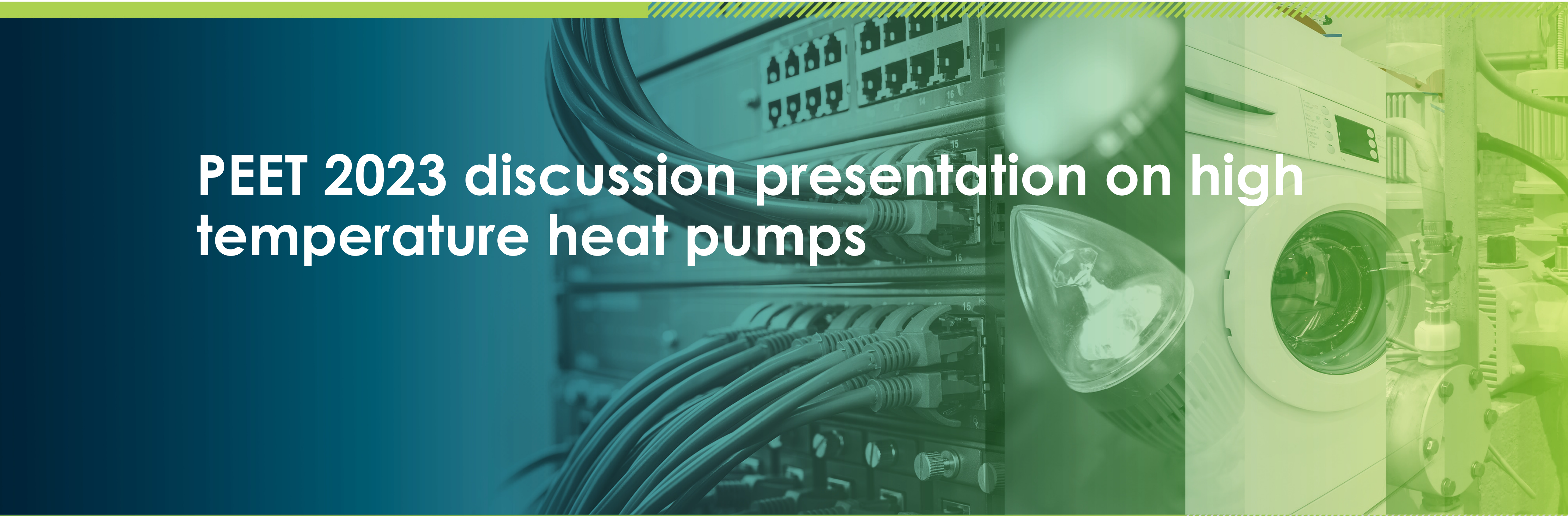
IEA Technology Collaboration Programme
on Energy Efficient End-Use Equipment



PEET 2023 discussion presentation on high temperature heat pumps

iea-4e.org

What are high temperature heat pumps?

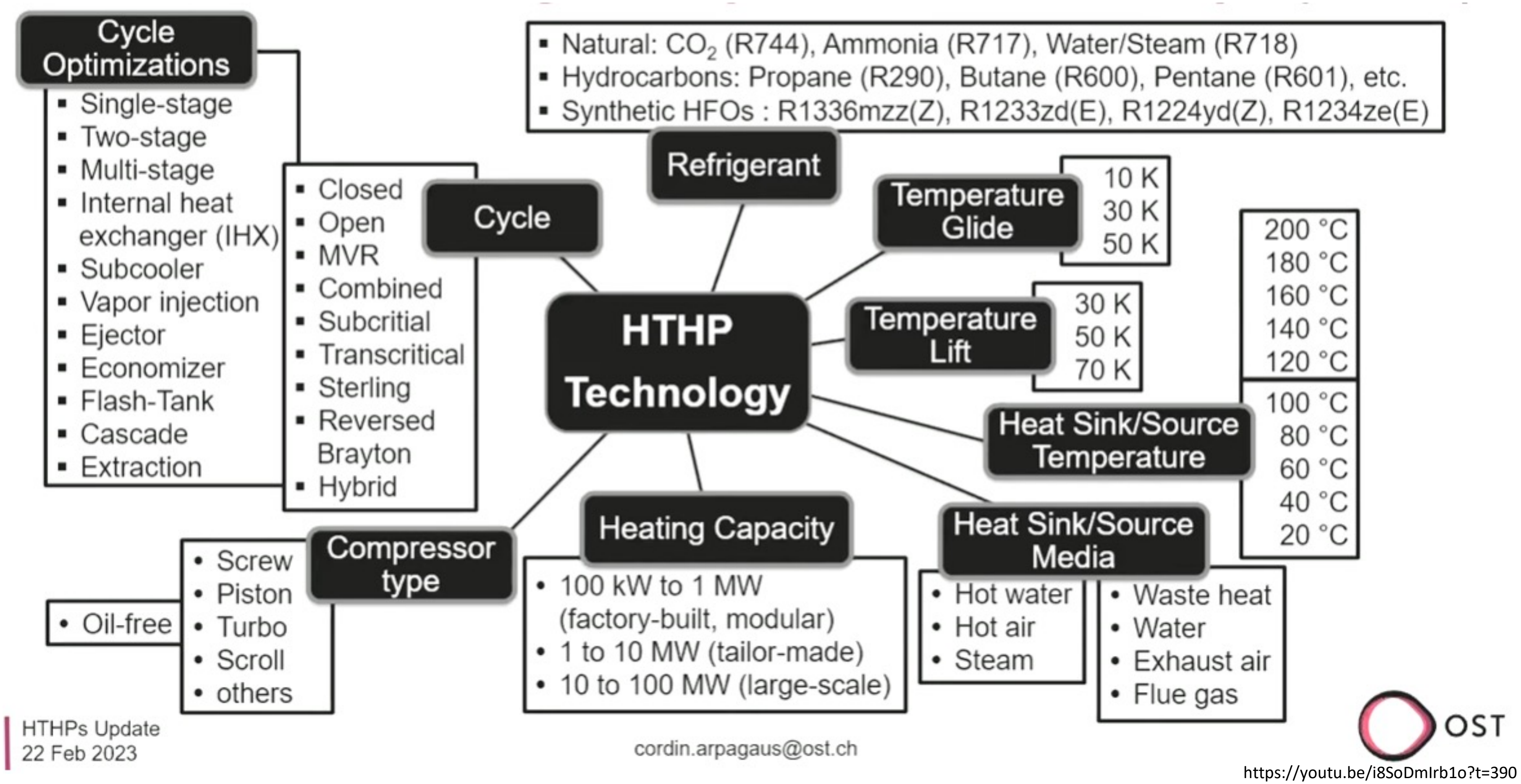
High temperature heat pumps definition

- There is no strict definition of what constitutes 'high'. The broadest application of the term includes any heat supply above 80°C i.e. not a 'conventional' heat pump (one designed for space heating/cooling or domestic hot water heating applications, or refrigeration applications)
- Broad sub-categorizing of HTHP by temperature is useful to describe technologies, applications and market readiness:
  - 80-100°C
  - 100-150°C
  - 150-200°C
  - 200+°C
- However, heat pump technologies and applications do not fit neatly into these subcategories
- They might also be referred to as medium temp HPs (typically below 100 °C), very high temp HP, and ultra-high temp HPs, or by process/heat demand temperature but these terms also do not correspond to any specific temperature ranges

Status of HTHP technology

Different HP technologies and factors influencing application and selection

Matching the required heat supply and HP performance with the appropriate HP design is complex



