Federal Ministry
for the Environment, Nature Conservation
and Nuclear Safety

Alternative technologies in heating and refrigeration

Edgar Timm

Senior Technical Expert, HEAT GmbH

CAPACITY BUILDING ON INNOVATIVE APPLICATIONS OF ENERGY-EFFICIENT CLIMATE-FRIENDLY COOLING AND HEATING TECHNOLOGIES IN UKRAINE

Workshop in Kyiv, Dnipro, Odessa

3.-6. September 2019

Umwelt Bundesamt

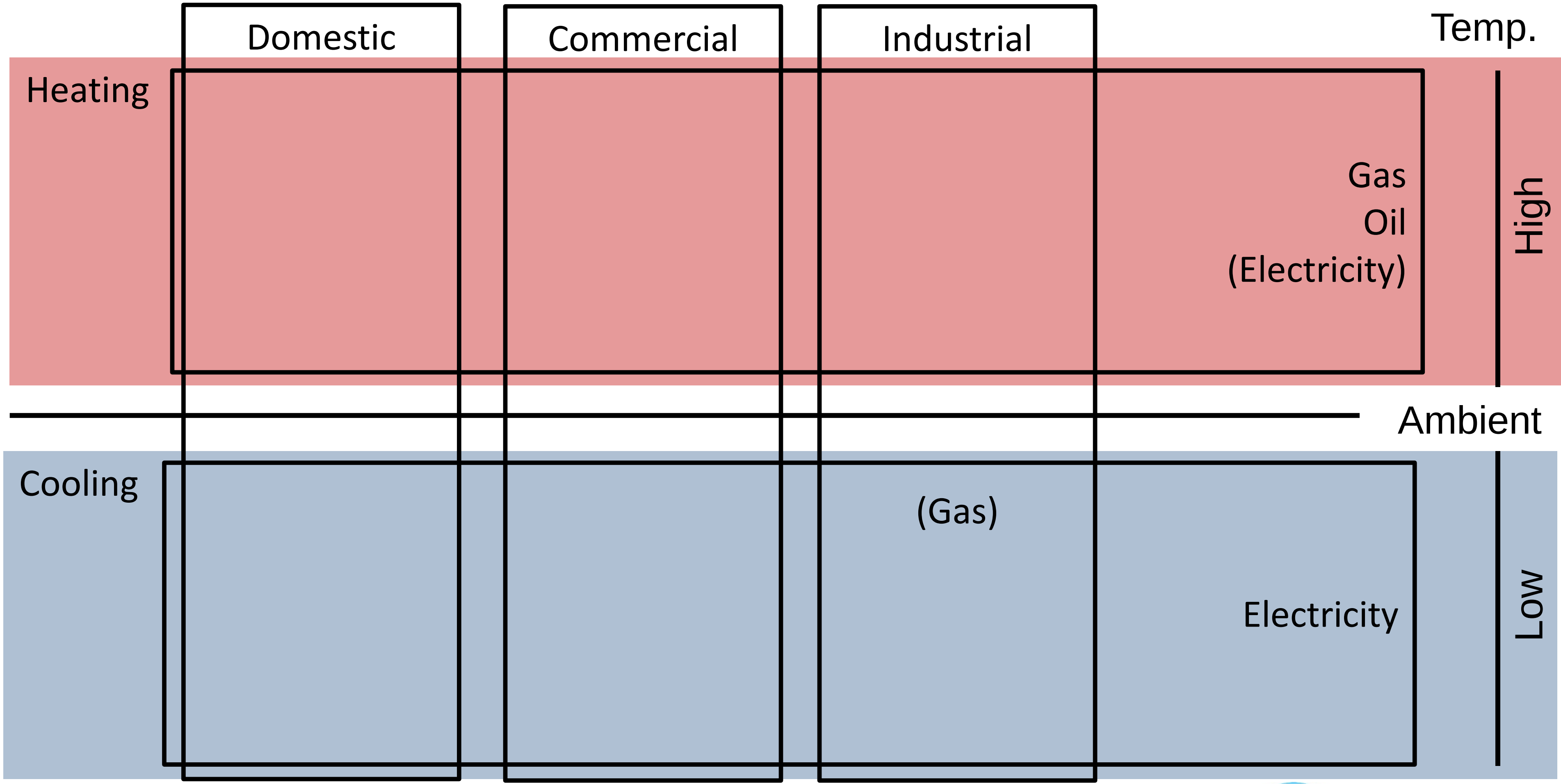
HEAT

REFRIGERATING
ASSOCIATION
OF UKRAINE PUBLIC UNION

Alternative Technologies Heating and Refrigeration

- A sector and vector view: Heating and Cooling
- The role of renewable energy
- Heating: Heat Pumps and Boilers
- RAC HP: Green working fluids
- Refrigeration: Green cooling technologies
- Summary and outlook

Heating and Cooling



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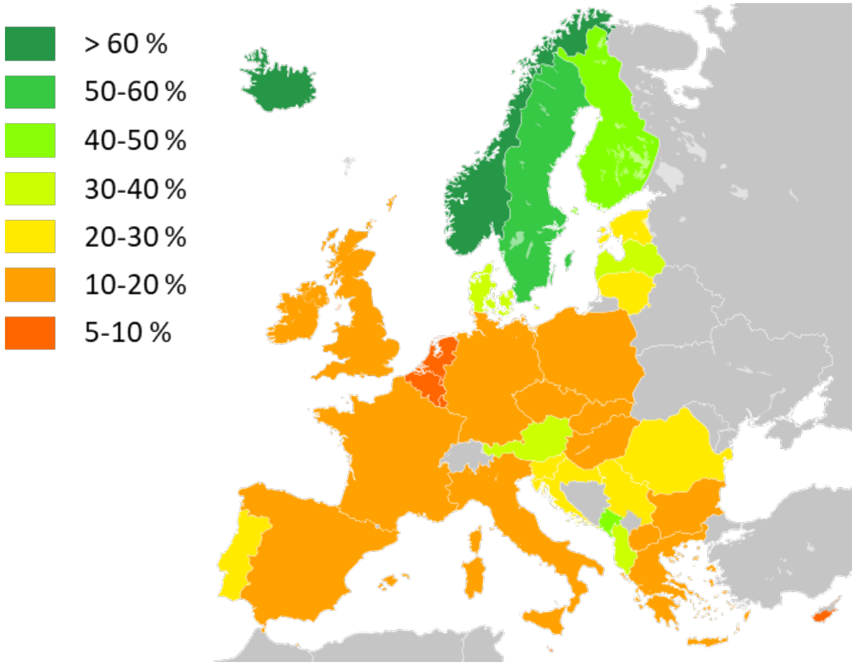
Use of renewable energy

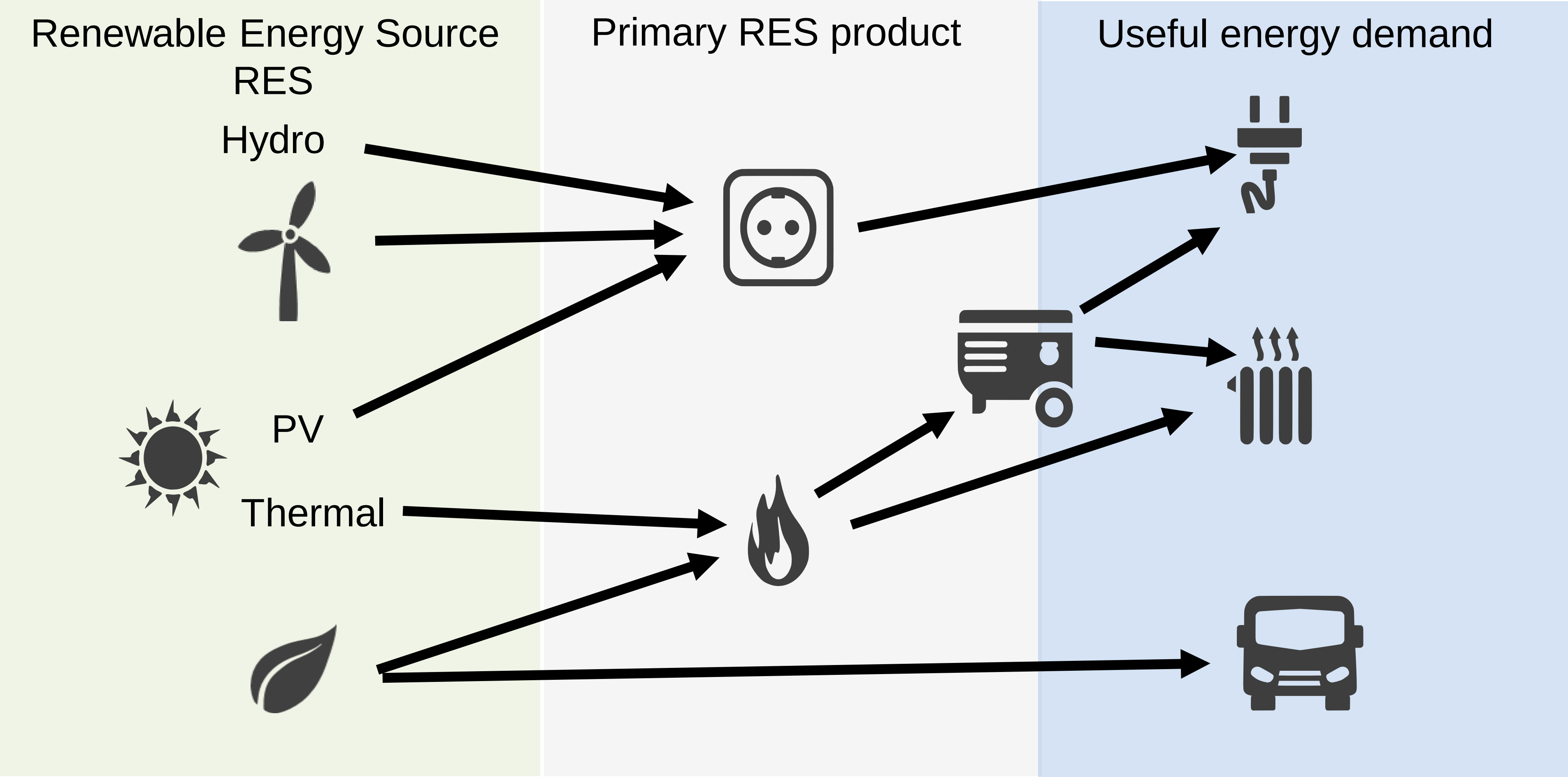


Source: By Edroeh - Location European nation states.svg: Ssolbergjdata source: Share of renewable energy in gross final energy consumption, Eurostat, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=79119369

Renewable issues

- Installed capacity vs. use (consumption)
- Power vs. work (kW vs kWh)
- Work vs. energy (time, location)
- Demand vs. production
- Primary vs. useful energy
- …

