Overview of refrigerant alternatives in the air conditioning sector *

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Sustainable Technologies for Air Conditioning Workshop
18 November 2017, ICAO, MONTREAL (CAN)

* ***This presentation is given in a personal capacity***

Outline

- Las Vegas conference February 2017
- AC equipment types considered
- Alternatives for new equipment, potential new alternatives
- AC equipment types, numbers & alternatives applied now and in future
- Maintaining equipment in use (standards and charge reduction)
- Refrigerants and refrigerant blends
- Some general considerations and concluding remarks

Las Vegas conference, February 2017

In Las Vegas, there were presentations

- Emphasising that R&D has to be completed, that most promising alternatives need further development, that final work is beginning
- Mentioning that inventories had been made which new refrigerants are available and that the next transition has begun
- Stressing that available alternative refrigerants do not imply that these are applied in commercially available equipment
- Giving new refrigerant blends info (two chemical manufacturers)

In summary, several overviews emphasised new R&D, also mentioning that work for the next transition has started, that it will cost many efforts before equipment will be "commercialized" -- with relatively little on concrete low GWP devlpmt's

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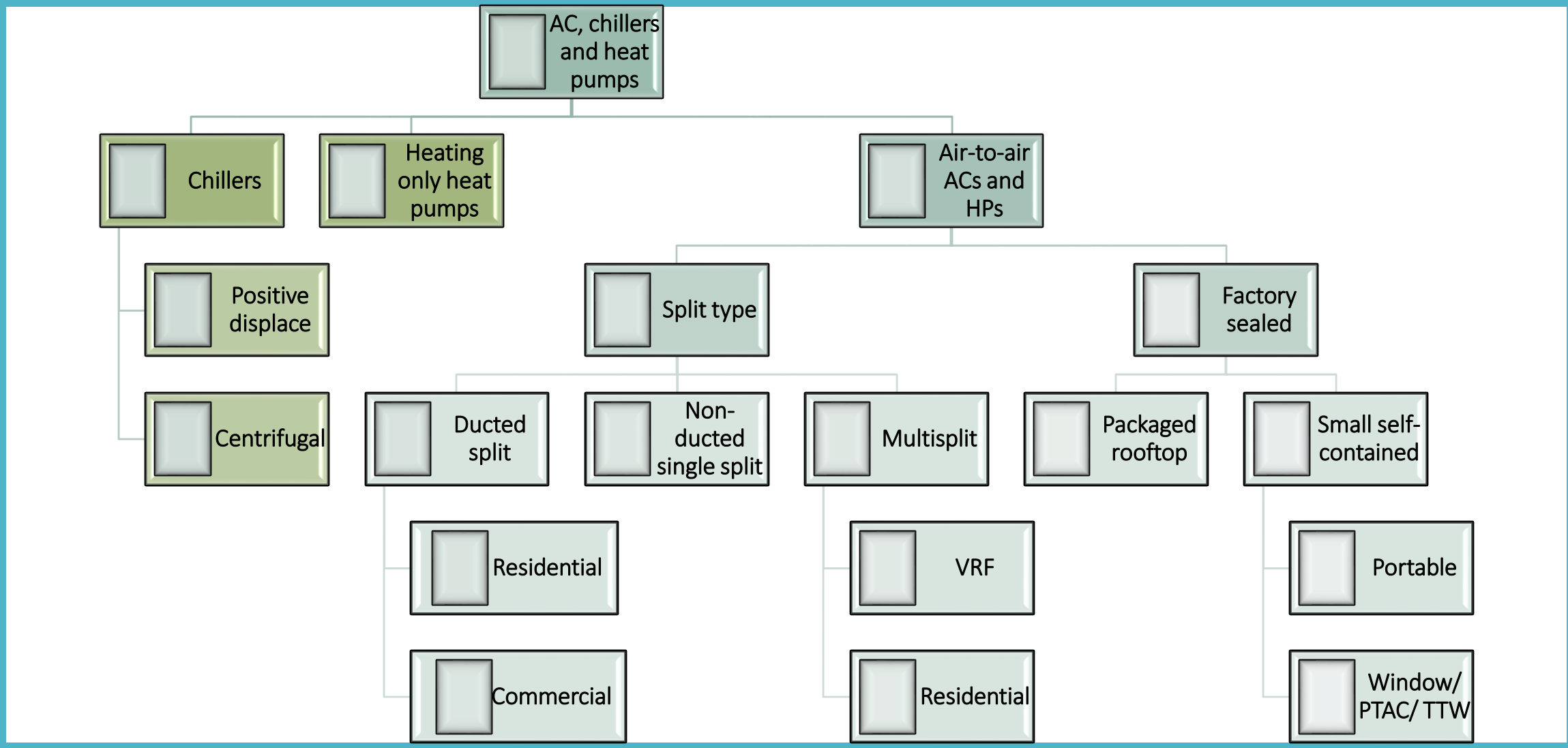
AC, chillers and heat pumps
Chillers
Heating only heat pumps
Air-to-air ACs and HPs
Positive displace
Centrifugal
Split type
Factory sealed
Ducted split
Non-ducted single split
Multisplit
Packaged rooftop
Small self-contained
Residential
Commercial
VRF
Residential
Portable
Window/ PTAC/ TTW