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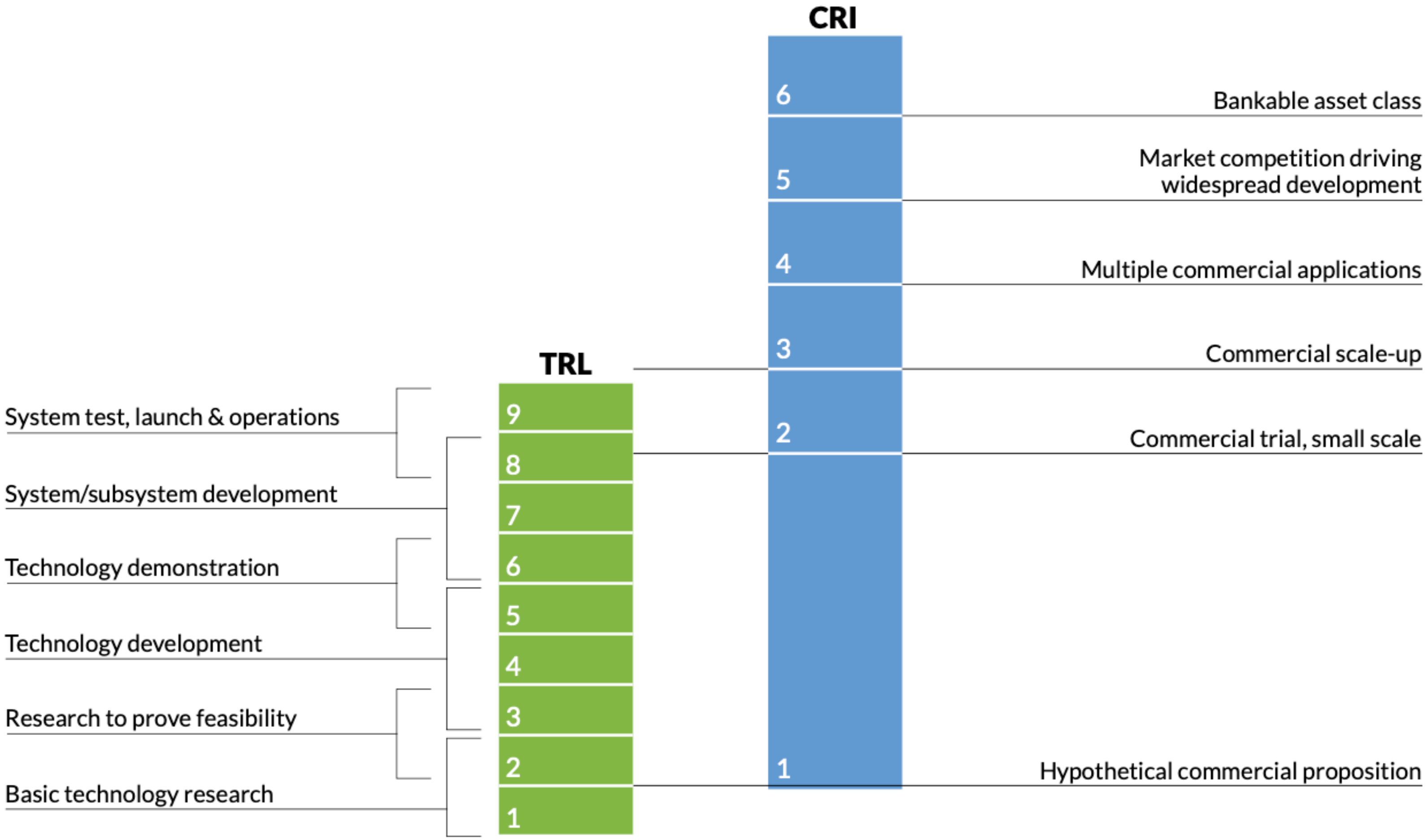
Technology readiness levels and Commercial readiness indicator



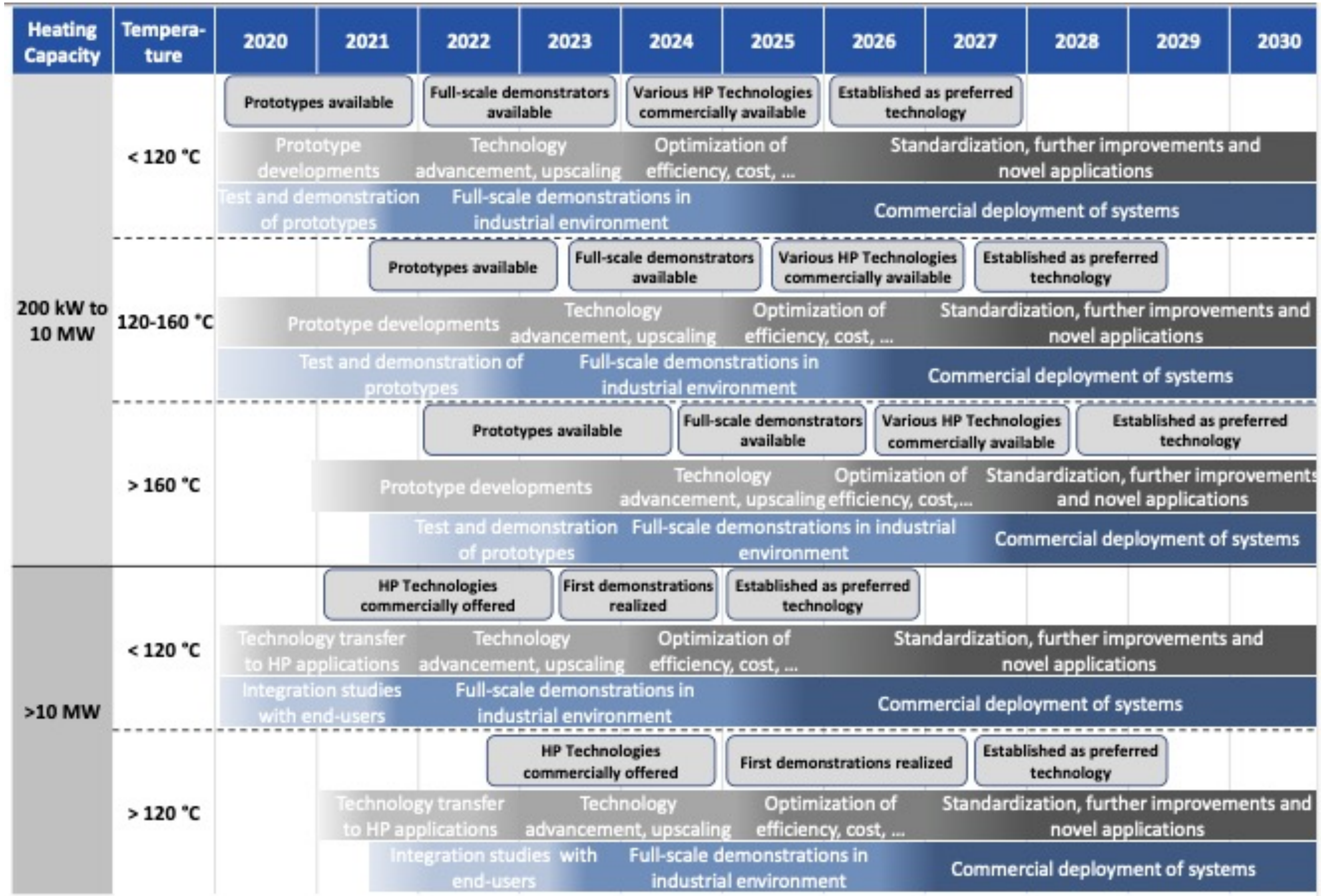
HP TCP Annex 58 supplier technology overview

Supplier	Compressor type	Working fluid	Capacity	Tmax supply °C	TRL
Skala Fabrikk	Piston	R-290, R-600	0.3 MW	115	7
Fuji Electric	Reciprocating	R-245fa	0.03 MW	120	9
Kobelco Compressors Corp. (SGH120)	Twin-screw	R-245fa	0.4 MW	120	9
Combitherm	Semi-hermetic screw	R-1233zd(E)	0.3-3.3 MW	120	9
Hybrid Energy	Piston, Screw	R-717, R-718	0.5-5.0 MW	120	9
Mayekawa (EcoSirocco)	Reciproating	R-744	0.1 MW	120	8 to 9
Mayekawa (EcoCircuit)	Reciprocating	R-1234ze(E)	0.1 MW	120	8 to 9
Johnson Controls	Reciprocating	R-717, R-600 (cascade)	0.5-5.0 MW	120	7 to 9
Mayekawa Europe (HS Comp)	Piston	R-600	0.8 MW	120	7
Emerson	Scroll and EVI Scroll	R-245fa, R410a, R-718	0.03 MW	120	6
Fenagy	Reciprocating	R-744	0.3-1.8 MW	120	5 to 6
Mitsubishi Heavy Industries	Two-stage centifugal	R-134a	0.6 MW	130	9
GEA	Semi-hermetic piston	R-744	0.1-1.2 MW	130	8
Mayekawa Europe (FC Comp)	Screw	R-601	1.0 MW	145	5
Epcon	HP centrifugal fan	R-718	0.5-30.0 MW	150	9
Ohmia Industry	Centrifugal / Piston	R-717, R-718	1.2-10.0 MW	150	7 to 8
MAN Energy Solutions	Centrifugal turbo with expander	R-744	10.0-50.0 MW	150	7 to 8
ecop	Centrifugal	ecop fluid 1	0.7 MW	150	6 to 7
Siemens Energy	Turbo (Geared / single-shaft)	R-1233zd(E) / R-1234ze(E)	8.0-70.0 MW	160	9 (to 90 °C)
Rank	Screw	R245fa, R-1336mzz(Z), R-1233zd(E)	0.12-2.0 MW	160	7
Weel & Sandvig	Turbo	R-718	1.0-5.0 MW	160	4 to 9
Enertime	Centrifugal	R-1336mzz(Z), R-1224yd(Z), R-1233zd(E)	2.0-10.0 MW	160	4 to 8
Heaten	Reciprocating, custom design	HFOs	1.0-6.0 MW	165	7 to 9
Sustainable Process Heat	Piston	HFOs	0.3-5.0 MW	165	6 to 8
SRM	Screw	R-718	0.25-2.0 MW	165	5
Kobelco Compressors Corp. (SGH165)	Twin-screw	R-245fa/R-134a, R-718	0.4 MW	175	9
Kobelco Compressors Corp. (MSRC160L)	Twin-screw	R-718	0.8 MW	175	9
ToCircle	Rotary vane	R-717, R-718	1.0-5.0 MW	188	6 to 7
Olvondo	Piston (double acting)	R-704	5.0 MW	200	9
Turboden	Turbon	Application specific	3.0-30.0 MW	200	7 to 9
Piller	Turbo	R-718	1.0-70.0 MW	212	8 to 9
Qpinch	Chemical adsorption heat transformer	R-718, H3PO4 and derivatives	>2.0 MW	230	9
Enerin	Piston	R-704	0.3-10.0 MW	250	6
Spilling	Piston	R-718	1.0-15.0 MW	280	9