Renewable issue: setting the scene for mechanical RAC & HP



Renewable Energy Source RES

Primary RES product

Useful energy demand

Hydro

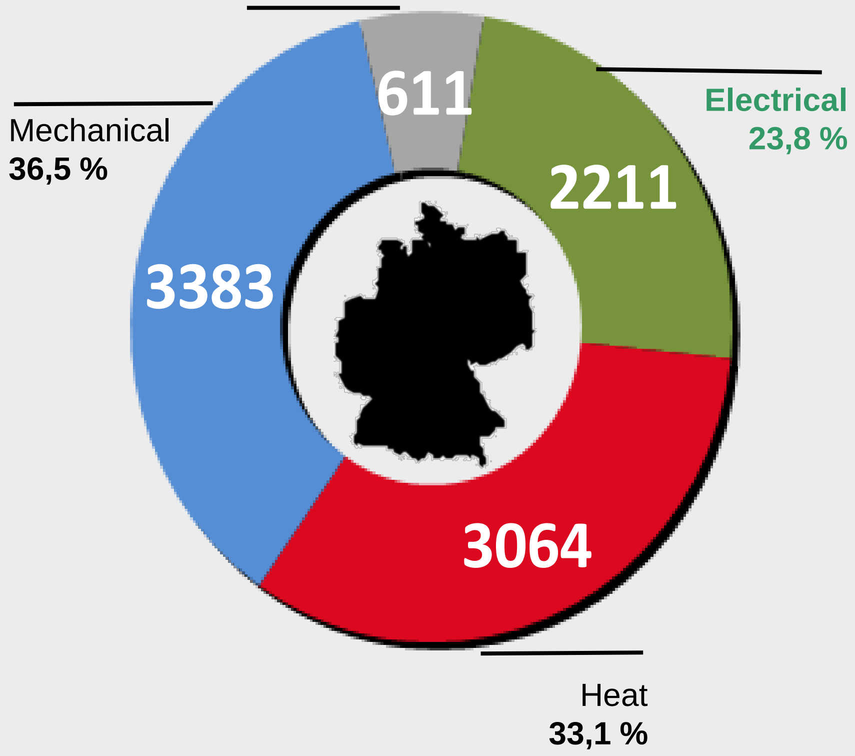
PV

Thermal

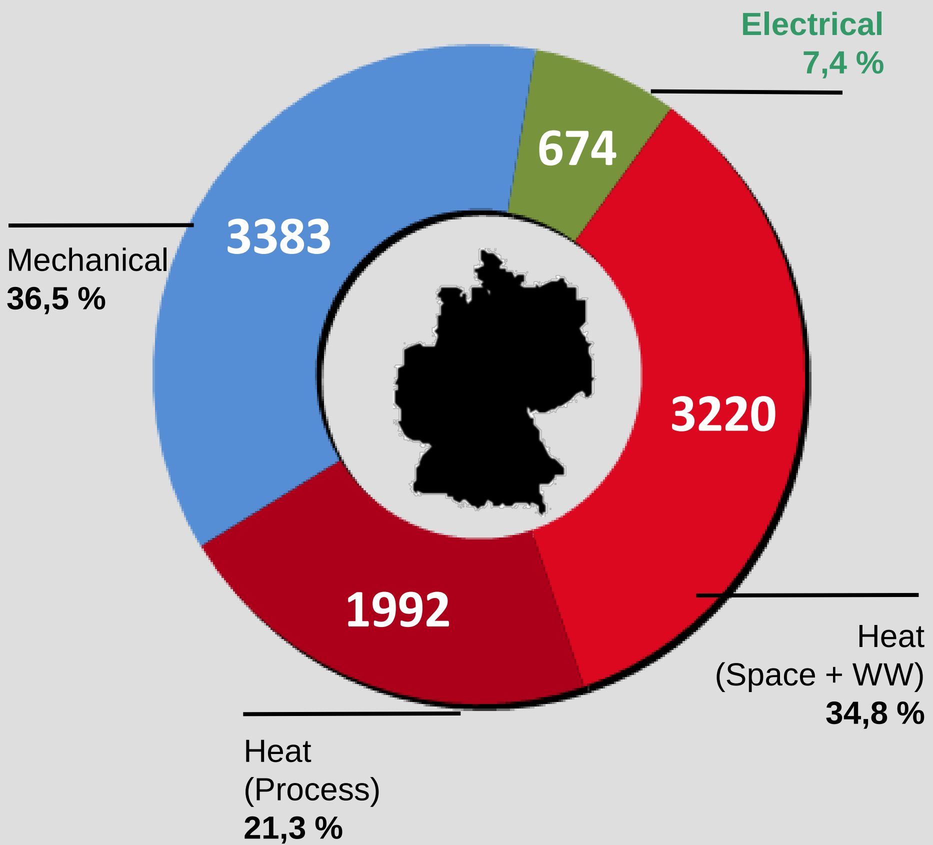
Primary and – useful energy

Energy consumption DE 2013
9.269 PJ (Peta-Joule) = 2.575 TWh

Primary energy



Use of energy



Quelle.
BMWi Energiedaten 03.2015

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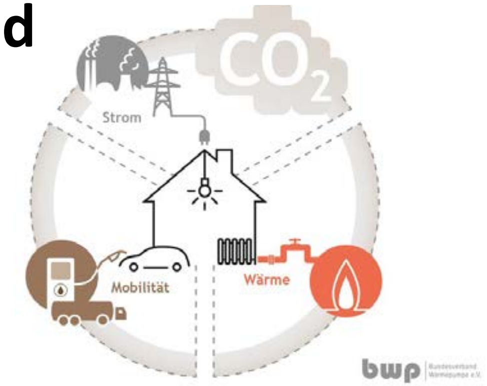
Coupling the (v)sectors

Old world



- Separate (central) production and(decentral) consumption
- Separate sectors and vectors:
    - Electrical, thermal, mechanical
    - Domestic, traffic, commercial, industrial

New world

- Combined decentral production/consumption: Prosumer
- Sector and vector coupling
- Smart Grids
- Need for storage, transformation and distribution

Source: bwp Bundesverband Wärmepumpe e.V

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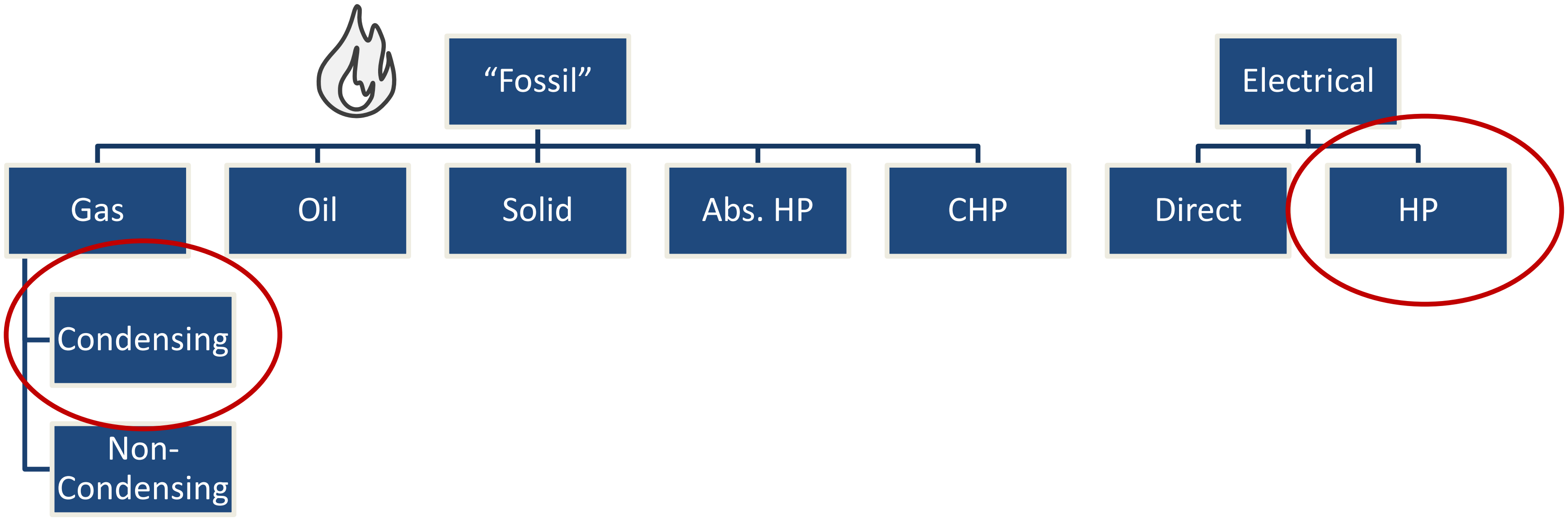
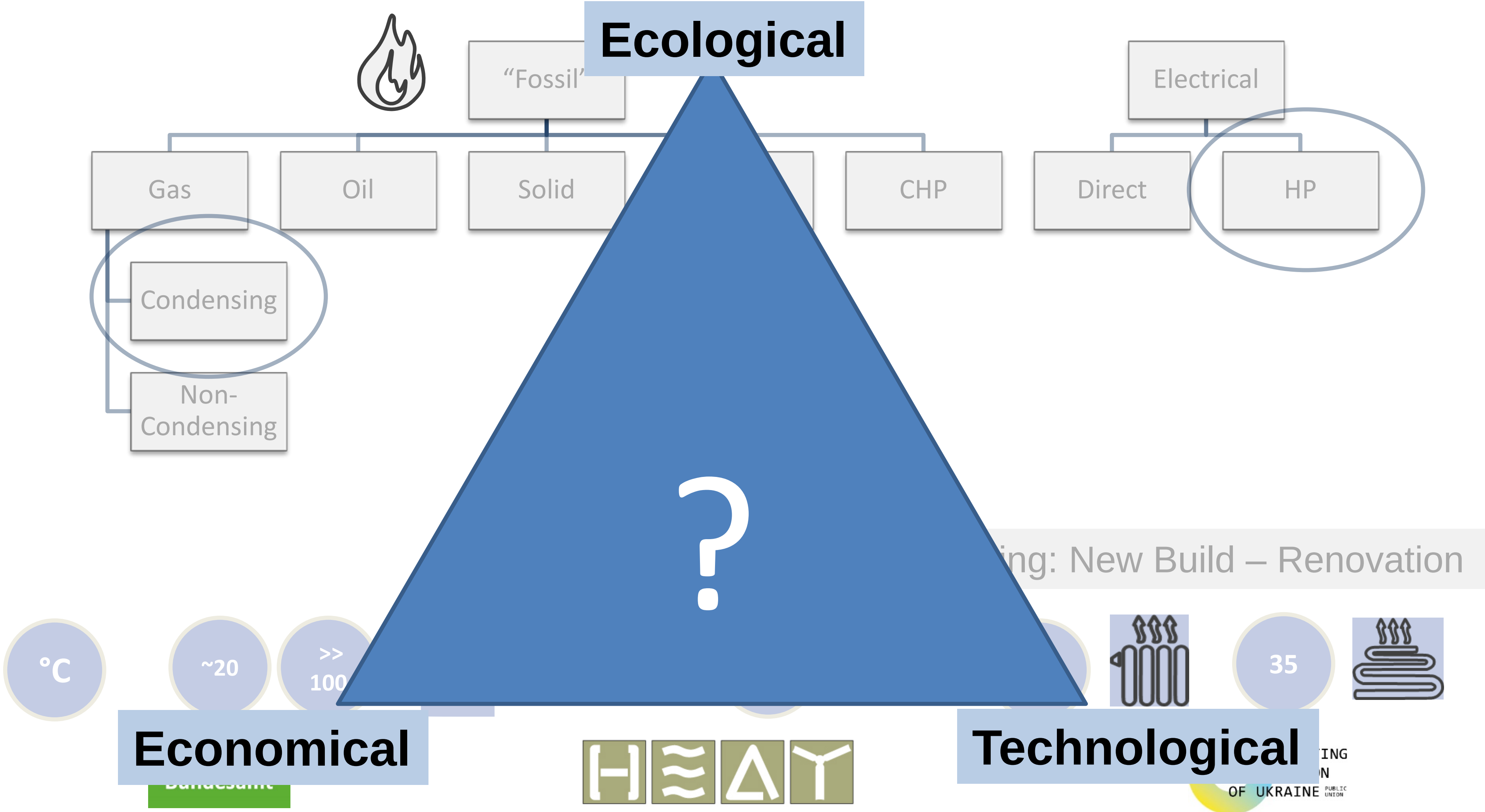
Heating Technologies