Air conditioning types (air-to-air)

Type		Primary configuration	System layout	Capacity range (kW)	HCFC-22 charge range (kg)
Small self-contained	Window	Small self-contained	Self-contained	1 – 10	0.3 – 3
	Portable	Small self-contained	Self-contained	1 – 10	0.3 – 3
	Through-the-wall	Small self-contained	Self-contained	1 – 10	0.3 – 3
	Packaged terminal	Small self-contained	Self-contained	1 – 10	0.3 – 3
		Non-ducted split	Remote	2 – 15	0.5 – 5
		Non-ducted & ducted split	Remote	4 – 300	2 – 240
		Ducted split	Remote	4 – 17.5	1 – 7
		Ducted commercial	Self-contained	7 – 750	5 – 200
		Ducted commercial	Remote	10 – 750	5 – 250

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New equipment

- The refrigerant used traditionally for AC is (was) **HCFC-22**; **HFC-134a** is the only single component HFC refrigerant in AC (to a limited extent)
- The two most widely used HFC blends are still **R-410A** and **R-407C**
- A number of blends emerged as replacements for HCFC-22 in AC, consisting of **HCs, HFC-32, -125, -134a, -152a, -1234yf** and/or **-1234ze(E)**
- The number of medium and lower GWP pure fluids and blends applied in new **commercially available** equipment is still very limited