https://heatpumpingtechnologies.org/annex58/task1/#Technology-overview

Status of HTHP technology

- Status varies based on the supply temperature and size
- Growing range of products, case studies and demonstrations (HPT TCP Annex 58)



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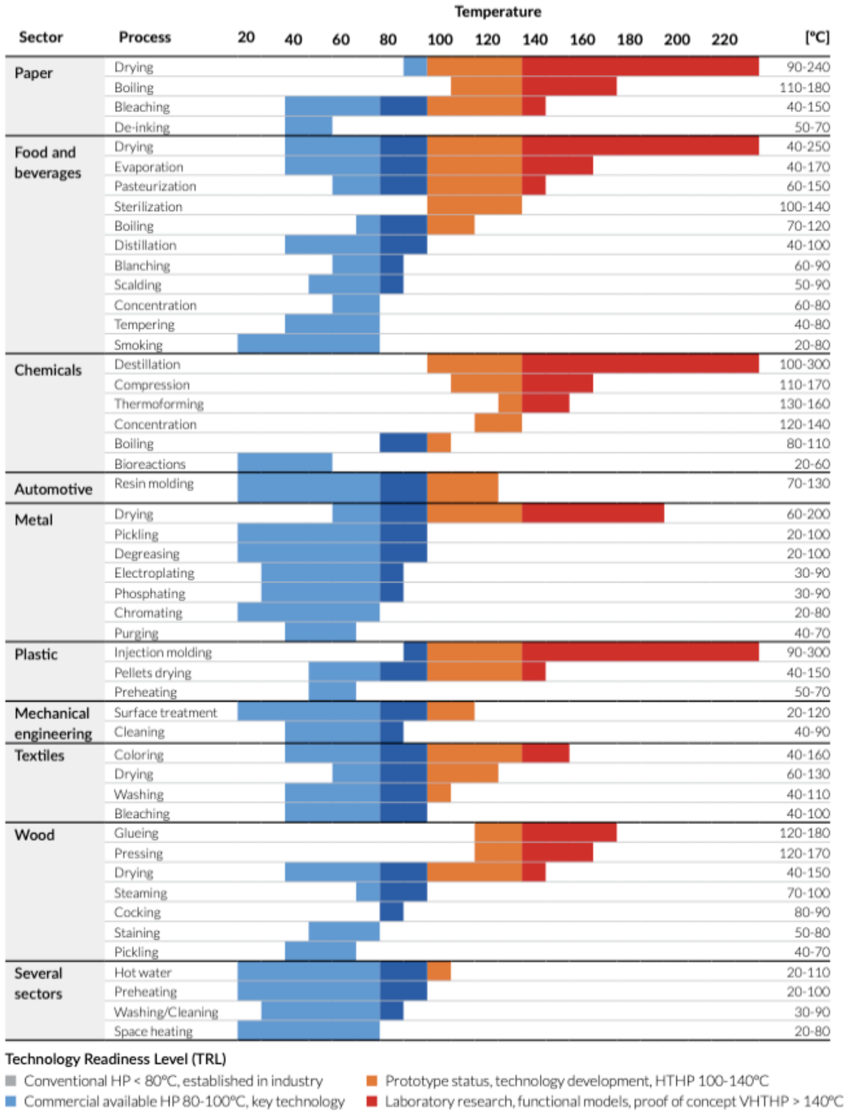
Applications for HTHPs

What applications could HTHPs be used for?



Source: Arpagaus 2020.

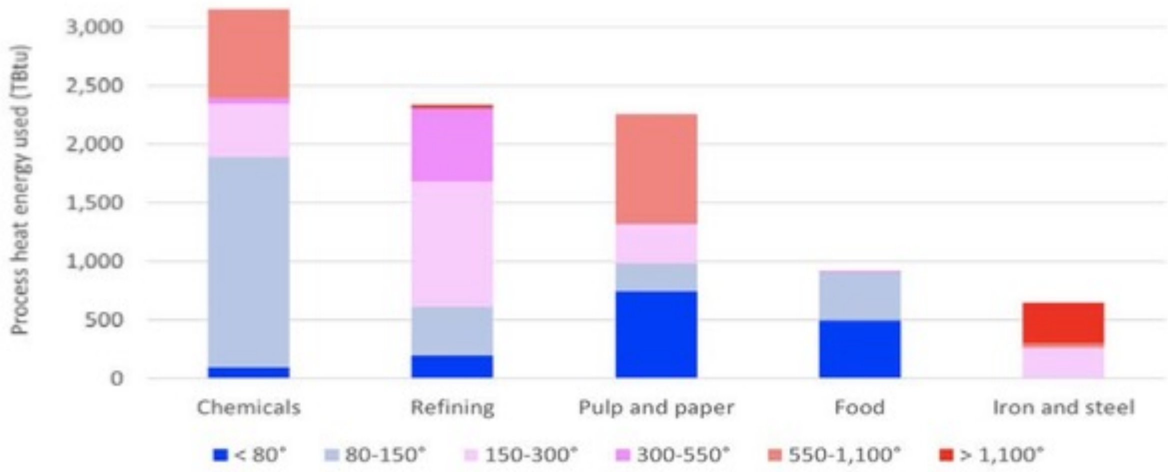
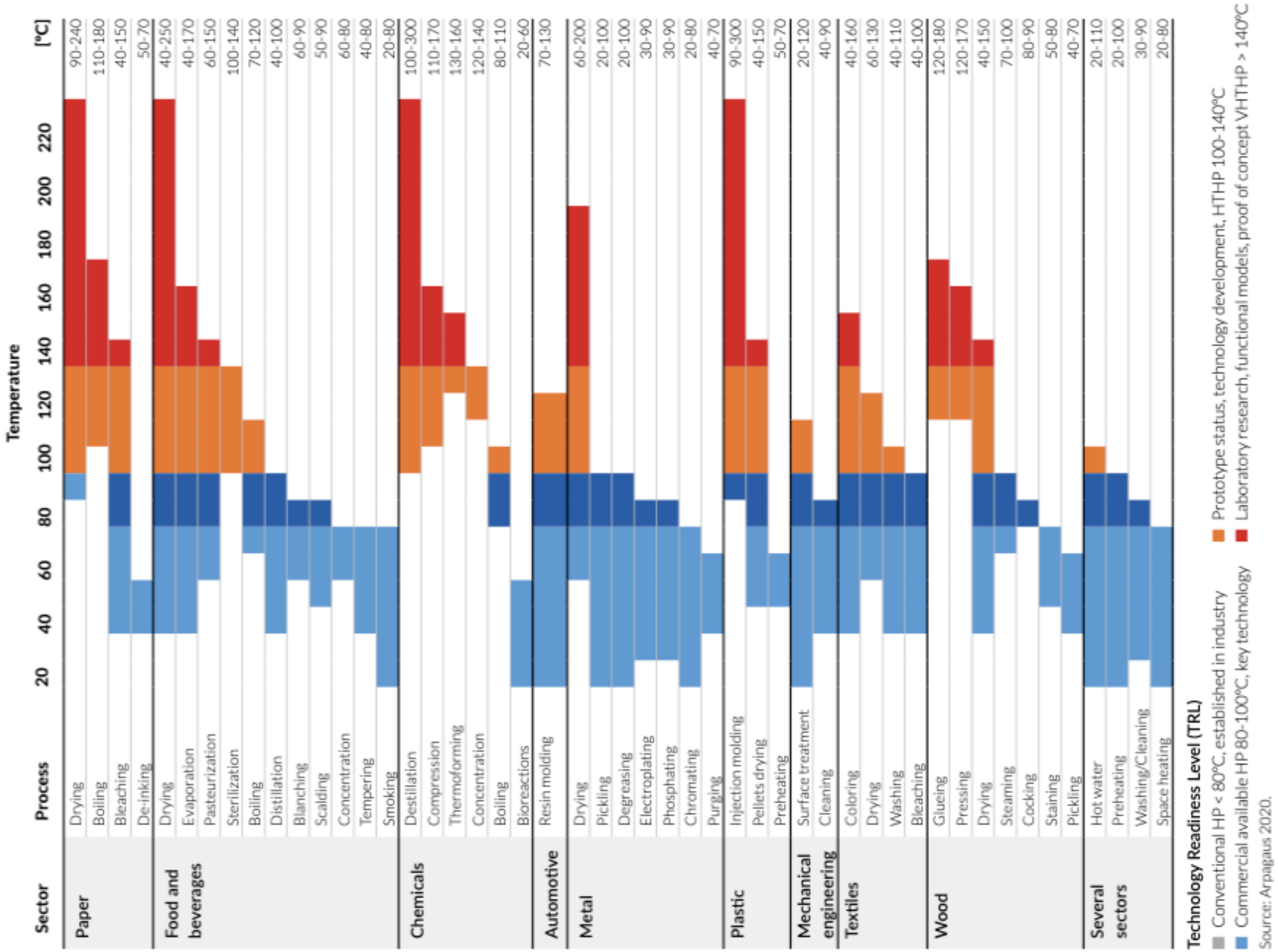