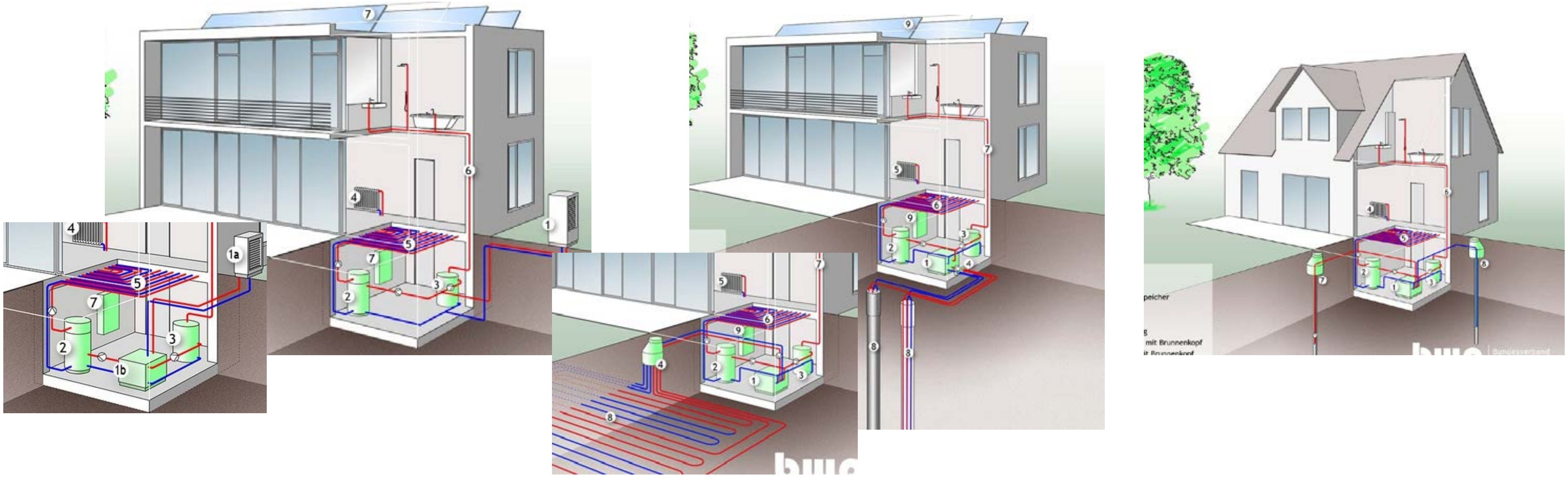


Space Heating: New Build – Renovation

Heating Technologies - Assessment



Heat pumps basics (typical serial product)



Air-Source

- Source temp : min. -20 °C
- Capacity: 5- 60 (100) kW
- SPF: ~3

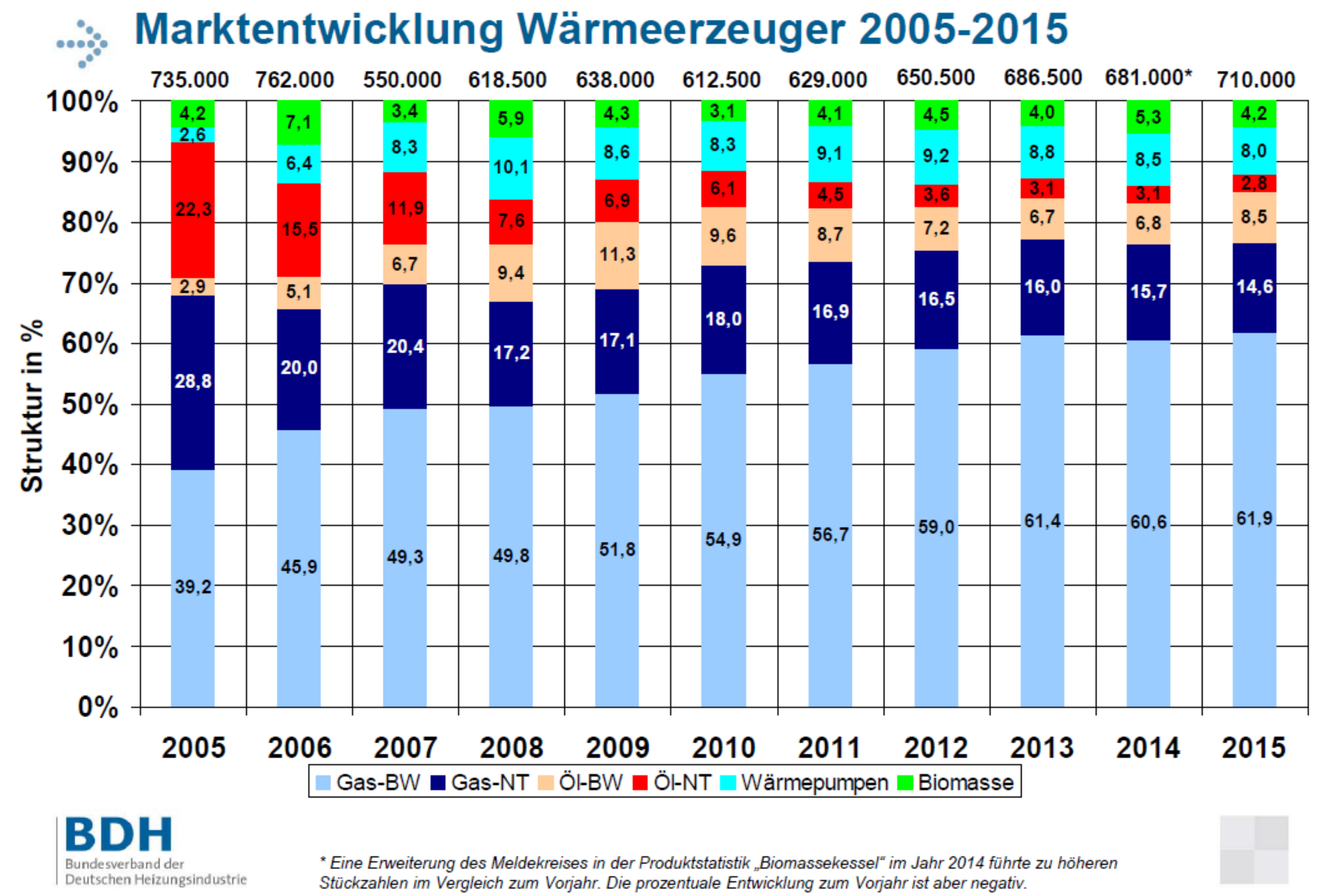
Ground-Source

- Source temp : min. 0 °C
- Capacity: >10 - 150 kW
- SPF: ~4

Water-Source

- Source temp : 10 °C
- Capacity: > 10 - 200 kW
- SPF: ~5

Heating Generation by type DE



Eine Erweiterung des Meldekreises in der Produktstatistik „Biomassekessel“ im Jahr 2014 führte zu höheren Stückzahlen im Vergleich zum Vorjahr. Die prozentuale Entwicklung zum Vorjahr ist aber negativ.

Primary energy assessment acc. VDI 4650

HP

Boiler

Solar thermal

el. back up

RES

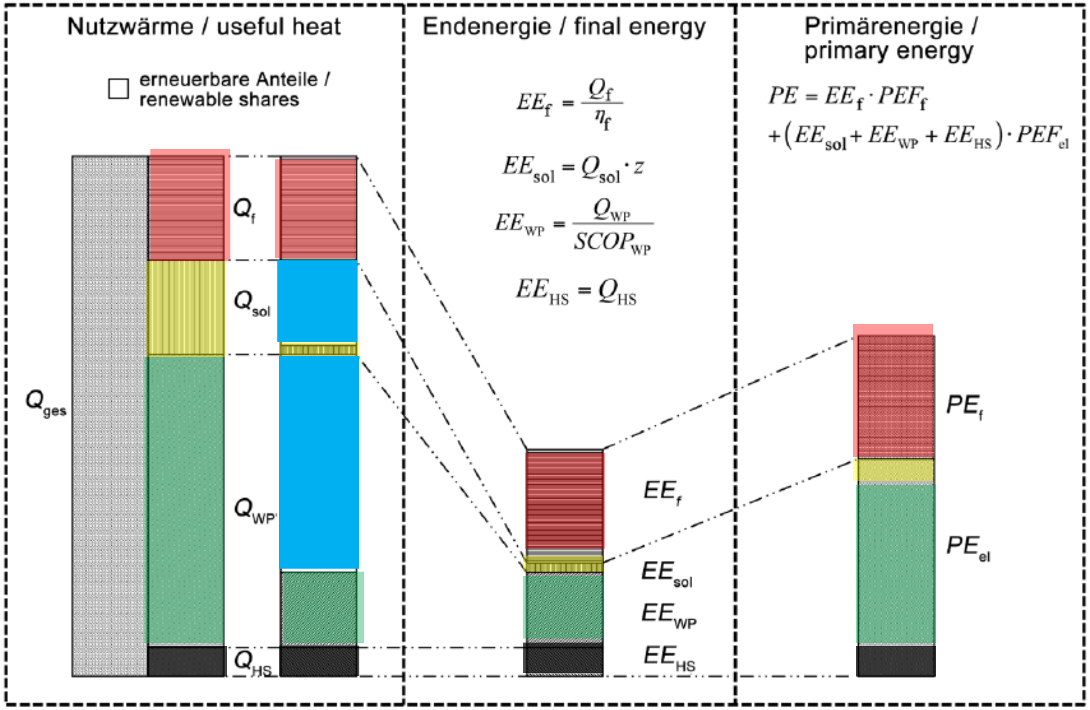


Bild 8. Berechnung der End- und Primärenergie einer bivalenten Wärmepumpenanlage mit mehreren Wärmeerzeugern (z = Stromverbrauch der Solarpumpe)

Figure 8. Calculation of the final energy and primary energy of a bivalent heat pump system with several heat generators (z = electrical power consumption of the solar pump)

Source: VDI 4650 Rework ETSuS UG

Heat Pumps vs. Boilers

Heat Pump

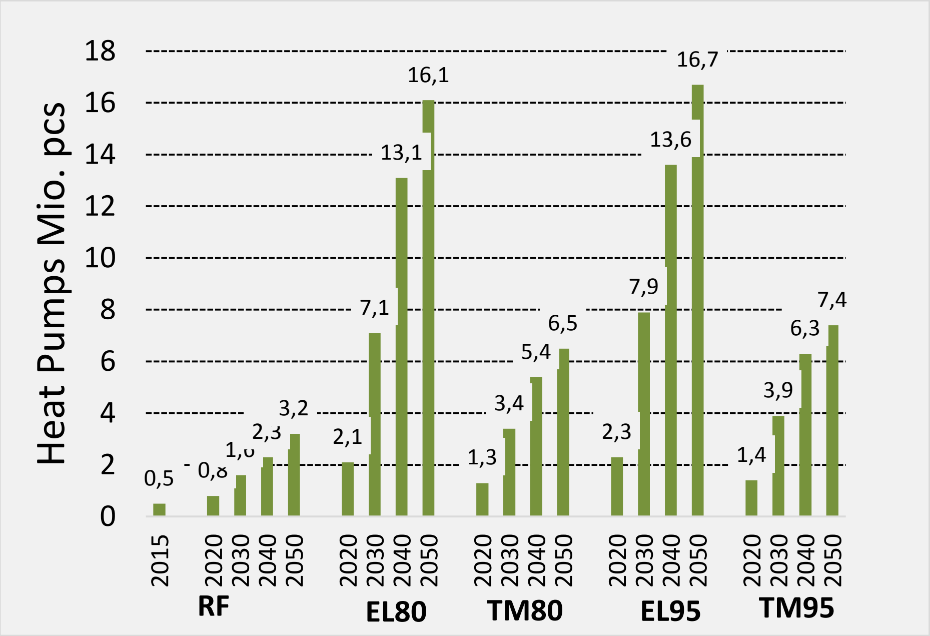
- Highest primary energy efficiency ++
- Best CO_2-Footprint ++
- Application temperature + 0
- Best RES fit
- DSM possible (Smart grids)
- Higher Up-front Cost –
- Running costs 0
- LCC ?