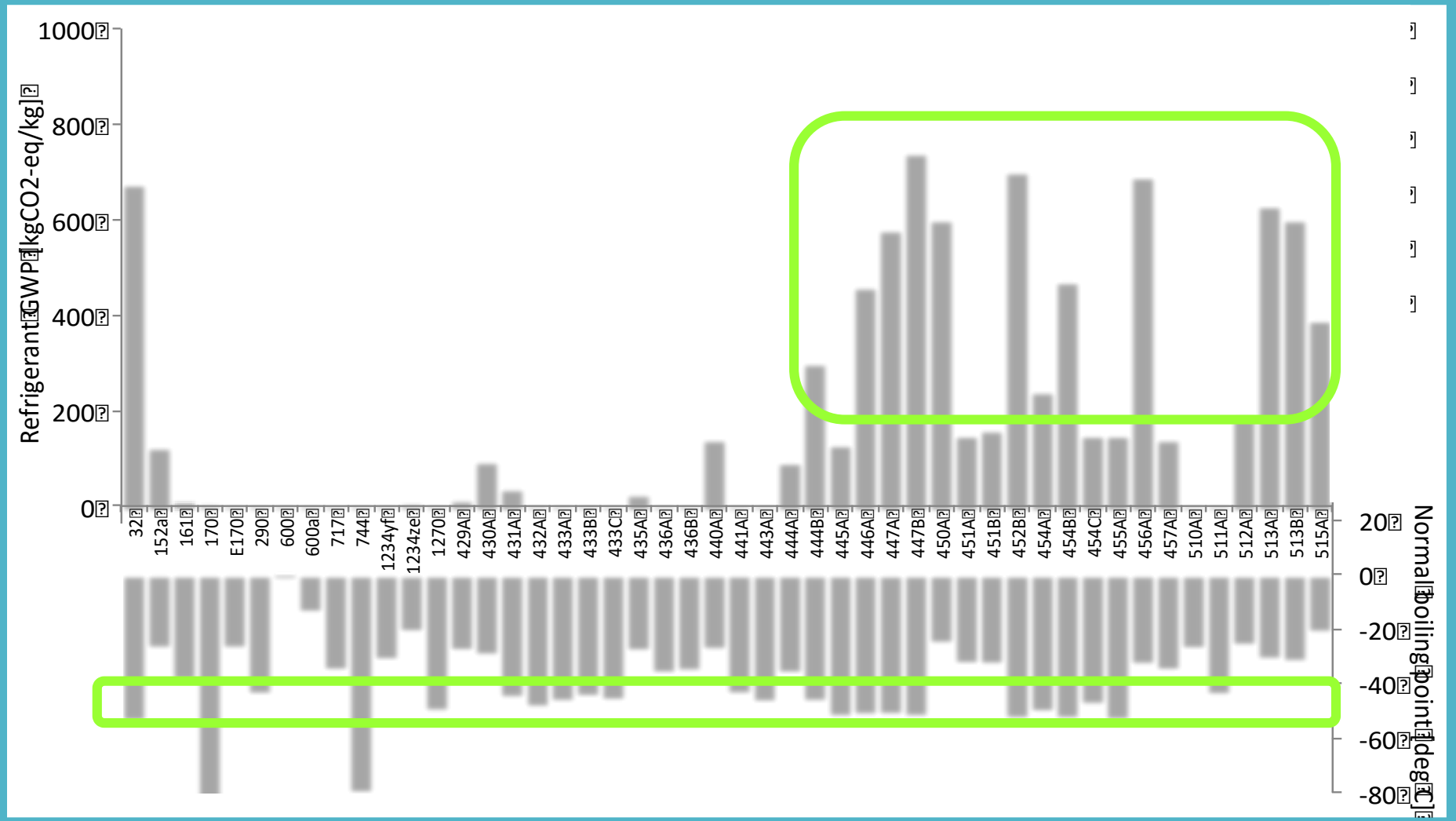
New equipment refrigerants

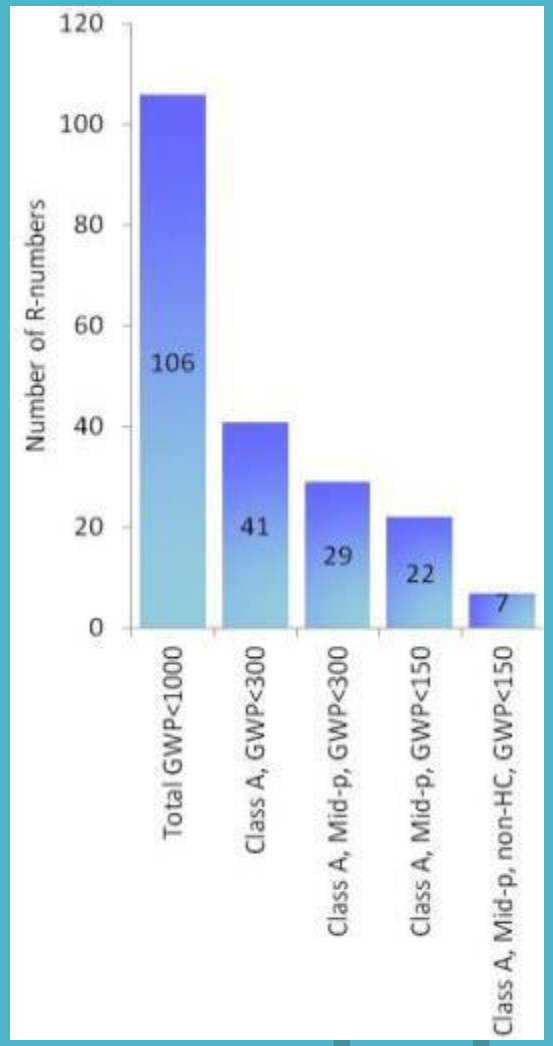
- **R-407C**: transitional refrigerant, GWP (1774), limited use in certain regions
- **R-410A**: the major candidate so far, due to more compact construction and better performance in certain type of ACs. Compared to HCFC-22, GWP (2088) not much higher, 5-10% lower performance at higher ambients
- **HFC-32**: available replacement for R-410A with medium GWP (675), slightly higher capacity, slightly lower charge weight, A2L flammability
- **HC-290**: commercially available in low charge systems, compared to HCFC-22 it has slightly higher efficiency and lower capacity, A3 flammability
- **HFC-HFO mixtures R-444B, R-446A, R-447A/B**: capacities similar to HCFC-22, broadly similar performance, higher costs compared to HCFC-22, GWP not low (300-800), A2L flammability