Figure 1. Process heat demand at different temperature (°C) levels in select U.S. Industrial l groups. Data source: McMillan 2019.

- District heating and hot water
- Steam generation (with boost)
- Thermal storage for grid flexibility

Larger version of previous figure



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The value proposition of HTHPs (vs fossil fuel boilers)

- In principle electrification with decarbonised electricity (such as renewables) will reduce carbon emissions. HPs can enhance this by taking advantage of ambient heat
- In practice the energy (and CO2) savings will depend on the temperature lift and related heat pump COP
- Whether operating cost reductions are achieved is dictated by heat pump COP and the gas to electricity price ratio, which is highly variable by economy e.g over 6 in the UK and almost a factor of 5 in USA (on average), but just over 1 in Sweden
- There are no simple trends to assess CapEx, which depends on application and level of integration, but larger HP installations are likely to be more cost effective
  - Like for like boiler replacement can be 5x more expensive
  - Costs should drop with economies of scale and more competition
- An ACEEE study suggests acceptable paybacks are achievable now if the gas to electricity price ratio < 3
- Thermal storage and grid flexibility could change the value proposition significantly

	Prices without refundable			OPEX Parity	
Country	Gas	Electricity	Price Ratio	COP	ΔT_Lift
Sweden	**4.1**	**4.8**	**1.17**	**1.1**	**229**
Finland	**4.5**	**5.4**	**1.20**	**1.1**	**222**
Luxembourg	2.3	4.1	1.78	1.6	132
Lithuania	3.0	6.8	2.27	2.0	96
Denmark	**3.1**	**7.0**	**2.26**	**2.0**	**96**
France	**2.8**	**6.4**	**2.29**	**2.1**	**95**
Netherlands	2.6	6.2	2.38	2.1	90
Slovenia	2.5	6.1	2.44	2.2	87
Estonia	3.0	7.1	2.37	2.1	91
Czech Republic	2.4	6.3	2.63	2.4	79
Austria	**2.8**	**7.4**	**2.64**	**2.4**	**78**
Latvia	2.7	7.5	2.78	2.5	73
Hungary	2.5	7.0	2.80	2.5	73
Greece	2.5	7.5	3.00	2.7	66
Poland	2.4	7.2	3.00	2.7	66
Romania	2.3	7.0	3.04	2.7	65
Croatia	2.3	7.2	3.13	2.8	63
Belgium	2.0	6.8	3.40	3.1	56
Germany	**2.6**	**8.6**	**3.31**	**3.0**	**58**
Bulgaria	2.0	6.8	3.40	3.1	56
Spain	**2.5**	**9.1**	**3.64**	**3.3**	**51**
Portugal	2.4	8.9	3.71	3.3	50
Ireland	2.7	10.0	3.70	3.3	50
Italy	**2.4**	**9.4**	**3.92**	**3.5**	**47**
Slovakia	2.5	10.2	4.08	3.7	44
UK	**2.1**	**12.8**	**6.10**	**5.5**	**26**
EU	**2.5**	**8.2**	**3.28**	**3.0**	**59**

https://www.aceee.org/sites/default/files/pdfs/IHP_Workshops_2023/Cordin_Arpagaus_-_OST.pdf

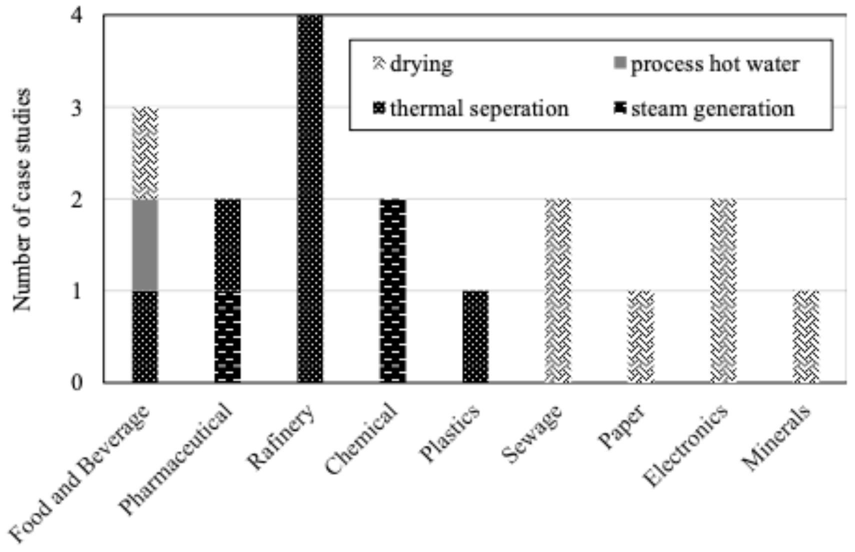
Early adopters and impediments for HTHPs

Impediments to widescale application

- Economics
  - Cost (and time) for integration, especially at current small economies of scale and lack of competition
  - Payback times ae highly variable and dependent on gas : electricity price ratio and their stability
- Technology
  - Higher temperatures still not proven – lubricants, materials and reliability are specific issues
  - Technology is not as flexible as boilers - selection is difficult and may not be suitable for future applications
- Workforce
  - Knowledge and skills for integration, implementation, and servicing
  - Training capacity for large scale deployment
- Information and awareness
  - Industries are unaware of the potential for heat pumps among users, consultants, investors, plant designers, producers, and installers
  - Factories unaware of their own heat demand, waste heat supply and suitability for heat pumps
- Availability and confidence
  - Limited choice of solutions, Europe appears to dominate HT heat pump R&D
  - Lack of confidence in manufacturers and customers of future market size and stability to invest and commit
- Regulatory and planning constraints
  - Import restrictions
  - Safety and standards for pipework, pressure vessels etc.
  - Planning (and space) restrictions to install HP

Which applications are most likely adopters

- The most likely adopters are large industries with high energy consumption, but specifically those:
- with very similar processes between factories
- applications at the lower end of the high temperature range
- with a potential for combined efficiency via simultaneous supply of process heating and cooling
- HP TCP Annex 58 case studies suggest F&B, refinery and drying processes are likely adopters
- Will probably vary between different regions
- Not just technical potential but other factors to consider, e.g. access to cheap financing, appetite for risk, sectoral engagement with green agenda, market reward from decarbonisation