Boiler

- Lower primary energy efficiency +
- Worse CO_2-Footprint -
- Application temperature ++ -
- Low RES fit
- No fit for DSM
- Lower Up-front cost +
- Running cost 0
- LCC ?

Indirect emissions: climate change in DE, role of HPs

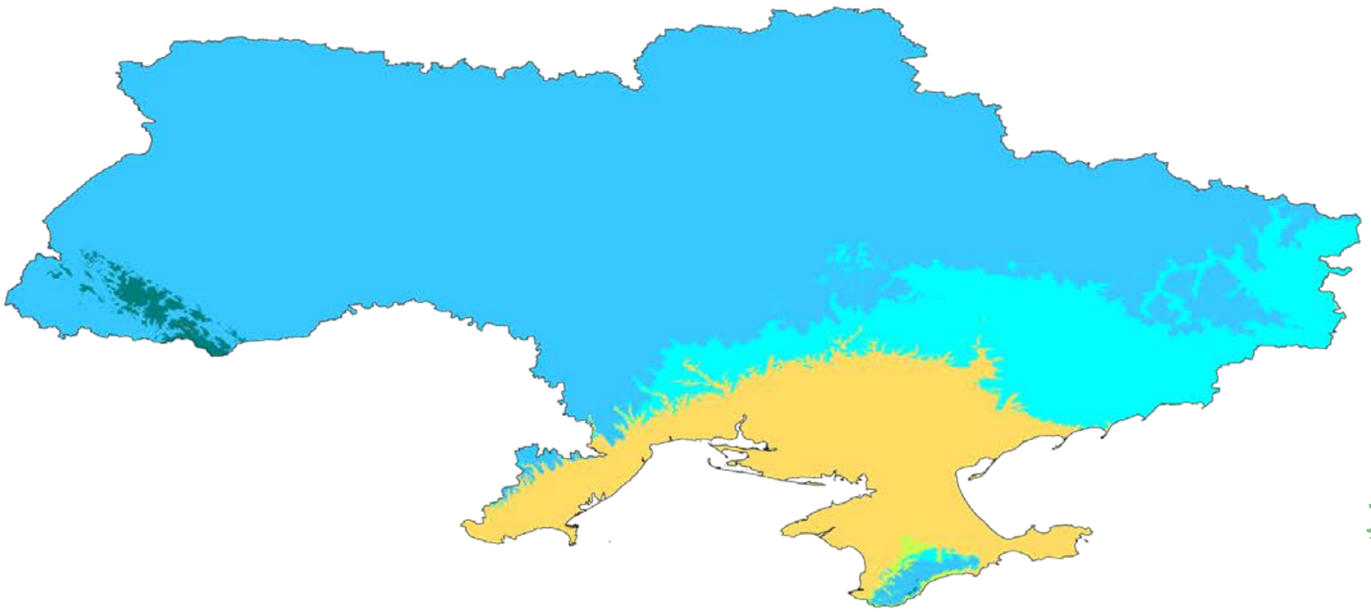
- Building envelope, installed technology und energy production
- 3 main scenarios
  - RF: „Reference“:
  - EL: „Electrification“: HP, Increase RES in E-Production
    - EL80
    - EL95
  - TM: „Technology Mix“: GHG-mitigation - RES Electricity, synthetic Bio-Fuels
    - TM80
    - TM95
  - EL und TM projection: significant increase of HP use



Source; dena geea Gebäudestudie, rework ETSuS UG

Climate Conditions for Heating (and cooling?)

Köppen–Geiger climate classification map for Ukraine (1980–2016)



Köppen-Geiger climate classification map for Germany (1980-2016)

Source: Beck et al.: Present and future Köppen-Geiger climate classification maps at 1-km resolution, Scientific Data 5:180214, doi:10.1038/sdata.2018.214 (2018)

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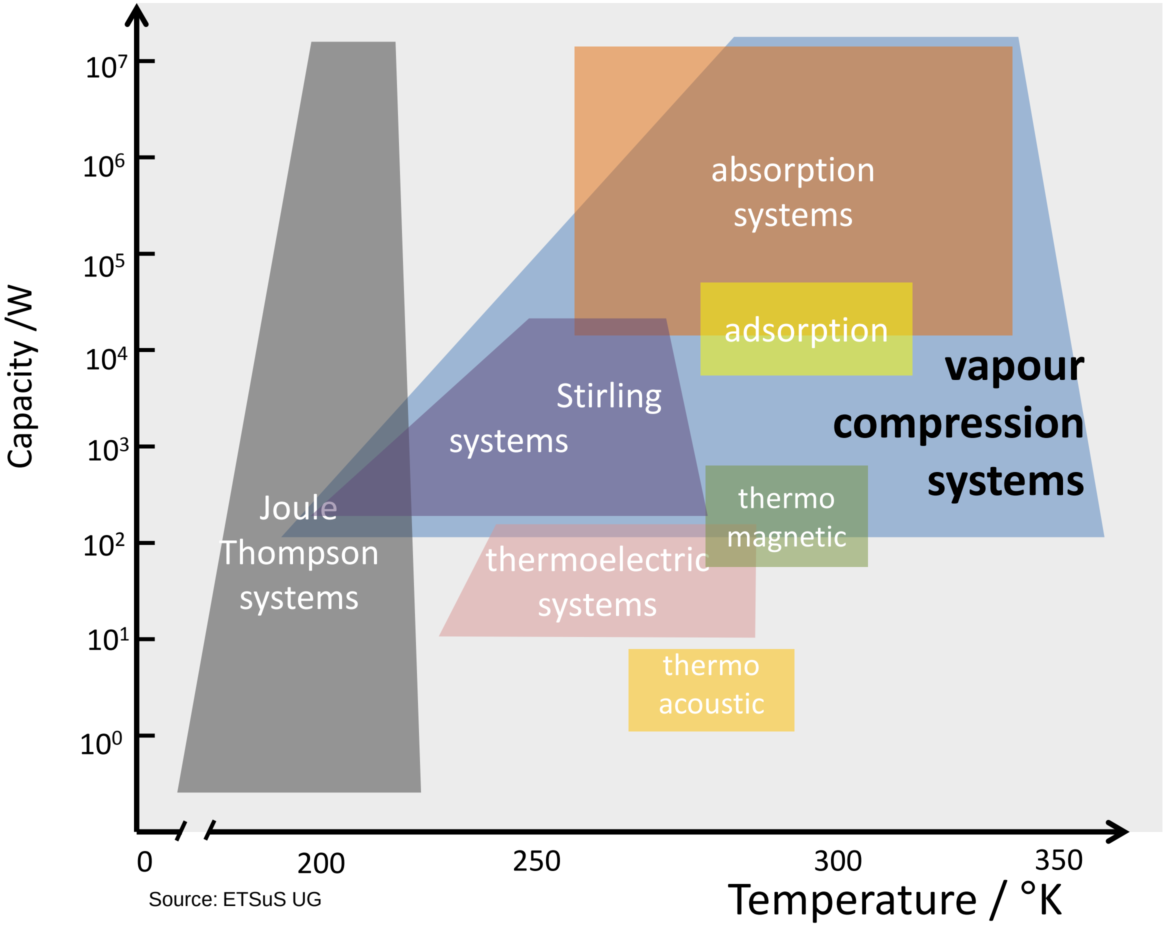
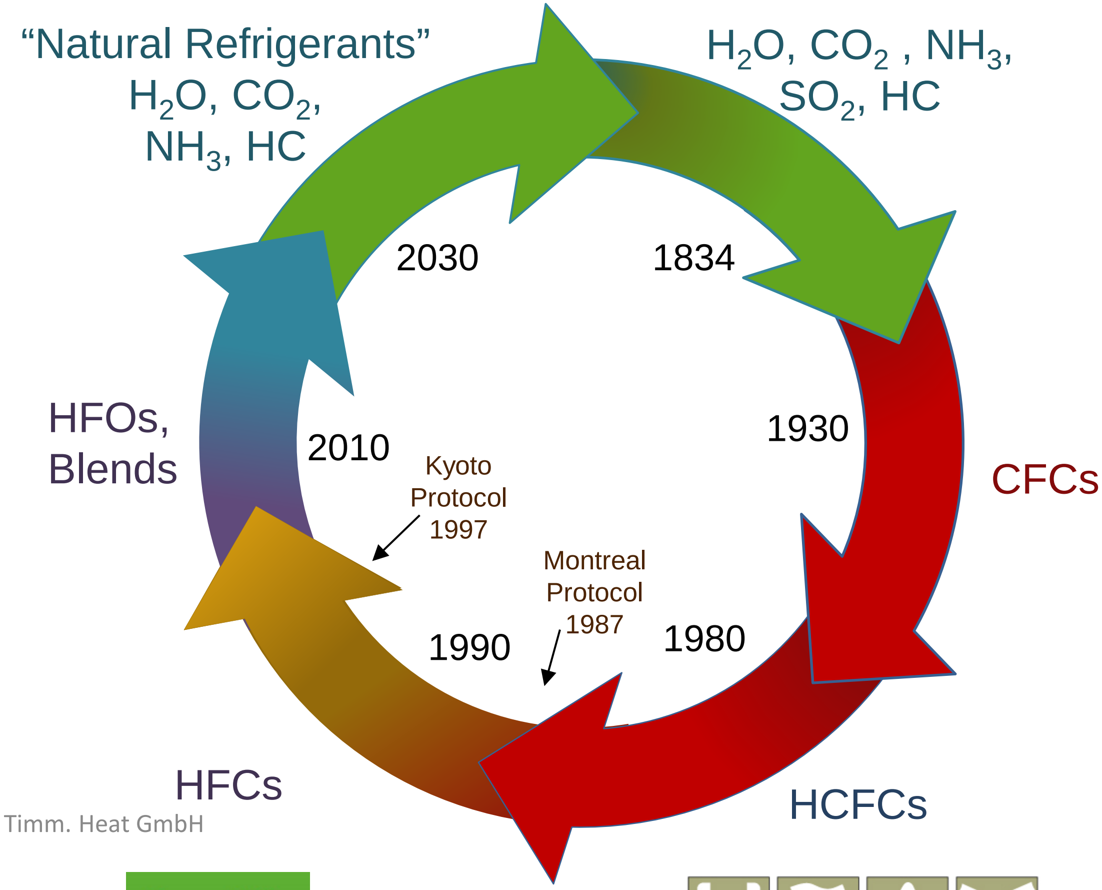
Cooling Technologies



Source: ETSuS UG

Refrigerants – historical development



“Natural Refrigerants”
H_2O, CO_2,
NH_3, HC

H_2O, CO_2 , NH_3,
SO_2, HC

CFCs

HCFCs

HFCs

HFOs,
Blends

E: Timm. Heat GmbH

🟥

Ozone Depleting Substances (ODS): Artificially substances and significant high Global Warming Potential (GWP) **highest** environmental impact

