFC price hikes not included
  - The data is from January 2018
  - Only R-134a would change it's rating,
  - Dropping from 4 to 3



* Price based on industrial tankers

Creating a rating methodology - Efficiency

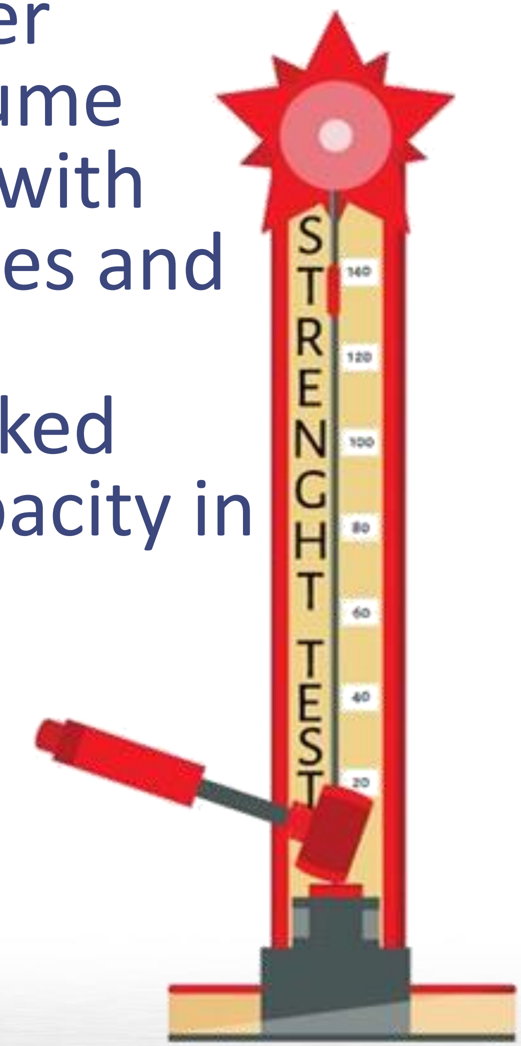
	R-12	R-22	NH3	CO2	HC	R-134a	R-32	R-1234yf
Efficiency	7	6	7	6	7	5	7	4

- In theory all refrigerants should give similar levels of efficiency in a Perkins vapour compression cycle
- Any differences are due to secondary effects
  - Pressure loss in key components
  - Amount of flash gas
  - Critical temperature
- Carnot is the benchmark
- All refrigerants fall short
- The grouping is quite tight
- Note the progressive decline from R-12 to R-1234yf