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Key organisations for HTHPs

Key organisations focusing on HTHPs

- International
  - Renewable thermal collaborative (RTC)
  - IEA HPT TCP Annex 58
- Australia
  - Australian Alliance for Energy Productivity
  - Energy Efficiency Council
  - Australian Govt DCCEEW
- China
  - Heat Pump Committee of the China Energy Conservation Association (CHPA)
  - China Academy of Building Research
- Europe
  - European Commission
  - European Heat Pump Association
  - Austrian Institute of Technology (AIT)
  - Danish Technological Institute
  - Technical University of Denmark (DTU)
  - Danish Energy Agency
  - Eastern Swiss University of Applied Sciences (OST)
  - German Aerospace Center (DLR)
  - Bundesverband Wärmepumpe (BWP)
  - TNO
- Japan
  - Heat Pump and Thermal Storage Technology Center of Japan (HPTCJ)
  - Japan Refrigeration and air conditioning industry Association
  - Ministry Economy Trade and Industry
  - NEDO (New Energy and Industrial Technology Development
  - Thermal Management Materials and Technology Research Association
  - Organization)
- USA
  - Air-Conditioning, Heating, and Refrigeration Institute (AHRI)
  - ACEEE
  - National Electrical Manufacturers Association (NEMA)
  - US DoE Office of EERE

Project brief

As the first of a series of analyses for IEA 4E Product Energy Efficiency Trends (PEET) 2023 project this presentation gives an overview of Heat Pumps for high temperature applications

Specifically, it aims to provide:

- 1.1 Summary of key potential applications (e.g. most likely to be early adopters)
- 1.2 Status of technology (e.g. research phase, demonstration/trials, commercial)
- 1.3 Key organisations focusing on this topic (e.g. HP TCP)

IEA Technology Collaboration Programme
on Energy Efficient End-Use Equipment

PEET 2023 discussion presentation on the transition to low-GWP refrigerants for residential AC/HP applications

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Background (what the Kigali Amendment means for 4E economies)

Kigali Amendment provisions

- The **Kigali Amendment to the Montreal Protocol** on Substances that Deplete the Ozone Layer dates from 15 October 2016

- Each Party shall ensure that for the twelve-month period commencing on 1 January 2019, and in each twelve-month period thereafter, its calculated level of consumption of the controlled substances in Annex F, expressed in CO2 equivalents, does not exceed the percentage, set out for the respective range of years specified in subparagraphs (a) to (e) below, of the annual average of its calculated levels of consumption of Annex F controlled substances for the years 2011, 2012 and 2013, plus fifteen per cent of its calculated level of consumption of Annex C, Group I, controlled substances as set out in paragraph 1 of Article 2F, expressed in CO2 equivalents:

- ✓ (a) 2019 to 2023: 90 per cent
- ✓ (b) 2024 to 2028: 60 per cent
- ✓ (c) 2029 to 2033: 30 per cent
- ✓ (d) 2034 to 2035: 20 per cent
- ✓ (e) 2036 and thereafter: 15 per cent

- Therefore, the annual CO2-equivalent weighted consumption of the Annex F controlled substances within any signatory jurisdiction must decline in accordance with the above schedule against the specified reference years

Kigali Amendment provisions

- The controlled substances (from Annex F) are:

Group	Substance	100-Year Global Warming Potential
Group I		
CHF_2CHF_2	HFC-134	1,100
CH_2FCF_3	HFC-134a	1,430
CH_2FCHF_2	HFC-143	353
$CHF_2CH_2CF_3$	HFC-245fa	1,030
$CF_3CH_2CF_2CH_3$	HFC-365mfc	794
CF_3CHFCF_3	HFC-227ea	3,220
$CH_2FCF_2CF_3$	HFC-236cb	1,340
CHF_2CHFCF_3	HFC-236ea	1,370
$CF_3CH_2CF_3$	HFC-236fa	9,810
$CH_2FCF_2CHF_2$	HFC-245ca	693
$CF_3CHFCHFCF_2CF_3$	HFC-43-10mee	1,640
CH_2F_2	HFC-32	675
CHF_2CF_3	HFC-125	3,500
CH_3CF_3	HFC-143a	4,470
CH_3F	HFC-41	92
CH_2FCH_2F	HFC-152	53
CH_3CHF_2	HFC-152a	124
Group II		
CHF3	HFC-23	14,800

Kigali Amendment ratification status

- The status of ratification by 4E member is:

4E Economy	Date	Kigali status
Australia	Oct-17	Acceptance
Canada	Nov-17	Ratification
China	Jun-21	Acceptance
EU	Sep-18	Approval
Japan	Dec-18	Acceptance
Korea	Jan-23	Ratification
New Zealand	Oct-19	Ratification
UK	Nov-17	Ratification
USA	Oct-22	Ratification

GWP of typical refrigerants for residential AC/HP

GWP of refrigerants used in AC/HP systems

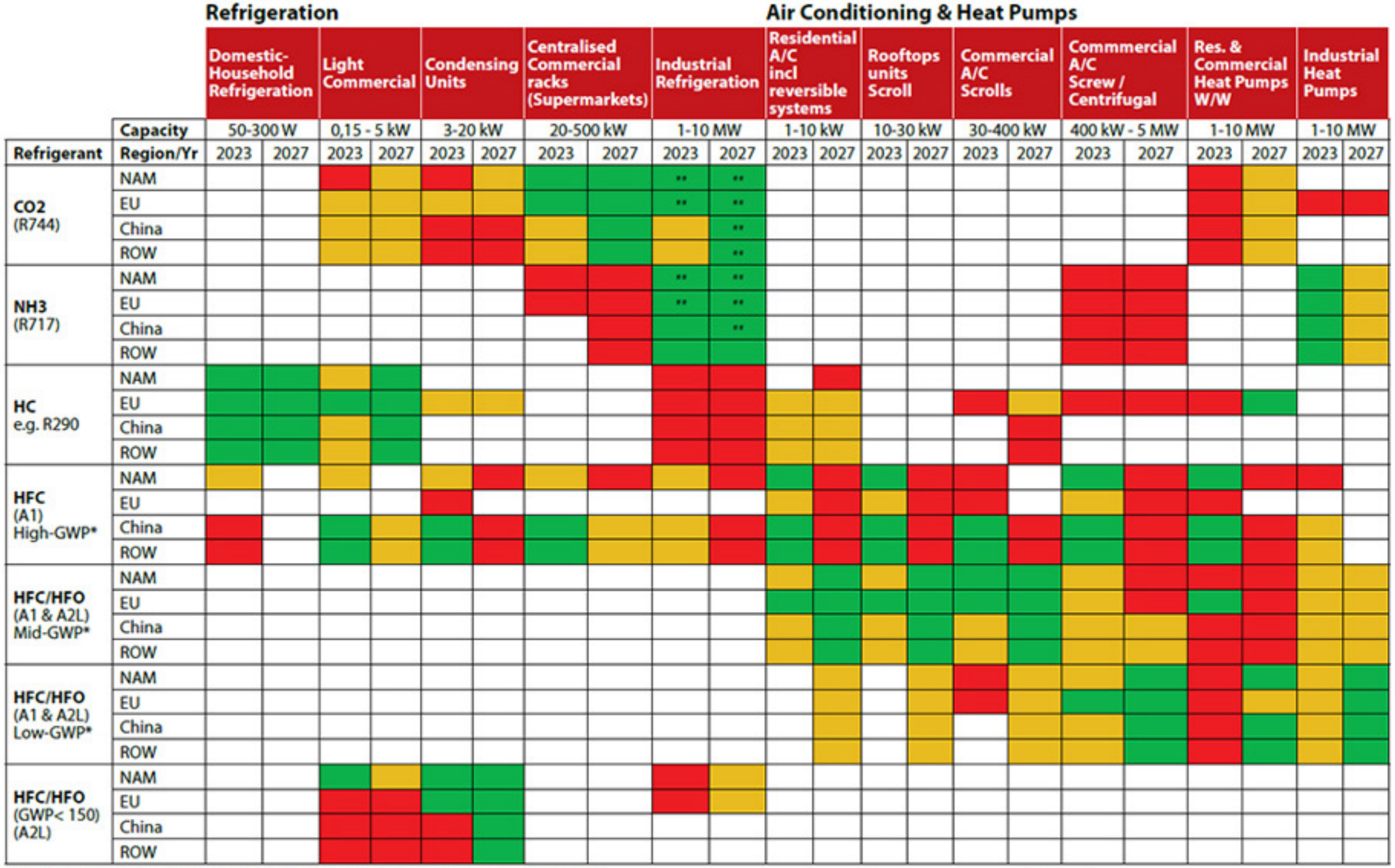
- Until recently the most commonly used refrigerant currently in air-to-air residential AC/HPs (both ducted and un-ducted types) is R410A which has a GWP of 2088. It is a zeotropic but near-azeotropic mixture of difluoromethane (R-32) and pentafluoroethane (R-125)
- The next most common is R32 which is an HFC with a GWP of 675. This is becoming the default replacement option but still has a relatively high GWP
- R407C is still sometimes found in older products and has a GWP of 2107. It is a mixture of HFCs specifically a zeotropic blend of difluoromethane (R-32), pentafluoroethane (R-125), and 1,1,1,2-tetrafluoroethane (R-134a) but production is now prohibited under the Montreal protocol
- Natural refrigerants (such as R290 (propane), R744 (CO2), butane, pentane etc.) are also options and these have a GWP of ≤ 3
- Other alternatives include hydrofluoroolefins or mixtures thereof such as:
- R454B with a GWP of 466 is a zeotropic blend of 68.9 percent difluoromethane (R-32), a hydrofluorocarbon, and 31.1 percent 2,3,3,3-tetrafluoropropene (R-1234yf) has so far been approved by at least one component manufacturer for use in their scroll compressors
- R454C (GWP 148; safety class A2L, an HFC/HFO mixture) with the optimum balance of properties to replace R404a and R22 refrigerants in medium- and low-temperature direct expansion applications - has been applied in Japan in air-to-air heat pumps for commercial use and in an air-to-water heat pumps by a German manufacturer. It is also considered as an option for room air conditioning applications, but some have expressed doubts on the cost-efficiency of this solution due to the need for larger compressors and heat exchangers