🟨

No Ozone Depletion Potential (ODP), but **high** GWP

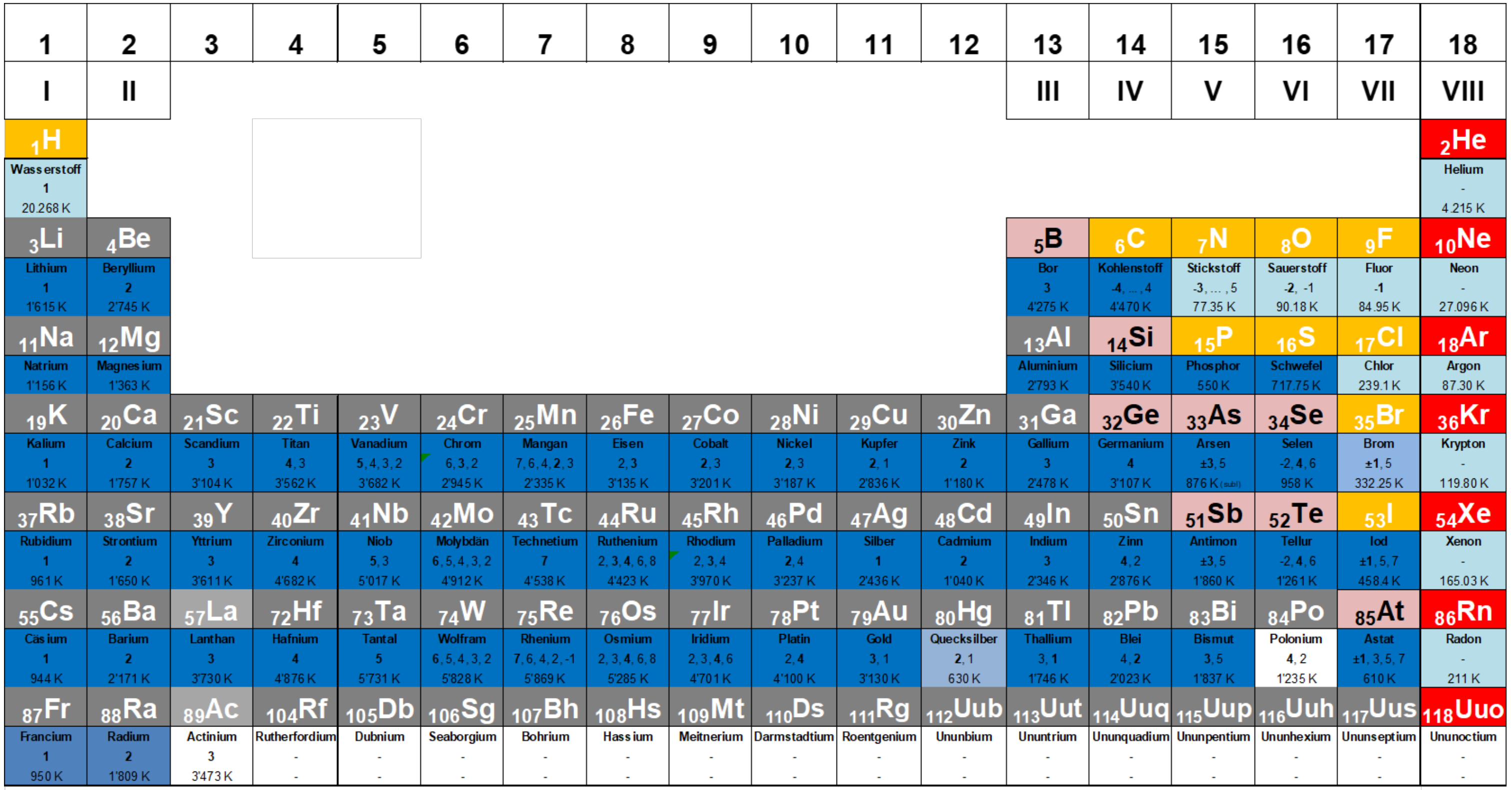
🟦

No ODP, lower (GWP) artificial substances with **lower** environmental impact

🟩

Naturally occurring substances with **lowest** environmental impact, (no ODP and lowest GWP)

Refrigerant cooking session – the ingredients



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
I	II											III	IV	V	VI	VII	VIII
$_{1}$H Wasserstoff 1 20.268 K																	$_{2}$He Helium - 4.215 K
$_{3}$Li Lithium 1 1'615 K	$_{4}$Be Beryllium 2 2'745 K											$_{5}$B Bor 3 4'275 K	$_{6}$C Kohlenstoff -4, ... , 4 4'470 K	$_{7}$N Stickstoff -3, ... , 5 77.35 K	$_{8}$O Sauerstoff -2, -1 90.18 K	$_{9}$F Fluor -1 84.95 K	$_{10}$Ne Neon - 27.096 K
$_{11}$Na Natrium 1'156 K	$_{12}$Mg Magnesium 1'363 K											$_{13}$Al Aluminium 2'793 K	$_{14}$Si Silicium 3'540 K	$_{15}$P Phosphor 550 K	$_{16}$S Schwefel 717.75 K	$_{17}$Cl Chlor 239.1 K	$_{18}$Ar Argon 87.30 K
$_{19}$K Kalium 1 1'032 K	$_{20}$Ca Calcium 2 1'757 K	$_{21}$Sc Scandium 3 3'104 K	$_{22}$Ti Titan 4, 3 3'562 K	$_{23}$V Vanadium 5, 4, 3, 2 3'682 K	$_{24}$Cr Chrom 6, 3, 2 2'945 K	$_{25}$Mn Mangan 7, 6, 4, 2, 3 2'335 K	$_{26}$Fe Eisen 2, 3 3'135 K	$_{27}$Co Cobalt 2, 3 3'201 K	$_{28}$Ni Nickel 2, 3 3'187 K	$_{29}$Cu Kupfer 2, 1 2'836 K	$_{30}$Zn Zink 2 1'180 K	$_{31}$Ga Gallium 3 2'478 K	$_{32}$Ge Germanium 4 3'107 K	$_{33}$As Arsen ±3, 5 876 K (subl)	$_{34}$Se Selen -2, 4, 6 958 K	$_{35}$Br Brom ±1, 5 332.25 K	$_{36}$Kr Krypton - 119.80 K
$_{37}$Rb Rubidium 1 961 K	$_{38}$Sr Strontium 2 1'650 K	$_{39}$Y Yttrium 3 3'611 K	$_{40}$Zr Zirconium 4 4'682 K	$_{41}$Nb Niob 5, 3 5'017 K	$_{42}$Mo Molybdän 6, 5, 4, 3, 2 4'912 K	$_{43}$Tc Technetium 7 4'538 K	$_{44}$Ru Ruthenium 2, 3, 4, 6, 8 4'423 K	$_{45}$Rh Rhodium 2, 3, 4 3'970 K	$_{46}$Pd Palladium 2, 4 3'237 K	$_{47}$Ag Silber 1 2'436 K	$_{48}$Cd Cadmium 2 1'040 K	$_{49}$In Indium 3 2'346 K	$_{50}$Sn Zinn 4, 2 2'876 K	$_{51}$Sb Antimon ±3, 5 1'860 K	$_{52}$Te Tellur -2, 4, 6 1'261 K	$_{53}$I Iod ±1, 5, 7 458.4 K	$_{54}$Xe Xenon - 165.03 K
$_{55}$Cs Cäsium 1 944 K	$_{56}$Ba Barium 2 2'171 K	$_{57}$La Lanthan 3 3'730 K	$_{72}$Hf Hafnium 4 4'876 K	$_{73}$Ta Tantal 5 5'731 K	$_{74}$W Wolfram 6, 5, 4, 3, 2 5'828 K	$_{75}$Re Rhenium 7, 6, 4, 2, -1 5'869 K	$_{76}$Os Osmium 2, 3, 4, 6, 8 5'285 K	$_{77}$Ir Iridium 2, 3, 4, 6 4'701 K	$_{78}$Pt Platin 2, 4 4'100 K	$_{79}$Au Gold 3, 1 3'130 K	$_{80}$Hg Quecksilber 2, 1 630 K	$_{81}$Tl Thallium 3, 1 1'746 K	$_{82}$Pb Blei 4, 2 2'023 K	$_{83}$Bi Bismut 3, 5 1'837 K	$_{84}$Po Polonium 4, 2 1'235 K	$_{85}$At Astat ±1, 3, 5, 7 610 K	$_{86}$Rn Radon - 211 K
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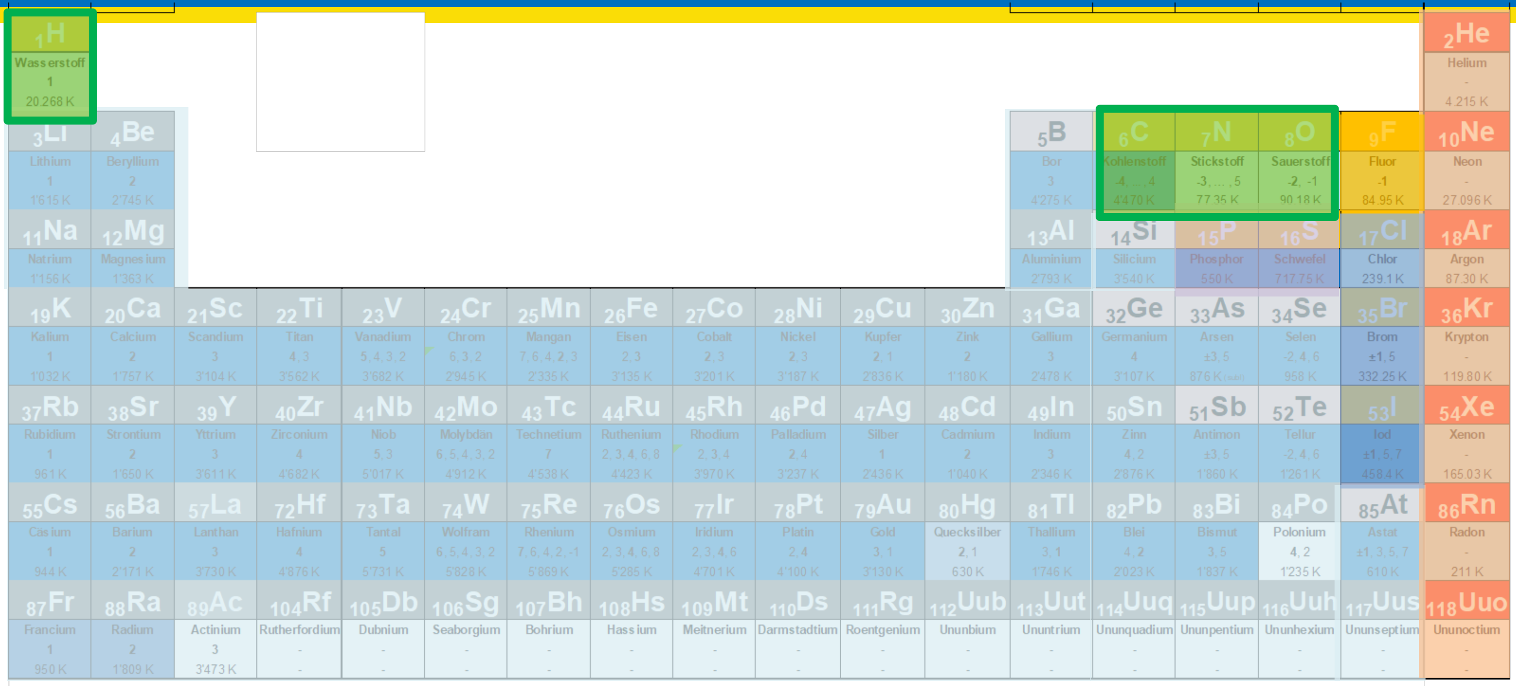
Source: ETSuS UG

Refrigerant cooking session – the ingredients – What's left?