Creating a rating methodology - Capacity

	R-12	R-22	NH3	CO2	HC	R-134a	R-32	R-1234yf
Capacity	5	7	7	9	7	5	8	5

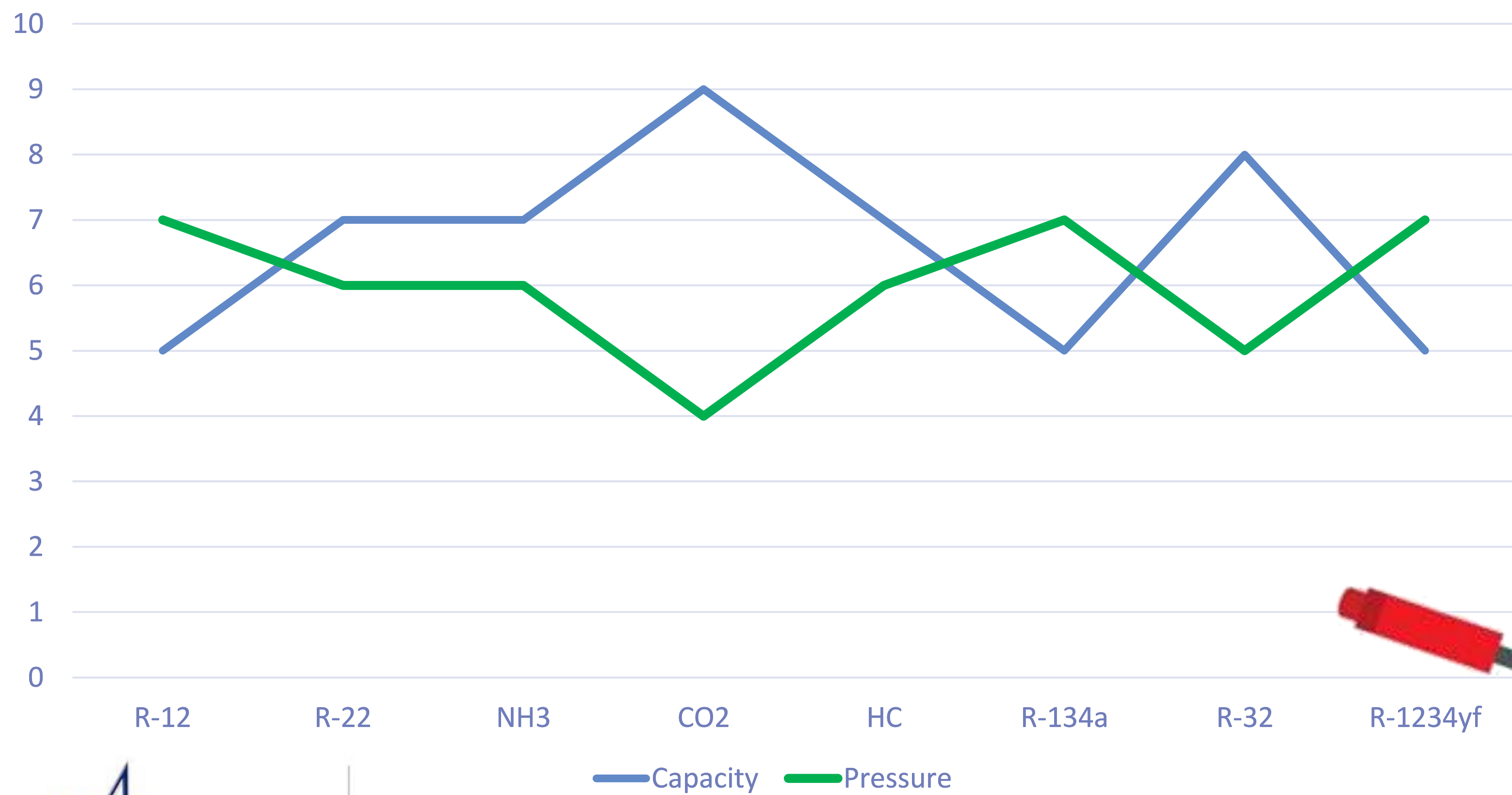
- High pressure refrigerants give higher capacity per unit of compressor volume
- In large systems this correlates well with system cost as compressors, pipe sizes and heat exchangers tend to be smaller
- CO_2 would score 10 here, but is marked down by 1 due to loss of cooling capacity in high ambient conditions



Creating a rating methodology – Operating Pressure

	R-12	R-22	NH3	CO2	HC	R-134a	R-32	R-1234yf
Pressure	7	6	6	4	6	7	5	7

- This is the flipside of the capacity scores



Creating a rating methodology - Flammability

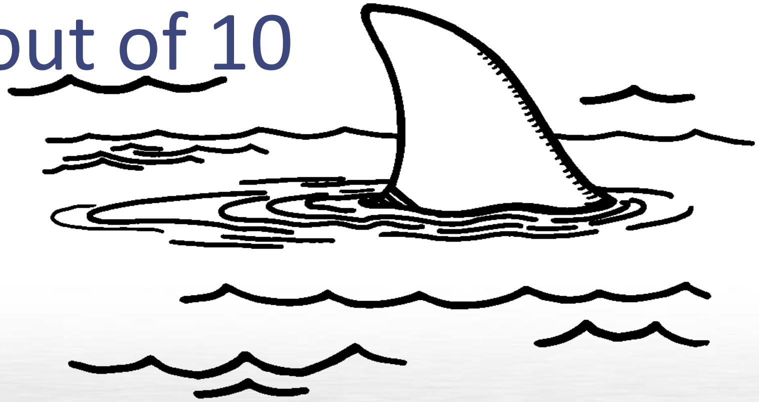
	R-12	R-22	NH3	CO2	HC	R-134a	R-32	R-1234yf
Flammability	9	7	5	10	3	7	5	5

- The ranking considers degree of flammability
- Including differences between R-12, R-22 and CO_2
- Toxic products of combustion are not considered
- They are included in the toxicity rating
- Which of the flammable refrigerants caused the explosion in the picture?