Other alternatives to R410A in AC/HPs include:

- R161 (GWP 12, an HFC) has been used in research on split AC to replace R22 and a demonstration project in China where a household air conditioner was developed but is not commercially available. The safety classification of R161 is incomplete due to the lack of toxicity testing, but it has been established as a flammable substance
- R452B (GWP 698; safety class A2L, an HFC/HFO30 mixture) has been approved by one component manufacturer for use in their scroll compressors. It is contained in industrial equipment such as reversible heat pumps and chillers supplied by several distributors in the EU, but not in split air conditioning at this stage
- Further options include R466A (an HFC mixture) and other mixtures with HCFOs31 or CF3I are at an early stage of refrigerant testing. Their suitability for split systems is not clear

Current practices in 4E Economies

Trends in refrigerant adoption



* GWP classification is somewhat dependent on current solution & operating pressure baseline. General guidance: High > 1000, Mid 300–1000, Low < 300.

** Ammonia/CO_2 cascades will dominate industrial refrigeration

Main refrigerant | Regular use | Limited use and only niche applications | Not applicable or unclear situation

Table: Global trends in refrigeration, air conditioning and heat pumps. Status January 2020.

EU and UK policies – F-gas regulation

- Products sold in the EU and UK must respect the provisions in the F-gas regulation to control emissions from fluorinated greenhouse gases (F-gases), including hydrofluorocarbons (HFCs). The current regulation came into effect on 1.1.2015. It is currently under review and the working document proposes significantly stricter refrigerant GWP requirements than are currently required
- The current Regulation strengthened the previous measures and introduced far-reaching changes by:

- **limiting the total amount** of the most important F-gases (HFCs) that can be sold in the EU from 2015 onwards and phasing them down in steps to one-fifth of 2014 sales in 2030. This will be the main driver of the move towards more climate-friendly technologies
- **banning the use** of F-gases in many new types of equipment where less harmful alternatives are widely available, including for air conditioning
- **preventing emissions** of F-gases from existing equipment by requiring checks, proper servicing and recovery of the gases at the end of the equipment's life
- On 5 April 2022, the European Commission presented a proposal for a regulation on fluorinated GHGs (F-gases) that would repeal the current F-gas Regulation. The proposal aims to reduce F-gas emissions further than the existing quota system, gradually reducing the supply of hydrofluorocarbons (HFC) to the EU market to 2.4 % of 2015 levels by 2048
- It would also ban F-gases in specific applications, and update the rules on implementing best practices, leak-checking, recordkeeping, training, waste treatment, and penalties

EU and UK - GWP of AC/HP refrigerants on the current market

- The EPREL product registration database does not report the refrigerant type for AC/HPs thus an analysis was done of the products in the Eurovent database of certified products
- From this the following information is determined:

- Single-split AC and HPs: 1481 models with R32 (GWP=675), 493 x R-410A (GWP:2088)
- Multi-split AC and HPs: 59 models with R32 (GWP=675), 57 x R-410A (GWP:2088)
- Electric air to water HPs up to 70kW: 986 models with R-410A (GWP:2088), 20xR32 (GWP=675), 18 x R-407C (GWP:2107)
- The model-weighted average GWP of the above is 1159
- There is also at least one AC/HP air-to-air split unit on the market that uses R290 (GWP: 3)

USA - policies

- The **AIM Act**, which was included in the **Consolidated Appropriations Act, 2021**, directs EPA to phase down production and consumption of HFCs in the United States by 85 percent over the next 15 years (see Table 2 below)
- The AIM Act directs EPA to phase down production and consumption1 of HFCs by 85% below baseline levels by 2036 through an allowance allocation and trading program. EPA has established U.S. production and consumption baselines using a formula provided by the AIM Act that considers past HFC, hydrochlorofluorocarbon (HCFC), and chlorofluorocarbon (CFC) amounts.2 By October 1 of each year, EPA must issue production and consumption allowances for the following calendar year, relative to those baselines
- Both HFC-32 (R-32) and HFC-125 (the constituents of R-410A) are included

Table 2: HFC Phasedown Schedule and Consumption & Production Allowance Caps

Year	Consumption & Production Allowance Caps as a Percentage of Baseline	Estimated Consumption and Production Allowance Caps in MMTEVe*
Baseline	**Consumption: 303.89 MMTEVe Production: 382.55 MMTEVe**	
2020–2023	90 percent	Consumption: 273.5 Production: 344.3
2024–2028	60 percent	Consumption: 182.3 Production: 229.5
2029–2033	30 percent	Consumption: 91.2 Production: 114.8
2034–2035	20 percent	Consumption: 60.8 Production: 76.5
2036 & after	15 percent	Consumption: 45.6 Production: 57.4

* Baselines and caps are expressed in million metric tons of exchange value equivalent (MMTEVe), which is numerically equivalent to one million metric ton of CO_2 equivalent ($MMTCO_2e$).

Canada - policies

- The Regulations Amending the **Ozone-depleting Substances and Halocarbon Alternatives Regulations** (amendments) aim to reduce the supply of hydrofluorocarbons (HFCs) that enter into Canada
- The phase down begins in 2019 with a 10% reduction in consumption with further reduction steps in 2024, 2029 and 2034 in order to achieve an 85 percent reduction in HFC consumption by 2036. The amendments also introduce prohibitions, by specific dates, on the manufacture and import of certain products and equipment that contain, or are designed to contain, HFCs and HFC blends, with a global warming potential (GWP) above a specific limit

USA and Canada - GWP of AC/HP refrigerants on the current market

- The AHRI database does not report the refrigerants being used
- From products in the EnergyStar database the following can be reported:
  - mini-split heat pumps use: 5263 x R-410A (GWP:2088), 1 x R-454B (GWP 450), 8 x R-32 (GWP=675)
  - Central AC (ducted) use: 163065 x R-410A (GWP:2088) i.e. 100% of all models
  - Heat Pumps (ducted) use: 47115 x R-410A (GWP:2088) i.e. 100% of all models
  - Room AC use from 1399 models: 10 x R-410A (GWP:2088), 212 x R-32 (GWP=675), 1117 x unreported
  - Geothermal heat pumps: 1527 models unreported (100%)
- The model-weighted average GWP of the above is 2087

China – policies and GWP of AC/HP refrigerants on the current market

- In 2021 China indicated an ambition to ratify the Kigali agreement
- China's **Green Cooling Action Plan** of June 2019 states that the HFC phase-down will follow the Montreal Protocol schemes agreed in October 2016 (see targets in the figures below).
- The refrigerant is not indicated on the lists of AC/HP models on government energy labelling websites; however, looking at a set of AC/HP suppliers it appears R32 dominates (over 50 models) although R22 (ODP of 0.055; GWP of 1810) was found for one product