New equipment potential refrigerants (cont'd)

- **HFC-161**: low GWP refrigerant, better performance (5-15%) than HCFC-22, not included in Kigali Annex F, flammable, tests ongoing at some places
- **HC-1270**: efficiency and cooling capacity better, slightly higher pressure than HCFC-22 (original olefin, propylene, actually propene), A3 flammability
- **R-744, CO_2**: low critical temperature, improvements needed to increase capacity and efficiency (there are now systems available 3-300 kW capacity)
- **R-452B, R-454A, R-455A, R-459A**: R-410A replacements with slightly different properties than R-410A, in most cases having a large percentage of HFC-32, certain percentages of HFO-1234yf or HFO-1234ze, GWPs in the range of 250-700, certain temperature glides, further investigations needed for overall performance, normally A2L flammability (mixture range is expanding further)

Breakdown of medium and low GWP options





Breakdown of medium and low GWP cont'd

- Graph lists all refrigerants and blends (possible options for AC), 106 in total
- For GWP<300, and "reasonable" evaporation pressure, the number is limited, it is about 30
- For GWP<150, and "reasonable" evaporation pressure, the number further decreases to 7 -- at present

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Numbers

Type	Produced/a	To N-Article 5	To Article 5	In operation
Small self contained	17 M	50%	50%	200 M
Split -non ducted (resid. & comm.)	70 M	20%	80%	1000 M
Split -ducted (resid. & comm.)	11 M	33%	67%	150 M
Multi-split (resid. & comm.)	1.2 M	25%	75%	7 M
Ducted commercial packaged	1 M	33%	67%	20 M

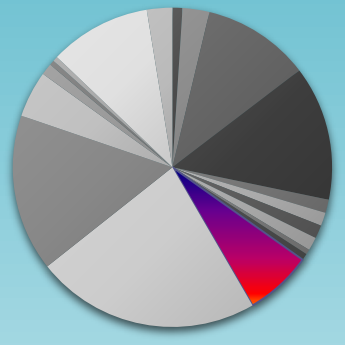
- **100 M pieces of equipment produced per year; 1400 M in operation**

Small factory sealed AC

2½–5kW

1kW → 10 → 100 → 1000

½–1 kg



Current (ODP)

R22

Current (0 ODP)

R410A, R407C, R290

Options

R290, R32, R444B, R446A, R447A, etc

Numbers

Type	Produced/a	To N-Article 5	To Article 5	In operation
Small self contained	17 M	50%	50%	200 M
Split -non ducted (resid. & comm.)	70 M	20%	80%	1000 M
Split -ducted (resid. & comm.)	11 M	33%	67%	150 M
Multi-split (resid. & comm.)	1.2 M	25%	75%	7 M
Ducted commercial packaged	1 M	33%	67%	20 M

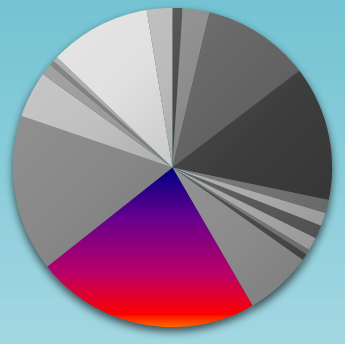
- **100 M pieces of equipment produced per year; 1400 M in operation**

Non-ducted single split AC (70 M/yr)

3 – 7 kW

1kW → 10 → 100 → 1000

1 – 1½ kg



Current (ODP)

R22

Current (0 ODP)