Creating a rating methodology - Toxicity

	R-12	R-22	NH3	CO2	HC	R-134a	R-32	R-1234yf
Toxicity	7	7	3	5	7	7	9	8

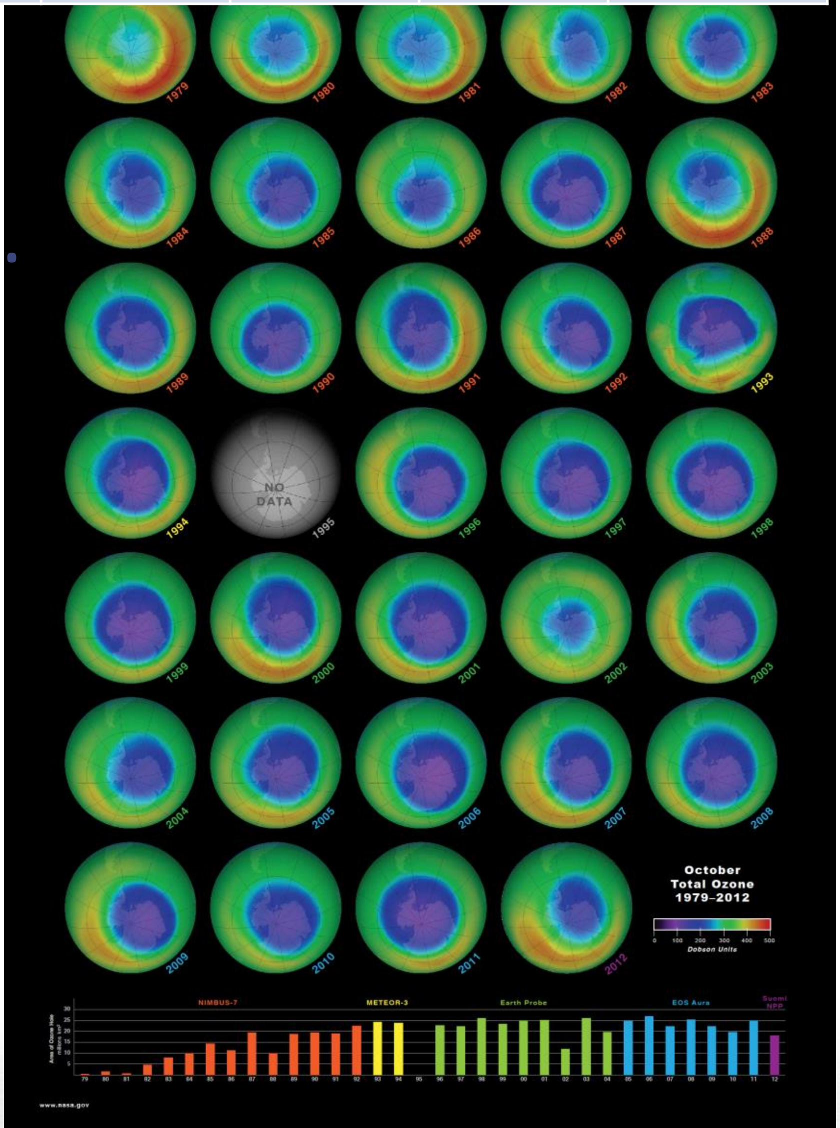
- No refrigerant scores 10 for toxicity
- They are all potentially harmful
- Factors considered include
  - Chronic toxicity (the only factor considered in A or B)
  - Acute toxicity (short term effect)
  - Central Nervous System effects
  - Whether the refrigerant has an odour
  - Whether the refrigerant affects the breathing reflex
  - Toxic products of combustion
- Only water would score 10 out of 10



Creating a rating methodology – Ozone Depletion

	R-12	R-22	NH3	CO2	HC	R-134a	R-32	R-1234yf
ODP	1	3	10	10	10	10	10	10

- We had stopped talking about ozone depletion but it is back in the news….
- R-11 in insulation foam
- Fugitive emissions of R-23
- The simplest classification
  - Any refrigerant with no effect on ozone scores 10
- Is there a case for review of these scores?