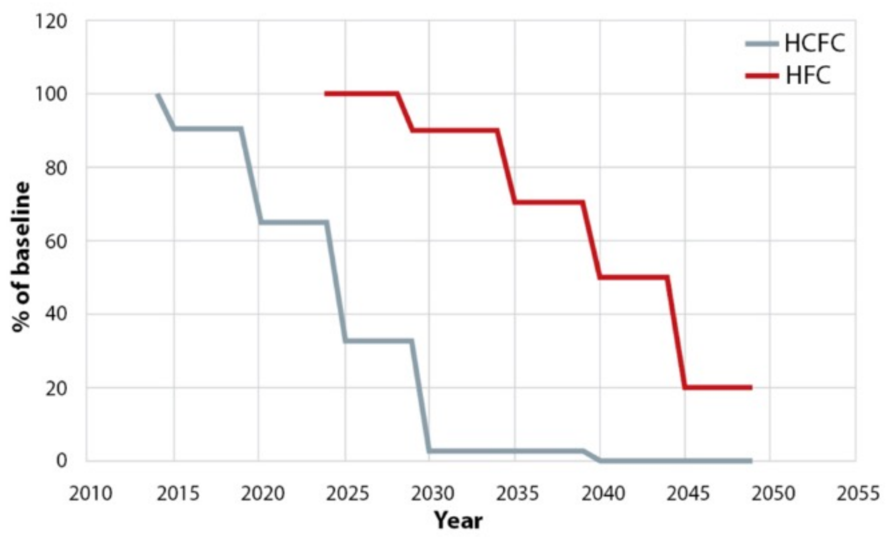


Figure: The HCFC phase-out and the HFC phase-down for China

Application	Present	Short term (-2020)	Long term (-2025)
Household refrigeration	R22 / R600a	R600a	R600a
Industrial and commercial refrigeration	R22 / R134a / R410A / NH_3	R134a , NH_3	NH_3/CO_2, R290, R600a, Low-GWP Blends
Small and medium chillers	R22, R410A	R410A,R32	R290, R32
Large chillers	R22, R123, R134a	R134a, R1234ze	R1234ze, NH_3
Unitary AC / VRF / heat pumps	R22, R410A, R407C	R410A,R32	R32 , Low-GWP blends
Room AC	R22, R410A	R410A,R290	R290, R32

Table: Refrigerant options per application

Japan – policies and GWP of AC/HP refrigerants on the current market

- The **Act on the Rational Use and Proper Management of Fluorocarbons** sets target GWP levels and target achievement years for each of the following product groups (among others):
  - "Residential AC mini-split" units have a target GWP of 750 by 2018
  - "Commercial AC units (split/smaller than 6hp)" have a target GWP of 750 by 2020
  - "Larger Commercial AC units (split - excluding VRF)" have a target GWP of 750 by 2023
- Other measures encourage reduced leakage and recovery as well as lower refrigerant charges
- The **High Pressure Gas Safety Act** regulates the flammability of refrigerants and currently permits the use of A2L classified refrigerants (see later slides)
- The METI product database doesn't indicate the refrigerant; however, inspection of products selected at random from the models in that database on manufacturer websites shows that the majority seem to use R32, some use R410A and some don't indicate the refrigerant
- JRAIA has a project to investigate and address the safety issues from using A3 flammability class refrigerants (e.g. hydrocarbon refrigerants, see later slides)

Korea – policies and GWP of AC/HP refrigerants on the current market

- On October 18, 2022, the Korea Ministry of Trade, Industry and Energy published an amended version of the **Act on the Control of Manufacture of Specific Substances for the Protection of the Ozone Layer** in order to implement regulations to reduce consumption (production and imports minus exports) of hydrofluorocarbons (HFCs) even inside the country under the Kigali Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer. According to the Ministry, South Korea needs to gradually reduce consumption to 80% of the reference quantity from 2024 to 2045
- No model data has been identified to allow the current prevalence of refrigerant types in AC/HPs to be appraised

Australia & New Zealand - policies and GWP of AC/HP refrigerants on the current market

- Australia's HFC phase-down started on 1 January 2018. The HFC phase-down is a gradual reduction in the maximum amount of HFCs permitted to be imported into Australia with a requirement to attain an 85 per cent reduction by 2036. New Zealand has adopted an equivalent policy
- The HFC phase-down is being implemented through the **Ozone Protection and Synthetic Greenhouse Gas Management Act 1989** and associated Regulations through a quota system for imports of HFCs as bulk gas
- The HFC phase-down covers only imports of bulk gas such as in cylinders. It does not cover gas imported in pre-charged equipment such as air-conditioners or refrigerators. HFCs contained in imported equipment are accounted for in the country of manufacture
- Analysis of the registration database of AC/HP products on the EnergyRating website gives the information on refrigerants shown in the table below. The model-weighted average GWP is 1249

Refrigerant	Number of models	Share of models	GWP
R410A	2618	43.7%	2088
R32	2883	48.1%	675
R290	439	7.3%	3
R404A	2	0.0%	3920
M50	4	0.1%	3
M60	13	0.2%	3
R134a	1	0.0%	1300
R407	19	0.3%	2107
R407c	11	0.2%	1774
Total	5990		1249

Summary of issues for transitioning to low GWP refrigerants

Impacts of adopting low GWP refrigerants

- Aside from the benefits of lower direct GWP emissions design changes to accommodate lower GWP refrigerants can affect other aspects including:
  - Safety
  - Energy efficiency
  - Heating/cooling capacity and trade off with refrigerant charge x GWP
  - Cost/size/material use
  - Noise
- Of these, safety is the most sensitive issue in most 4E markets

Safety

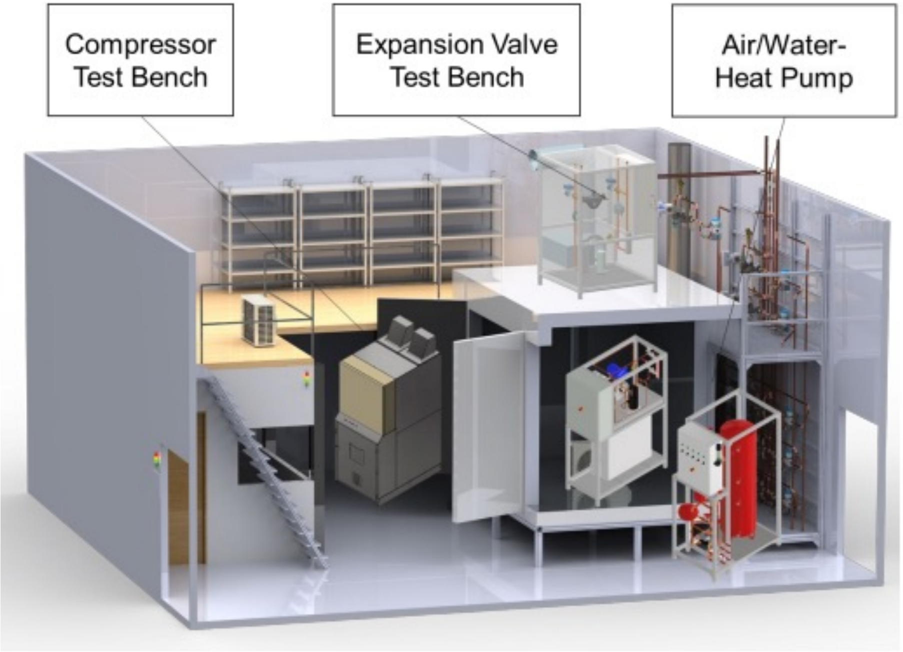
- A downside of lowering the GWP of refrigerant gases tends to be an increase in refrigerant gas flammability levels and/or other safety related issues
- There are three levels of refrigerant flammability under the internationally accepted ASHRAE classification: class 1 (A1), for refrigerants that do not propagate a flame when tested as per the standard such as R410A; class 2 (A2), for refrigerants of lower flammability; and class 3 (A3), for highly flammable refrigerants such as hydrocarbons. The class 2 classification has been split into an A2 and A2L sub-class where those in A2L sub class tend to be hard to ignite and have a slow burning velocity of ≤ 10 cm/s under test conditions. As such, they are considered to be safe for use in approved systems and can be considered safe for general handling with certain provisos
- Many of the replacements for current standard HFCs are in the new ASHRAE classification A2L but the Hydrocarbons are in the A3 class
- The flammability risk can be mitigated by: only using gases with higher flammability in systems with small charge, or using approved leak detectors if larger charges are required; proper processes/training/equipment when installing/servicing/or recovering refrigerants
- Refrigerant toxicity is another safety risk