R410A, R407C, R290, R32

Options

R290, R32, R444B, R446A, R447A, etc

Numbers

Type	Produced/a	To N-Article 5	To Article 5	In operation
Small self contained	17 M	50%	50%	200 M
Split -non ducted (resid. & comm.)	70 M	20%	80%	1000 M
Split -ducted (resid. & comm.)	11 M	33%	67%	150 M
Multi-split (resid. & comm.)	1.2 M	25%	75%	7 M
Ducted commercial packaged	1 M	33%	67%	20 M

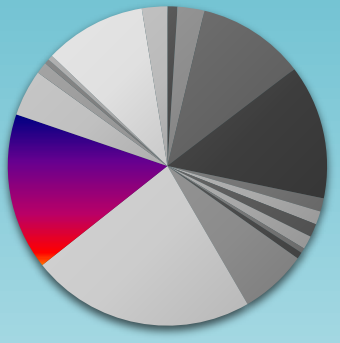
- **100 M pieces of equipment produced per year; 1400 M in operation**

Ducted split AC (11 M/yr)

20 – 200 kW

1kW → 10 → 100 → 1000

5 – 50 kg



Current (ODP)	Current (0 ODP)	Options
R22	R410A, R407C, R744	R744, R32, R444B, R446A, R447A, etc (R290)

Numbers

Type	Produced/a	To N-Article 5	To Article 5	In operation
Small self contained	17 M	50%	50%	200 M
Split -non ducted (resid. & comm.)	70 M	20%	80%	1000 M
Split -ducted (resid. & comm.)	11 M	33%	67%	150 M
Multi-split (resid. & comm.)	1.2 M	25%	75%	7 M
Ducted commercial packaged	1 M	33%	67%	20 M

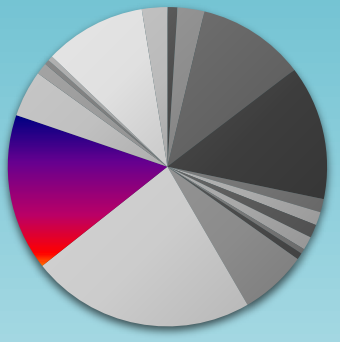
- **100 M pieces of equipment produced per year; 1400 M in operation**

Multi-split systems (1.7 M/yr)

10 – 150 kW

1kW → 10 → 100 → 1000

4 – 60 kg



Current (ODP)

R22

Current (0 ODP)

R410A, R407C

Options

R32, R444B, R446A, R447A, etc (R290)

Numbers

Type	Produced/a	To N-Article 5	To Article 5	In operation
Small self contained	17 M	50%	50%	200 M
Split -non ducted (resid. & comm.)	70 M	20%	80%	1000 M
Split -ducted (resid. & comm.)	11 M	33%	67%	150 M
Multi-split (resid. & comm.)	1.2 M	25%	75%	7 M
Ducted commercial packaged	1 M	33%	67%	20 M

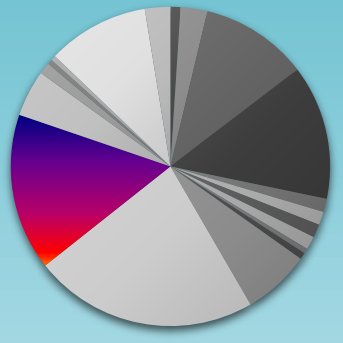
- **100 M pieces of equipment produced per year; 1400 M in operation**

Packaged "rooftop" ducted AC (1 M/yr)

20–100 kW

1kW → 10 → 100 → 1000

5 – 30 kg



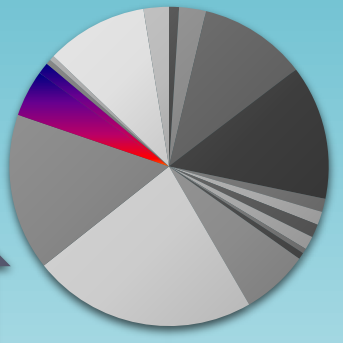
Current (ODP)	Current (0 ODP)	Options
R22	R410A, R407C, R134a, R744	R744, R290, R32, R444B, R446A, R447A, etc

Chillers (not further addressed here)