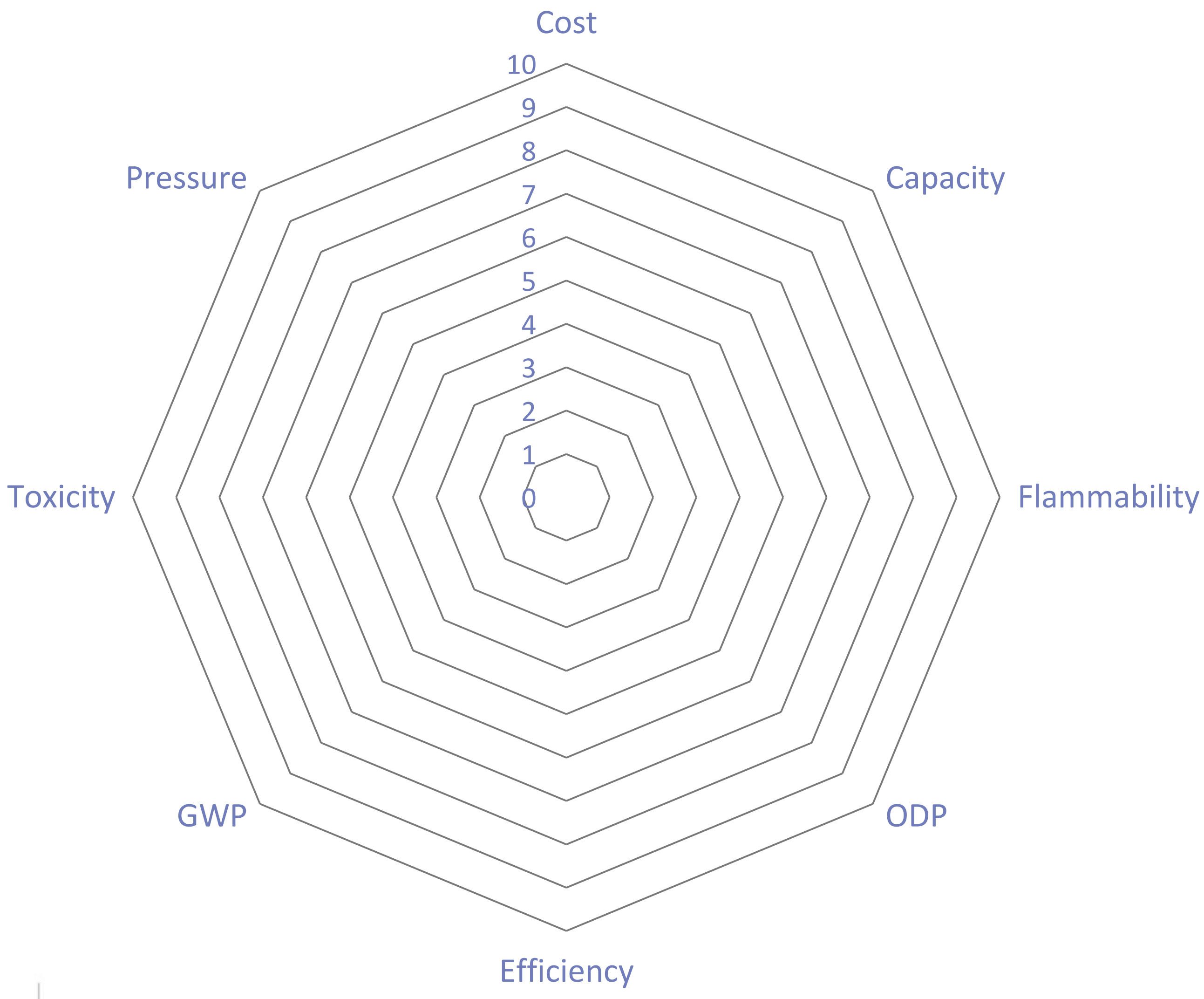
Creating a rating methodology - GWP

	R-12	R-22	NH3	CO2	HC	R-134a	R-32	R-1234yf
GWP	1	3	9	9	9	3	5	7

- GWP value is broken into logarithmic bands
- A value below 10 scores 9 points
- 10-30=8 points, 30-100=7 points and so on
- The value is an estimate of whole life GWP
- It includes assumptions about production
- Based on 500g/kWh CO_2 emission
- The estimated effect for fluorocarbons is 30
- Except for R-1234yf, which is 70 (harder to make)

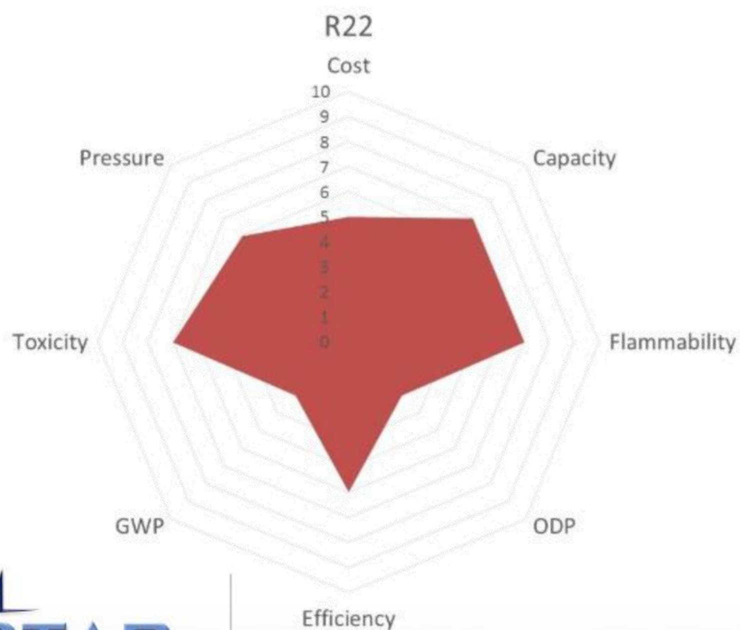
GWP	<10	10-30	30-100	100-300	300-1000	1k-3k	3k-10k	>10k
Rating	9	8	7	6	5	3	2	1
Examples	NH_3		R1234yf		R-32	R-134a		R-12