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Do not form gases

Ozone depleting

Remaining candidates

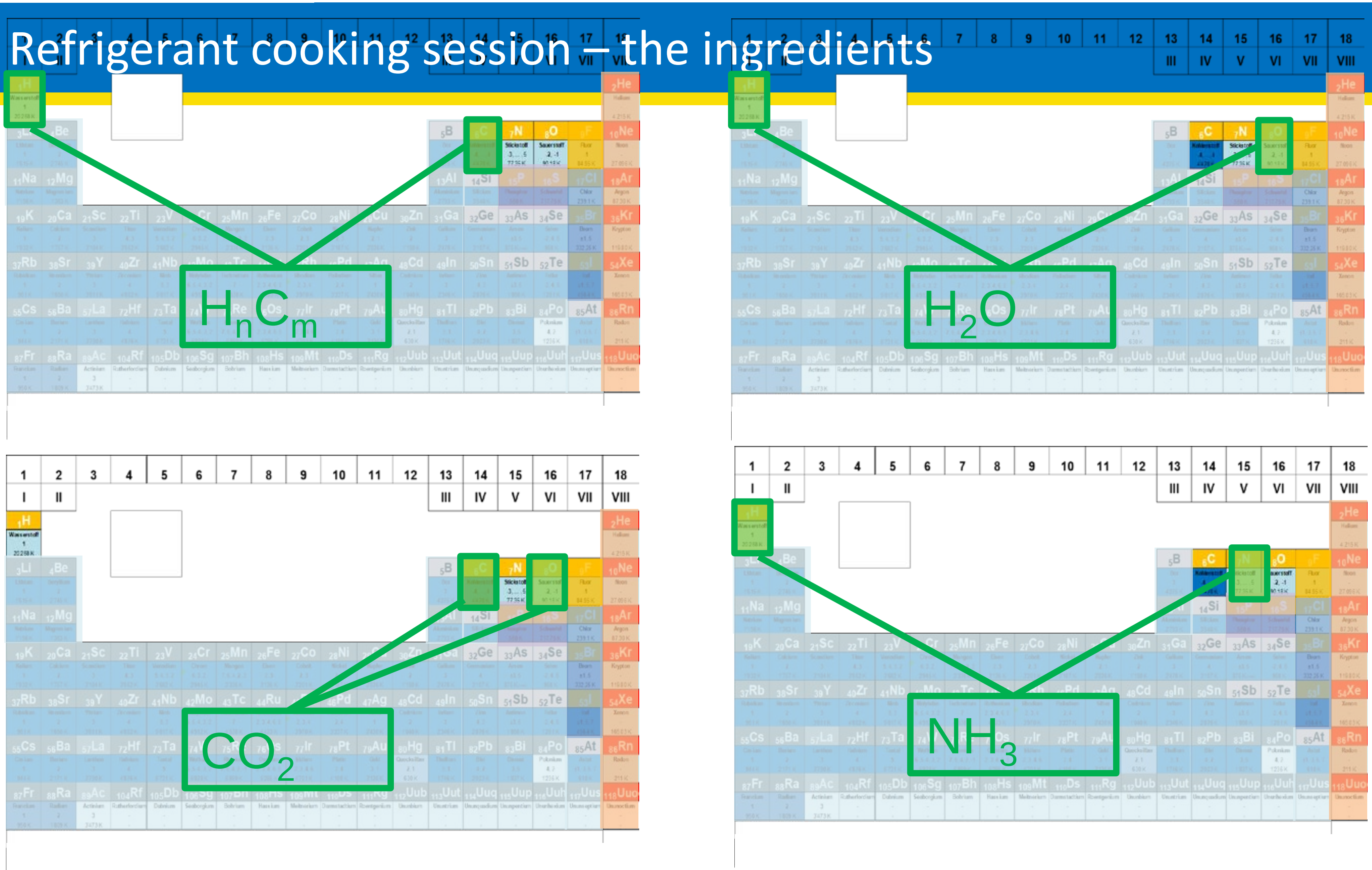
Do not react at all

Greenhouse effect

Toxic

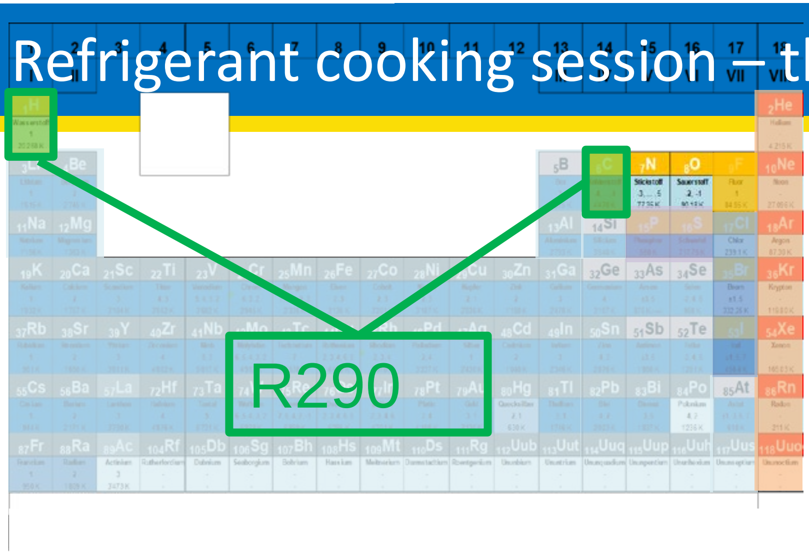
Source: ETSuS UG

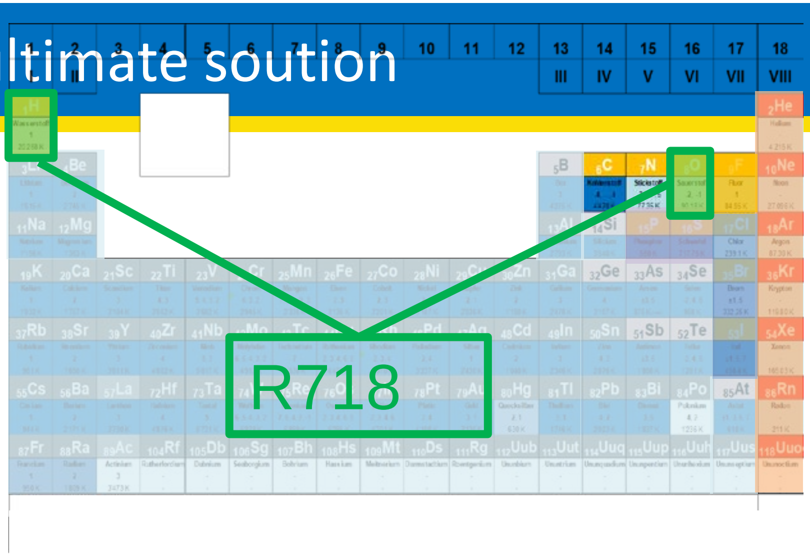
Refrigerant cooking session – the ingredients

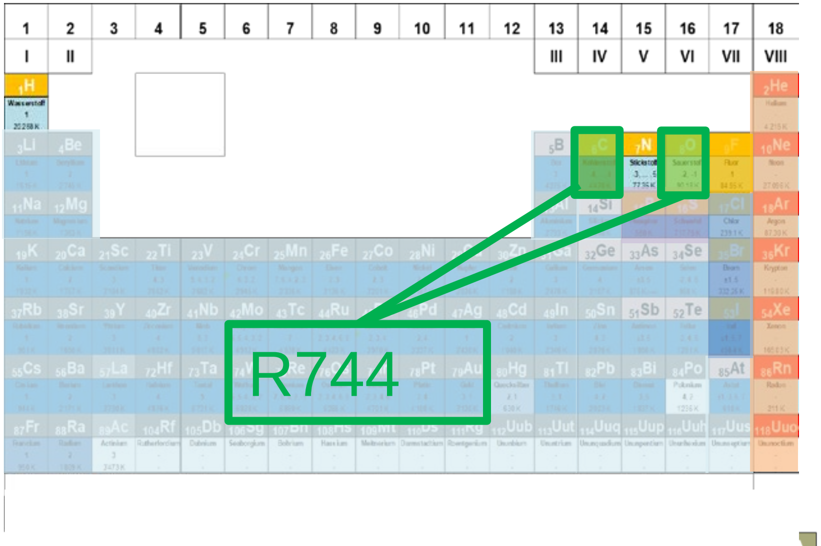


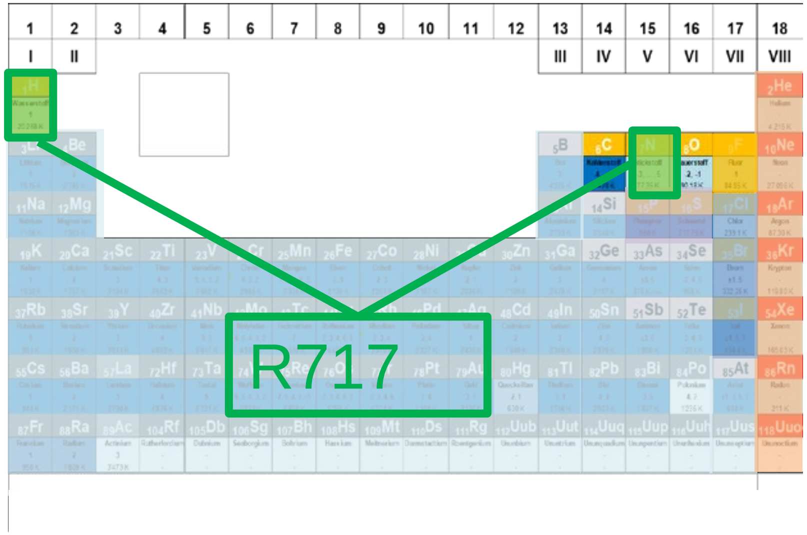
Source: ETSuS UG

Refrigerant cooking session – the ultimate soution









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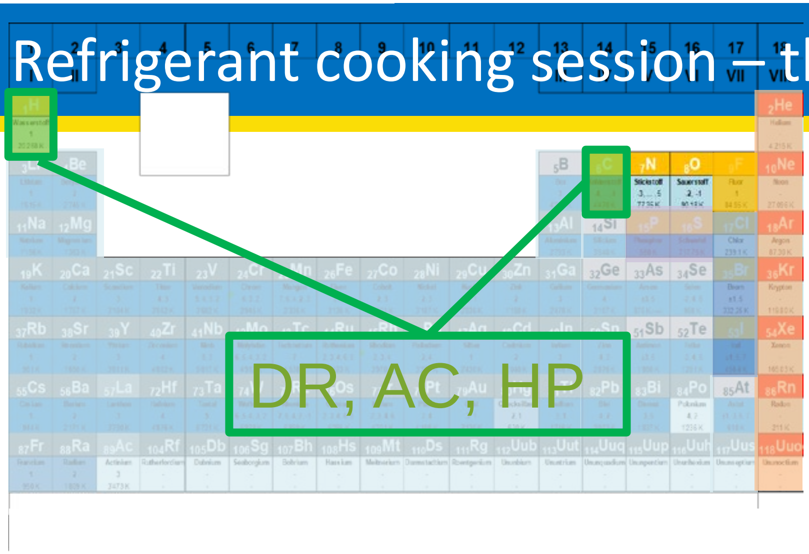
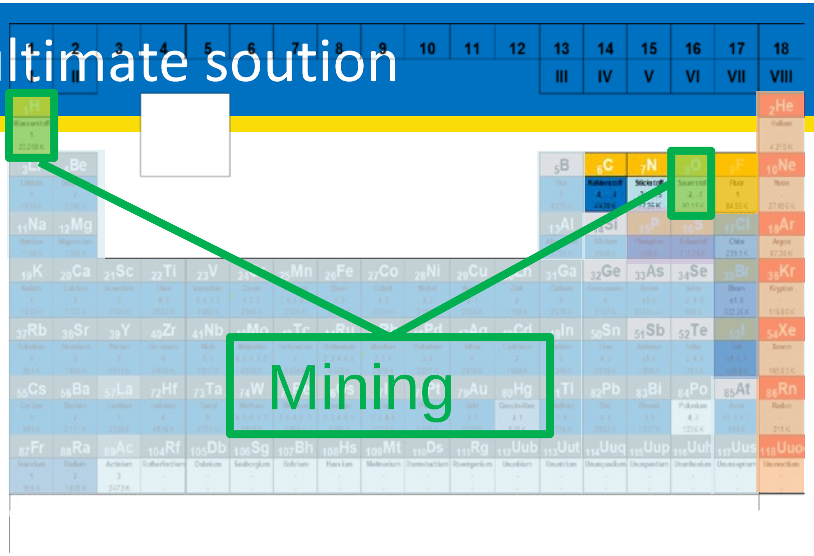
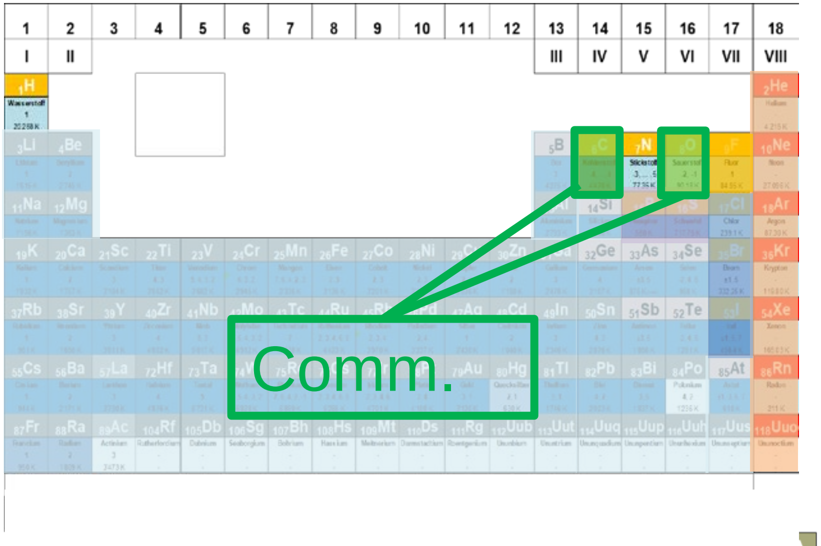
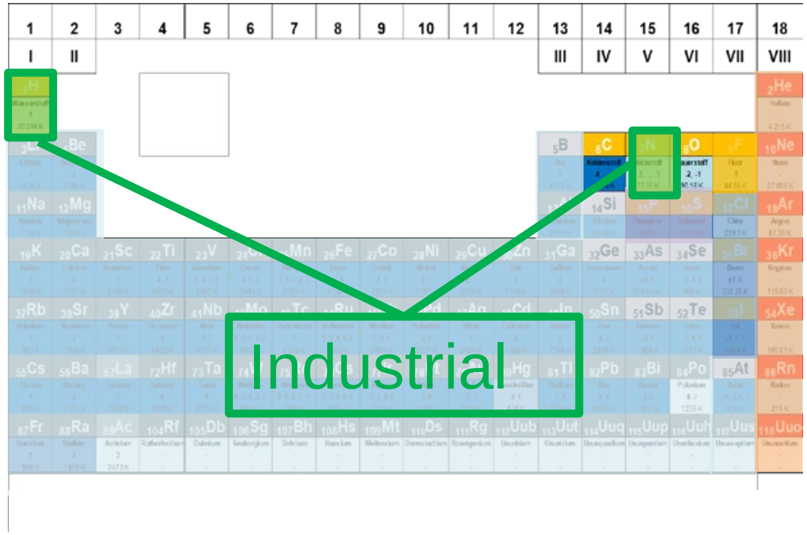