10 – 1000 kW; 1-5 MW

1kW → 10 → 100 → 1000

4 – 300 kg; 0.5-2.5 Mt



Current (ODP)

R22, R123

Current (0 ODP)

R410A, R407C, R290, R1270, R744, R717, R1233zd, R1234ze

Options

R717, R744, R290, R1270, R1234ze, R1233zd, R1234yf, R32, R444B, R446A, R447A, etc

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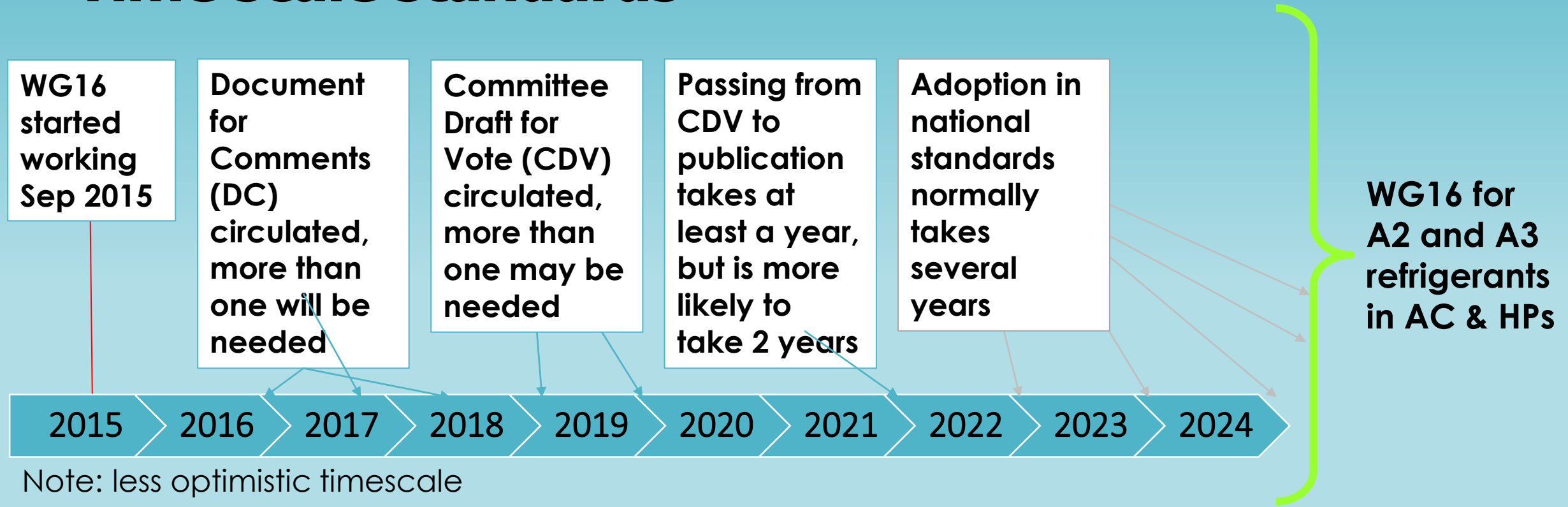
Time scale standards