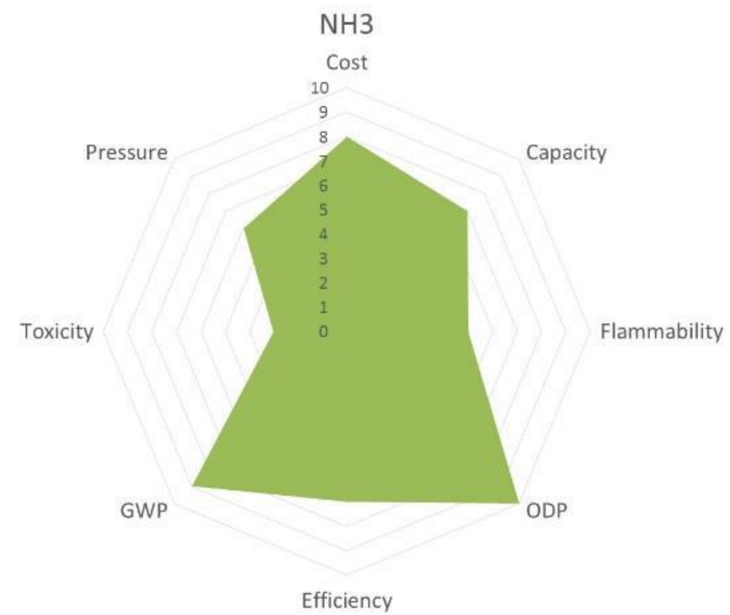
Creating a rating methodology – Output Presentation



A graphical representation – R-22 vs NH_3

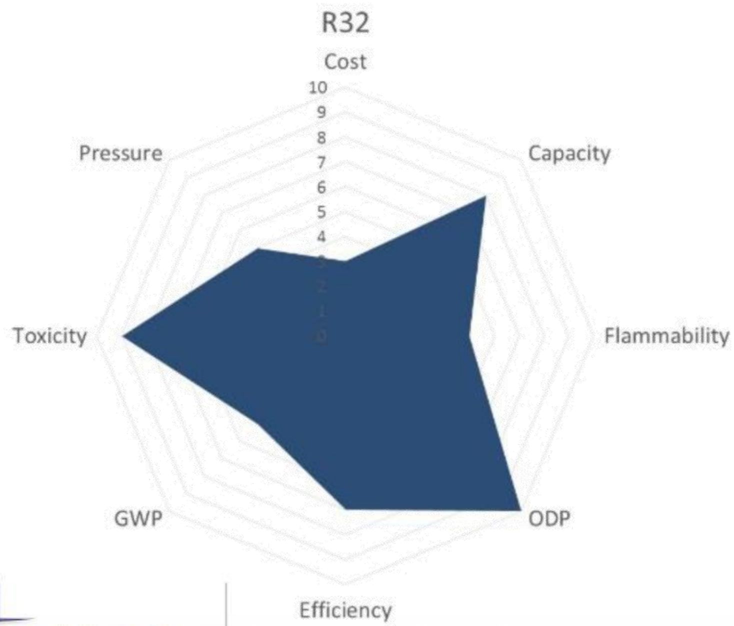
- Compare R-22 with its "competitor", NH_3
- NH_3 solves the ozone and GWP problems
- But it's a trade off for toxicity and flammability
- R-22 is worse in terms of cost
- But similar in terms of efficiency
- There is scope for improvement in R-22