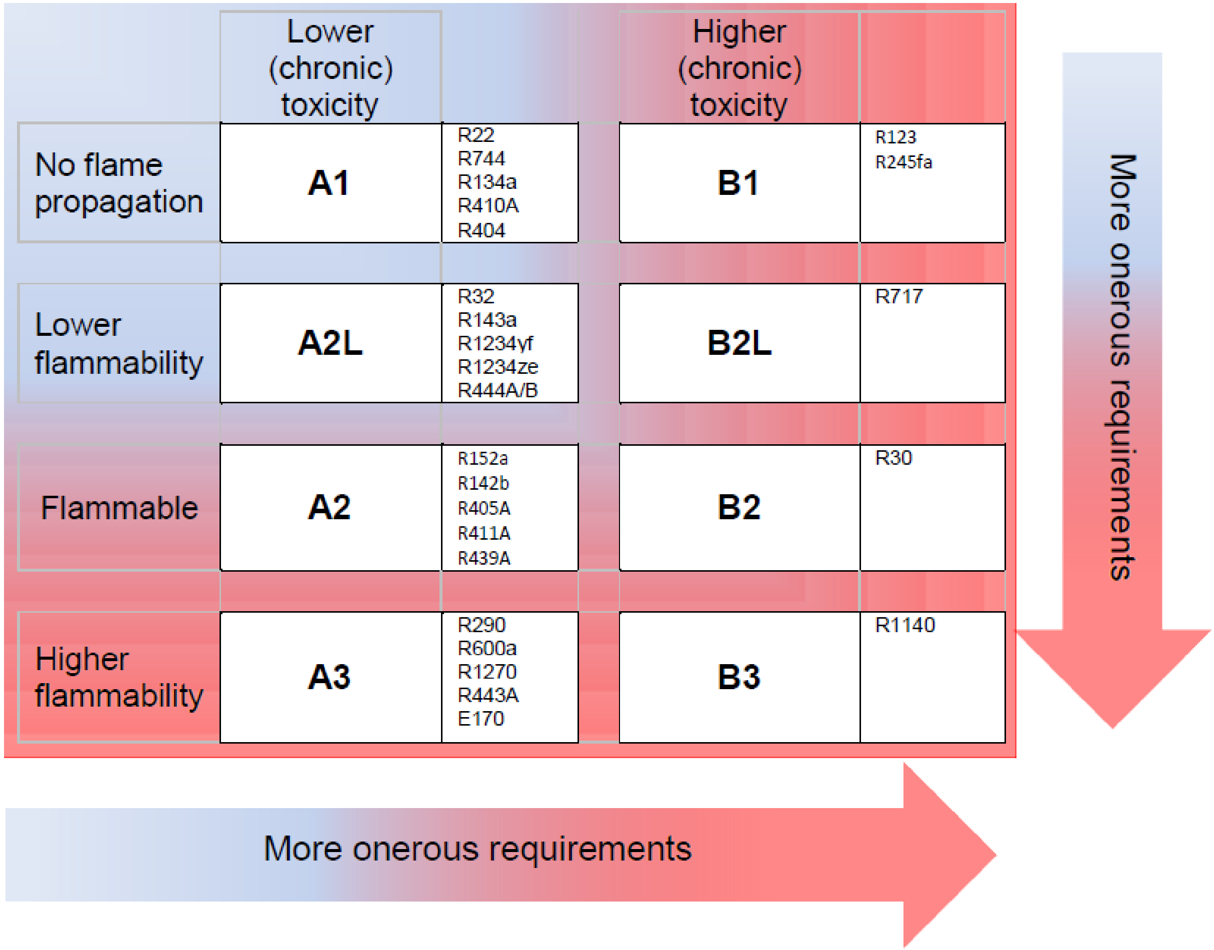


Source: ETSuS UG

Safety Classification of refrigerants

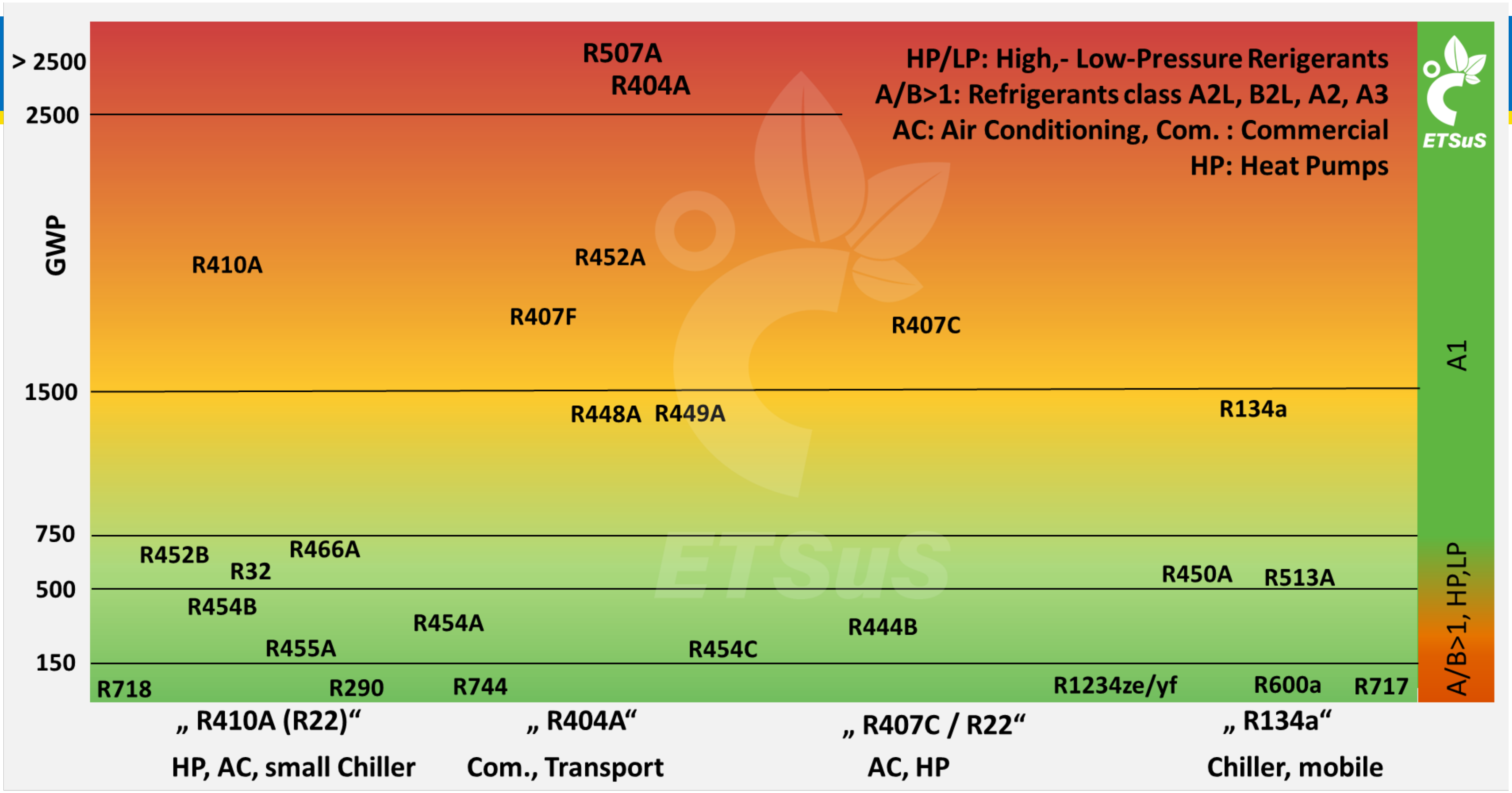
A "higher" classification (i.e. toxicity class B instead of class A, and flammability class 3 instead of class 1) means:

- the refrigerating system has more demanding design requirements,
- in order to handle the higher risk represented by the refrigerant.