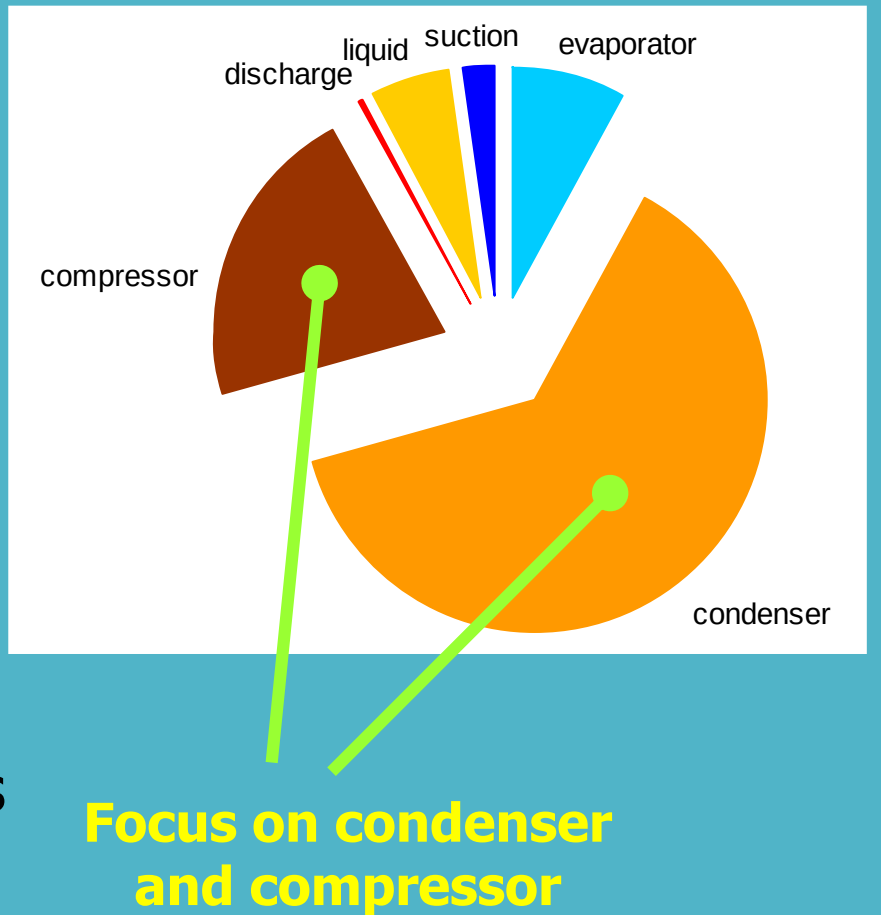
Note: less optimistic timescale

WG9 for A2L refrigerants in AC & HPs -
Final Draft International Standard (FDIS) currently out for vote

Refrigerant charge reduction

Refrigerant charge reduction increasingly important:

- Cost reduction. Lower charge ⇒ smaller component volumes, less expenditure of material and refrigerant
- Reduction in environmental impact. Smaller charge corresponds to a smaller potential contained impact
- Risk mitigation. For all refrigerants, but particularly for flammable substances, smaller charges equate to smaller risk. Safety standards impose charge limits, charge reduction allows wider use of given refrigerants



Focus on condenser and compressor

Maintaining equipment in use

Maintaining equipment in operation until end of life involves

- Use of existing refrigerant
  - Continue using HCFC-22 (R-410A etc.)
- Refrigerant replacement only
  - Normally use of blends of HFCs with some HC, R-417A, R-438A (oil return?)
- Retrofit (refrigerant and component change)
  - Often a retrofit from HCFC-22 to R-407C is considered (moderate temperature glide)
  - Using flammables HC-290, -1270, R-433, R-441. Capacity and efficiency close to HCFC-22 but significant safety hazards. Not recommended in systems that HAVE NOT BEEN designed or "re-manufactured" appropriately for A3 flammables (safety standards to be strictly followed)

Refrigerant options for new & existing 22 equipment

Type	Options for new equipment	Options for existing equipment	
		Refrigerant replacement (only)	Retrofit
Window	R-410A, R-407C, HC-290, HC-1270, HFC-32, R-444B, R-446A, R-447A	R-417A	
Portable		R-417B	
Through-the-wall		R-422A	R-407A
Packaged terminal		R-422B	R-407B
Split (non-ducted) smaller		R-422C	R-407C
Split (ducted)		R-422D	R-407D
Split (non-ducted) larger		R-424A	R-407E
Multi-split	R-410A, R-407C, HFC-32, R-444B, R-446A, R-447A	R-425A	R-421A
Packaged rooftop		R-428A	R-421B
Ducted commercial split		R-434A	R-427A
		R-438A	
		R-442A	

NOTE: All the options are not universally applicable in the listed equipment types and this list is not exhaustive.

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Refrigerants - a delicate choice

- The use of pure refrigerants, i.e., low and medium GWP HFCs and "natural" refrigerants is definitely going to expand, even more after 2019-2020
- Logically, some manufacturing industries go for ONE way forward (even when it might not be for the long term), while especially chemical manufacturers now come forward with an ever growing string of mixtures
- How many HFOs will there be ? The number is likely to be limited …
- HFO-1234yf is to be applied in MACs, as a pure fluid not in many other applications; it is proposed as a component in HFC-HFO blends for AC
- HFO-1234ze and -1233zd have a future probably only in chillers (-1234ze in blends, maybe ORCs). No other HFO alternatives (-1224yd, -1132, -1336) ?