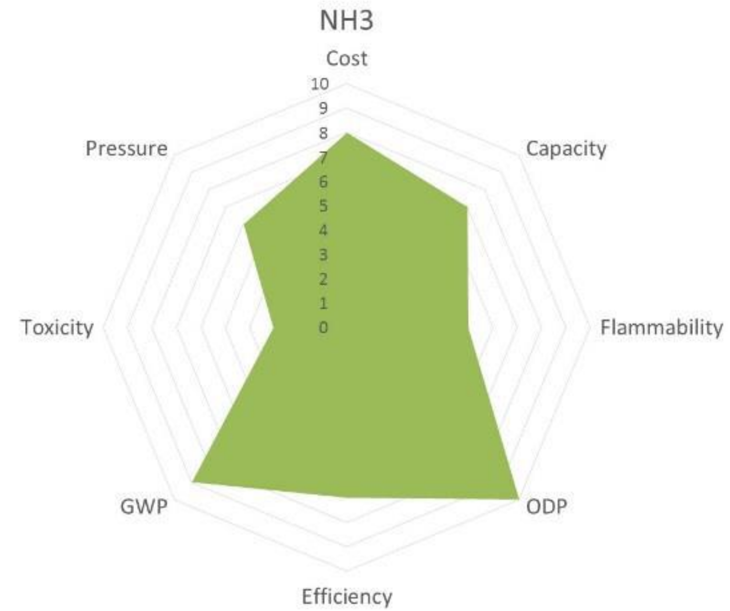




A graphical representation – R-32 vs NH_3

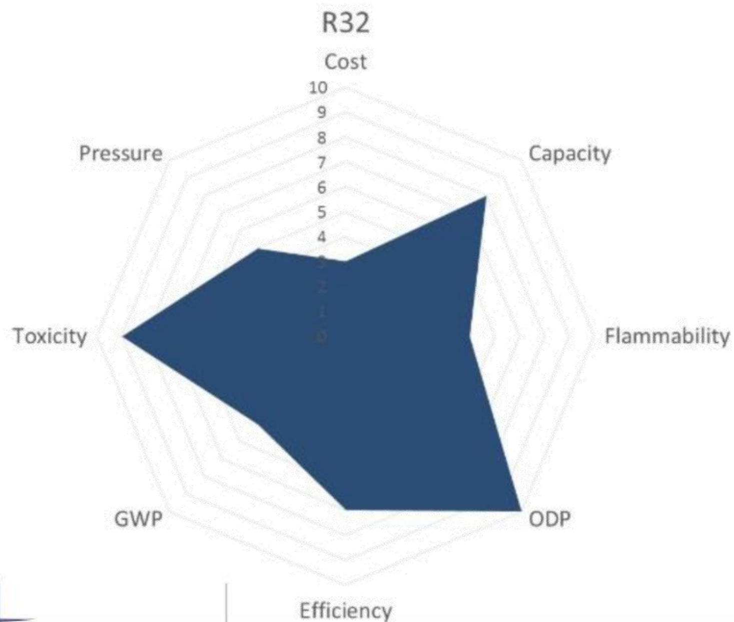
- Compare R-32 with its "competitor", NH_3
- R-32 solves the ozone problem but not GWP
- It scores well for toxicity
- It is worse in terms of cost
- But similar in terms of efficiency and flammability
- It does not look good for large industrial systems

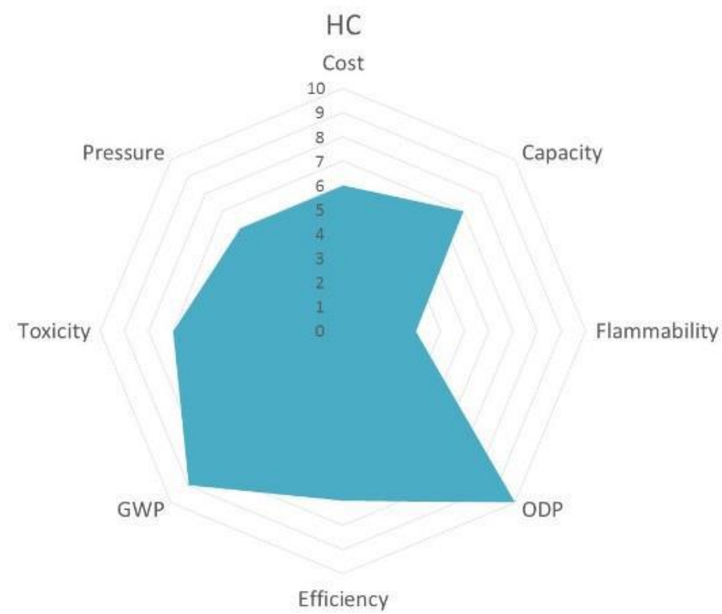




A graphical representation – R-32 vs HC

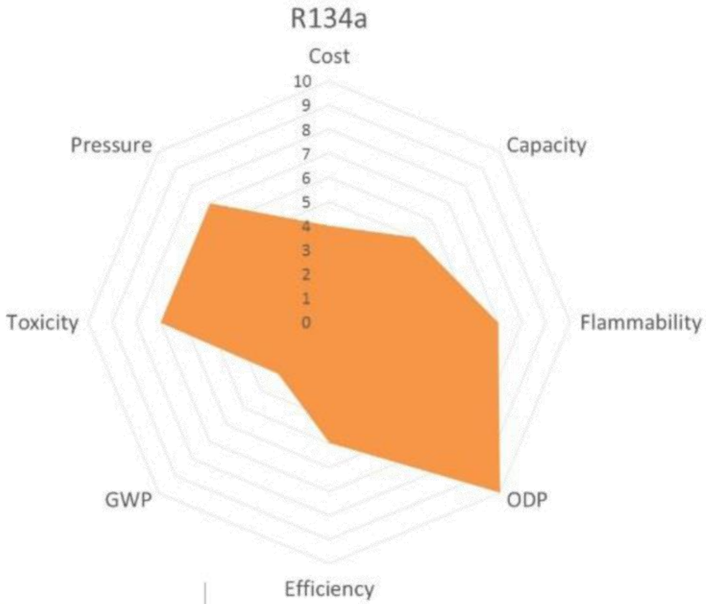
- Compare R-32 with its "competitor", hydrocarbon
- R-32 solves the ozone problem but not GWP
- HC is well-rounded except for it's flammability
- It is a better proposition for small (domestic)
- And possible for medium (air-con) systems
- If the flammability can be addressed safely