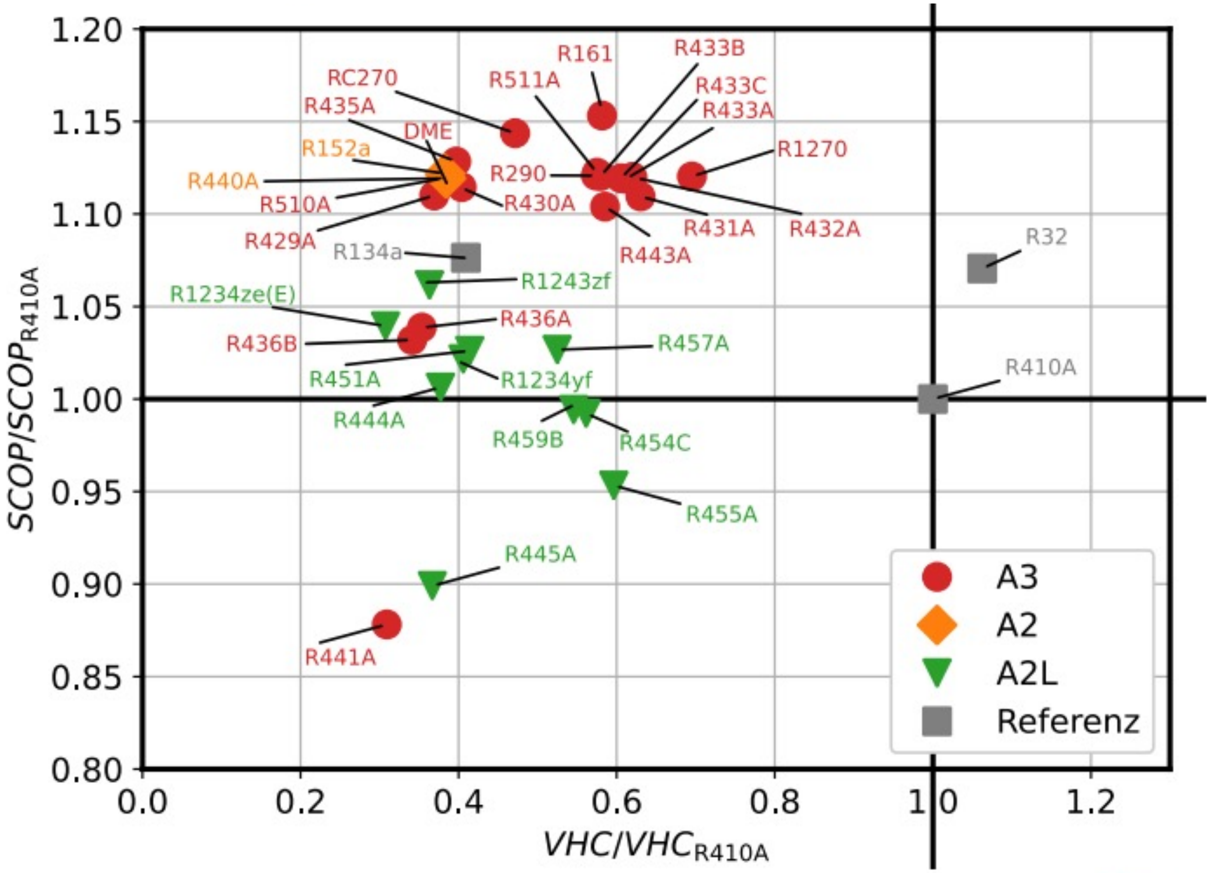
A2L flammability class refrigerant substitutes to R410A

Refrigerant	GWP	Applications
R32	675	Small and light commercial AC split systems; next generation hybrid VRF possibility. Performance similar to R410A - average 5% efficiency improvements on like for like is reported.
R1234ze	7	Chillers and integral units. Capacity is lower than with R134a - not a "drop in" retrospective replacement gas.
R1234yf	4	Automotive AC replacement for R134a
Solstice L40X (R455A), Solstice L41y (R452B)	146 675	Honeywell replacements for R404A and R410A respectively.
XL20(R454C)/XL40(R454A), XL41(R454B)/XL55(R452B)	<700	Chemours replacements for R404A and R410A respectively.

Efficiency, heating capacity (and flammability)

- The energy efficiency of AC/HPs using low GWP refrigerants is often better or equivalent to those using higher GWP refrigerants; however, sometimes claims made about this are application dependent and actual performance may depend on a myriad of factors





Determining emissions for an equivalent service

- The aim of adopting lower GWP refrigerants is to reduce climate impacts, thus it is important to choose options that lower the sum of the equivalent emissions from energy consumed in use (indirect emissions) with the direct emissions of the refrigerant itself over the product lifecycle i.e. deliver life cycle climate performance (LCCP) reduction
- The total direct GWP effect of a refrigerant is the product of the GWP of the refrigerant multiplied by the required charge (refrigerant mass)
- To achieve the same cooling/heating capacity with two different refrigerants may require changes in the charge thus to compare direct emissions it's important to consider the product of the GWP and the charge
- For split systems that shift from R410A to R32, the GWP decreases from 2088 to 675 while the required refrigerant charge is thought to be about 15 % lower for R32 units at equal capacity and efficiency. So switching from R410A to R32 results in equivalent direct CO2 emission of about 27 % (= 675 / 2088 * 0.85) compared to R410A units
- However, if higher refrigerant charges are needed for other lower GWP substitutes the net direct emissions benefit will be reduced proportionally
- Indirect emissions will fall as the energy efficiency improves

Noise/capacity/HEX size/cost

- Noise emissions from AC/HPs tends to be sensitive to the size of the heat exchanger (HEX) and the amount of heat to be transferred
- For a given heat transfer rate, the smaller the HEX used the faster the fan needs to work (all other factors being equal) and the greater the noise – conversely the larger the HEX the larger, slower and quieter the fan can be for the same heat transfer rate
- If the heat transfer achieved is constant for any given choice of refrigerant there will be no impact on noise
- However, if the overall heat transfer has to be increased to compensate for a lower heating/cooling capacity then either the HEX dimensions need to be increased or the fan speed (or both) to achieve the same effect – thus, this could increase noise as well as material use/cost or both
- Some industrial actors have argued that overly aggressive targets on refrigerant GWP could lead to the imposition of solutions that would increase AC/HP cost/size/noise and hence lower the acceptability of (especially HPs) in the market and hence threaten energy transition goals with regards to the decarbonisation of heat; however, this view is also challenged by other agencies

Key organisations working on these issues

Key organisations focusing on low GWP residential AC/HPs

- International
  - Kigali cooling efficiency programme
  - IEA HPT TCP ANNEX 54 Heat pump systems with low Global Warming Potential (GWP) refrigerants
  - IEA HPT TCP ANNEX 64 Safety measures for flammable refrigerants
  - International Institute of Refrigeration
  - United Nations Environment Programme
  - IEC and ISO
- Australia & New Zealand
  - Australian Dept of Climate Change, Energy, the Environment & Water
  - New Zealand Environmental Protection Authority
- China
  - Heat pump committee of the China energy conservation association (CHPA）
  - Chinese Ministry of Ecology and Environment (MEE)
- Europe
  - DG ENV + DG ENER + DG CLIMA + JRC
  - European heat pump association
  - Fraunhofer ISI
  - CETIAT
  - Austrian Institute of Technology (AIT)
  - Politechnico Milano
  - RWTH Aachen
  - Uni of Padova
  - European Partnership for Energy and the Environment (EPEE)
  - NTB
  - Danish Technological Institute
  - DTU
  - Danish Energy Agency
  - UK Dept. for Environment, Food and Rural Affairs
  - Refcom (UK)
- Japan
  - NEDO (New Energy and Industrial Technology Development Organization)
  - Technology Center of Japan (HPTCJ)
  - Japan Refrigeration and air conditioning industry Association
  - Ministry Economy Trade and Industry
  - Thermal Management Materials and Technology Research Association
- USA and Canada
  - US EPA
  - Air-Conditioning, Heating, and Refrigeration Institute (AHRI)
  - National Electrical Manufacturers Association (NEMA)
  - US DoE Office of EERE
  - Uni of Maryland
  - LBNL
  - NIST
  - Canadian Ministry of Environment
  - Natural Resources Canada

Project brief

As the first of a series of analyses for IEA 4E Product Energy Efficiency Trends (PEET) 2023 project this presentation gives an overview of Heat Pumps for high temperature applications

Specifically, it aims to provide:

- 1.4 Background (what the Kigali Amendment means for 4E economies)
- 1.5 GWP of typical refrigerants for residential AC/HP
- 1.6 Current practices in 4E Economies (e.g. Spread of refrigerants from EPREL, EnergyRating, US and other databases)
- 1.7 Summary of issues for transitioning to low GWP refrigerants
- 1.8 Key organisations working on these issues