Refrigerant blend developments - general

- Statement: "HFC(HFO) blends are a good solution for the "low-GWP issue"
- Does equipment need adjustments here, or totally re-engineered designs ?
- They contain high-GWP HFCs (to be phased down) which makes their (high GWP) HFC reporting necessary under "Kigali"
- An ever growing number of HFC/HFO blends has been given "400" and "500" series numbers, with the latest ones R-459A/B and R-460A/B; many more to come; is the AC industry taking this issue less seriously, going to "wait and see"? (continuing drip-drip-.. of new mixtures allows industry to procrastinate…)
- The (servicing) sector cannot cope with a huge number of blends; reduction to a "commercialised" low number (perhaps 3-5) seems desirable (how many would this be for AC ?)

Refrigerant HFC-HFO blends (AC and other)

Designation	Refrigerants	Composition	GWP	Replacement for
R-444A	HFC-32/-152a/-1234ze	12/5/83	92	HFC-134a replacement MAC
R-444B	HFC-32/-152a/-1234ze	41.5/10/48.5	296	HCFC-22 replacement
R-445A	R-744/-134a/-1234ze	6/9/85	135	HFC-134a replacement MAC
R-446A	HFC-32/-1234ze/HC-600	68/29/3	461	R-410A replacement
R-447A	HFC-32/-125/-1234ze	68/3.5/28.5	583	R-410A replacement
R-448A	HFC-32/-125/-1234yf/-134a/-1234ze	26/26/20/21/7	1390	R-404A replacement
R-449A	HFC-32/-125/-134a/-1234yf	24.3/24.7/25.3/25.7	1400	R-404A replacement
R-450A	HFC-134a/-1234ze	42/58	605	HFC-134a replacement
R-452A	HFC-32/-125/-1234yf	11/59/30	2140	R-404A replacement (transp. refr.)
R-452B	HFC-32/125/1234ze	68/8/24	710	R-410A replacement
R-454A	HFC-32/1234yf	65/35	250	R-410A replacement
R-456A	HFC-32/-134a/-1234ze	6/45/49	650	HFC-134a replacement
R-457A	HFC-134a/-1234yf/-152a	18/70/12	150	R-404A replacement
R-459A	**HFC-32/-1234yf/-1234ze**	**21/69/10**	**530**	**R-410A replacement**
R-460A	**HFC-32/-125/-134a/-1234ze**	**28/25/20/27**	**3000**	
R-513A	HFC-134a/-1234yf	44/56	630	HFC-134a replacement
R-515A	HFC-1234ze/HFC-227ea	88/12	390	

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Refrigerants – low GWP

- There is a high level of activity in AC equipment R&D related to low GWP; emphasis on equipment with improved and high energy efficiency characteristics containing low-GWP refrigerants is more significant than ever
- Many investigations globally ask for further optimisation and expanding use of hydrocarbons, carbon dioxide and ammonia in various AC applications
- Charge reduction is very important – also via more integrated refrigerant – water AC designs
- Further evaluation regarding the application of "natural" versus synthetic refrigerants, and which advantages certain types of refrigerants will have, given the timescale of industrial and standards developments in AC (!!)

Concluding remarks

- Kigali has really reinforced the momentum towards low-GWP refrigerants
- But regional and national regulations will also form an important cornerstone for many developments, also for AC
- Adequate addressing of issues surrounding flammability expected in equipment standards (international, national), such as IEC 60335-2-40 and ISO 5149
- The low-GWP argument is an important factor, but not the only one that will determine which alternatives will be “the future ones”
- Ultimate objective amongst most stakeholders is a negligible GWP (i.e., to eliminate the issue) – whether via a step-change or a gradual shift
- **In the medium term, one will likely see the most appropriate combination of equipment energy efficiency and cost/price levels, together with good environmental performance, including particularly low-GWP, as well as safety, good servicing aspects etc.**