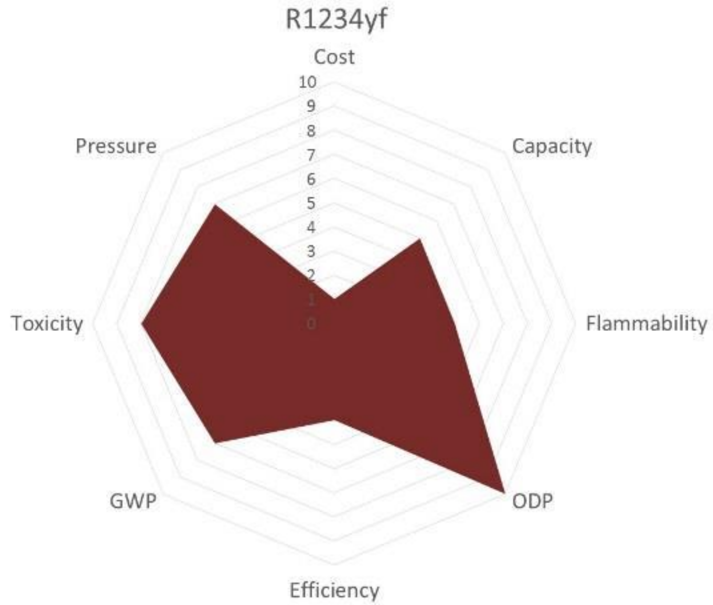




A graphical representation – R-134a vs R-1234yf

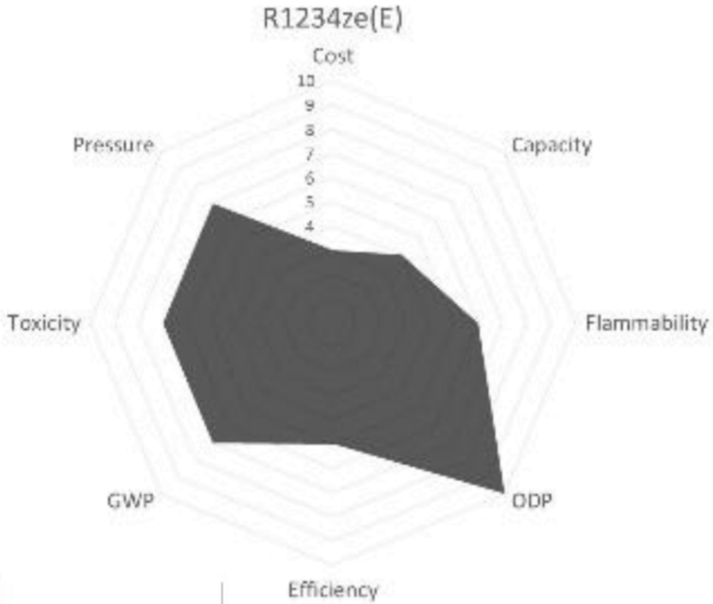
- They are remarkably similar
- R-1234yf is worse on cost and efficiency
- It is better on GWP
- But not the full solution on a whole life basis
- It's not the well-rounded solution we'd like to see

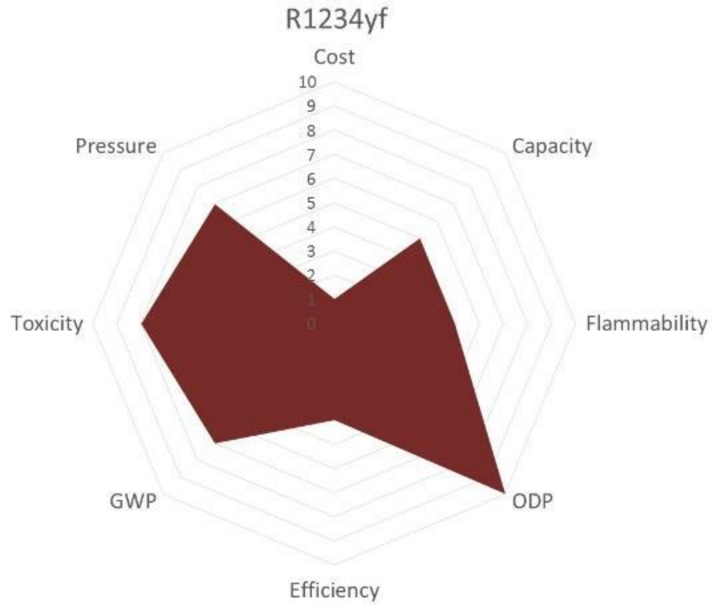




A graphical representation – R-1234ze(E) vs R-1234yf

- They are also remarkably similar
- R-1234yf is still worse on cost and efficiency
- R-1234ze(E) is worse on capacity
- It is the same on GWP, flammability and toxicity
- But still not the full solution on a whole life basis
- Although it's closer to the well-rounded solution





The next destinations.....

Organic Refrigerants

- 1980s: CFC&HCFC
- 1990s: HCFC&HFC
- 2000s: HCFC&HFC
- 2010s: HFC&HFO
- 2020s: HFC&HFO
- 2030s: HFO

Natural Refrigerants

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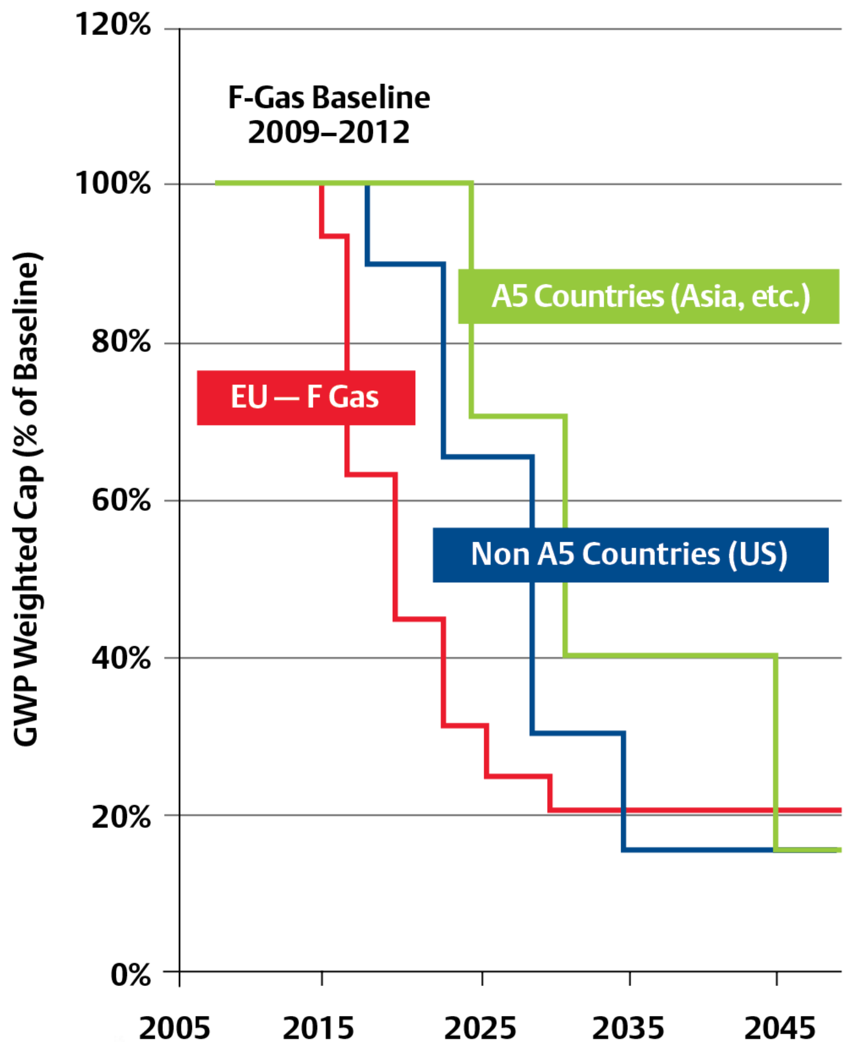
- 2000s: NH_3,CO_2&HC
- 2010s: NH_3,H_2O,CO_2&HC
- 2020s: NH_3,H_2O,CO_2&HC
- 2030s: NH_3,H_2O,CO_2&HC

What happens in Kigali.....

The Kigali Amendment



- Introduces HFCs to the Montreal process
- Uses same process as CFC phase out
- Follows similar path to EU f-gas directive
- Ends up at a lower level than Europe
- Enters into force on 1 January 2019
- Applies everywhere

Summary

- ***We have come a long way from R-12 use***
- ***This has involved a series of trade-offs***
- ***Looking at HFO's there is a need to address***
  - ***Cost***
  - ***Efficiency***
  - ***Flammability***
  - ***Indirect GWP (production methods)***