	Lower (chronic) toxicity		Higher (chronic) toxicity	
No flame propagation	**A1**	R22 R744 R134a R410A R404	**B1**	R123 R245fa
Lower flammability	**A2L**	R32 R143a R1234yf R1234ze R444A/B	**B2L**	R717
Flammable	**A2**	R152a R142b R405A R411A R439A	**B2**	R30
Higher flammability	**A3**	R290 R600a R1270 R443A E170	**B3**	R1140

CAPACITY BUILDING ON INNOVATIVE APPLICATIONS OF ENERGY-FICIENT CLIMATE-FRIENDLY COOLING AND HEATING TECHNOLOGIES



SOURCE: ETSuS UG

Umwelt Bundesamt

REFRIGERATING ASSOCIATION OF UKRAINE PUBLIC UNION

Safety vs. “Environmental” classification

Toxicity Flammability	Lower Chronic Toxicity	Higher Chronic Toxicity
No Flame Propagation	A1	B1
Lower Flammability	A2L	B2L
Flammable	A2	B2
Higher Flammibility	A3	B3

	GWP
Highest GWP	A1
High GWP	A2, A2L
Lower GWP	A2L
Lowest / GDP	A3, B2L, R744

Safety vs. Enivonmental classification

Toxicity / Flammability	Lower Chronic Toxicity	Higher Chronic Toxicity
No Flame Propagation	A1	B1
Lower Flammability	A2L	B2L
Flammable	A2	B2
Higher Flammibility	A3	B3

Technical Tackle Feasible

Only Technical Tackle Is AVOIDANCE of USE

	GWP
Highest GWP	A1
High GWP	A2, A2L
Lower GWP	A2L
Lowest / GDP	A3, B2L, R744

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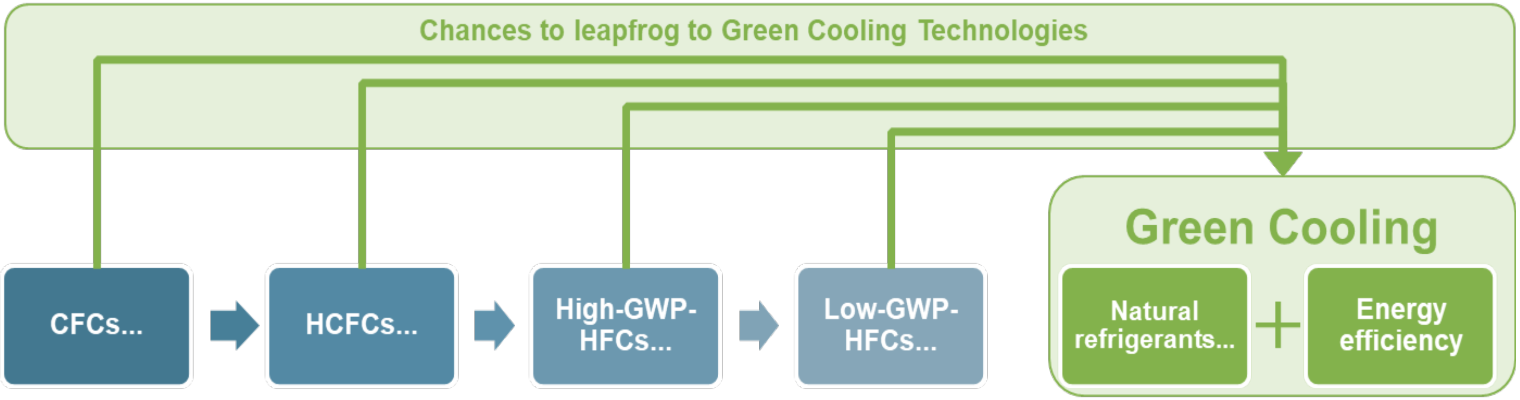
- A sector and vector view: Heating and Cooling
- The role of renewable energy
- Heating: Heat Pumps and Boilers
- RAC HP: Green working fluids
- Refrigeration: Green cooling technologies
- Summary and outlook

Leapfrog to Green Technologies



CFCs...

... are ozone depleting and contribute to global warming

... deplete natural resources

... are phased out by the Montreal Protocol

HCFCs...

... were introduced as transitional substitutes for CFCs

... deplete natural resources

... are less ozone depleting but contribute to global warming

... are phased out by the Montreal Protocol

High-GWP-HFCs...

... were introduced as transitional substitutes for CFCs and HCFCs

... deplete natural resources

... contribute to global warming

... are controlled by climate regime and may be phased down by the Montreal Protocol

Low-GWP-HFCs...

... were developed as „climate-friendly“ alternatives

... deplete natural resources

... produce dangerous hydrogen fluoride when they burn and transform to trifluoro-acetic acid in the atmosphere

...are patented and manufactured by chemical industry and costly

Natural refrigerants...

... are naturally occuring substances that can be used as refrigerants in almost all RAC applications

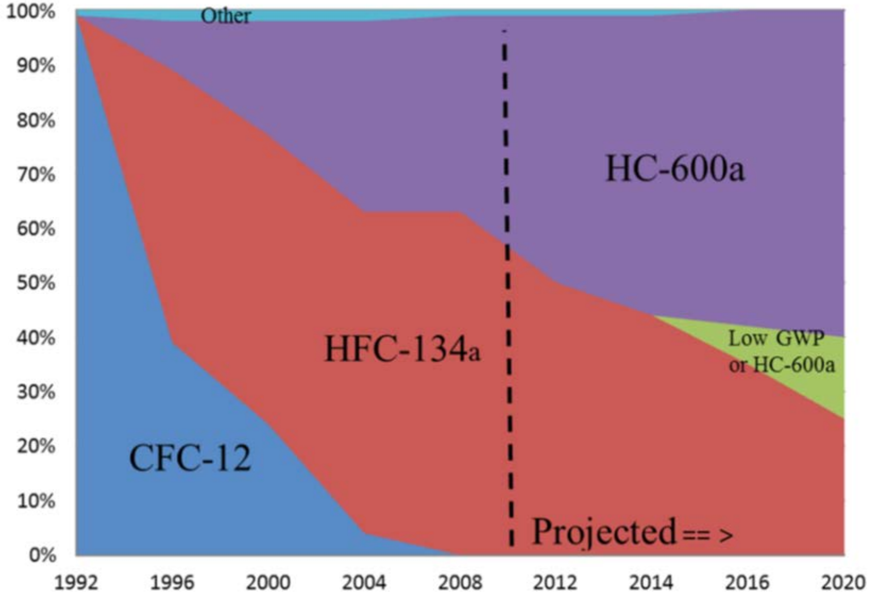
... are typically more energy efficient than F-gases

... do not harm the environment

... can be handled safely with due care

... are not patented by chemical industry and less costly than HFCs

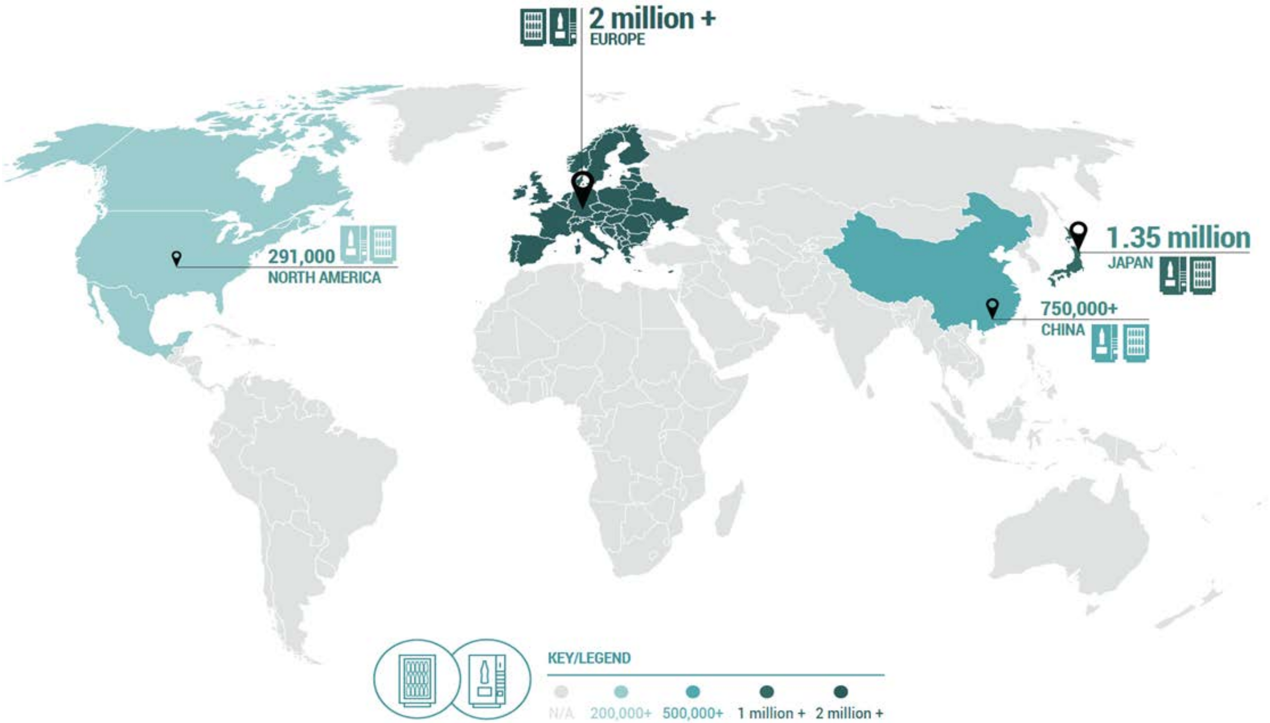
Domestic refrigeration: Hydrocarbon success story



- More than 700 million domestic refrigerators already use hydrocarbons today
- HC is the standard for 50% global production of new domestic refrigeration equipment
- By 2020, 75% of new production globally will use R600a/ R290

Light commercial HC

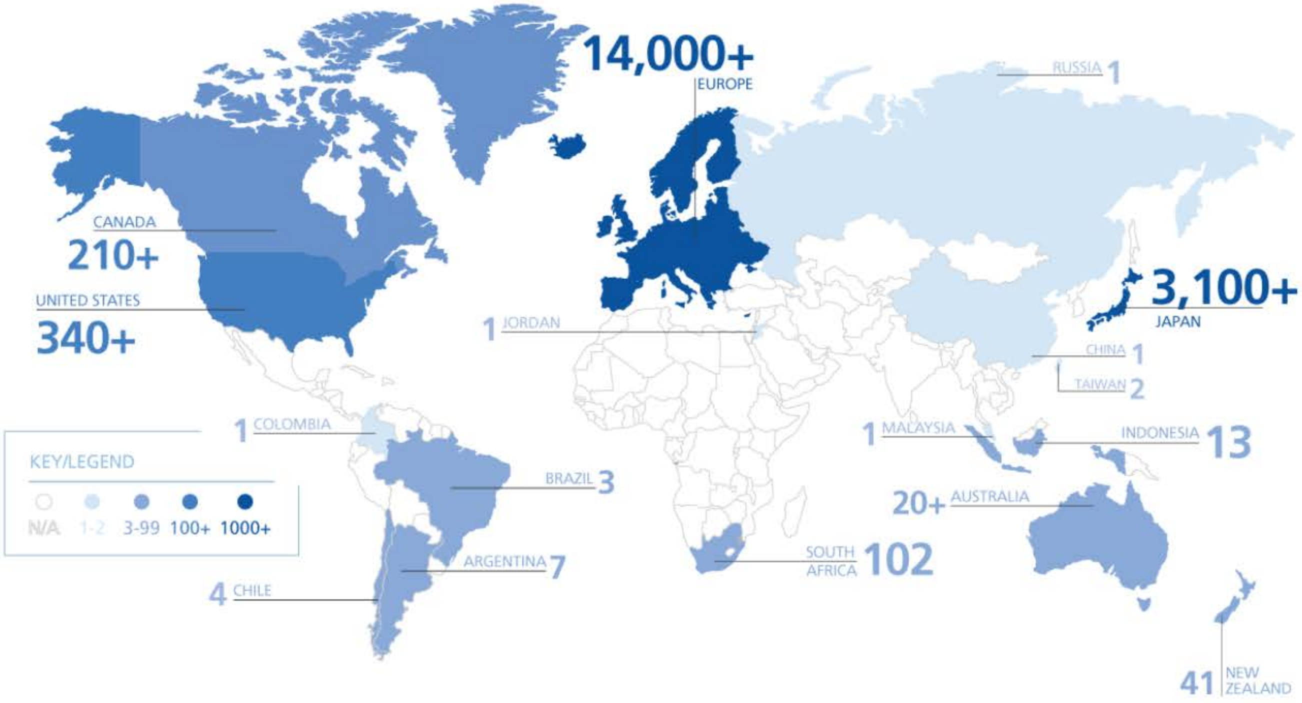
- self-contained water loop HC-based refrigeration systems are a clear trend
- used with leading retailers in DE ,UK - now also coming to North America, Asia and Australia
- 90% reduced refrigerant charge, better capacity than R404A and a fast break-even to recover invest.



Commercial refrigeration: CO_2

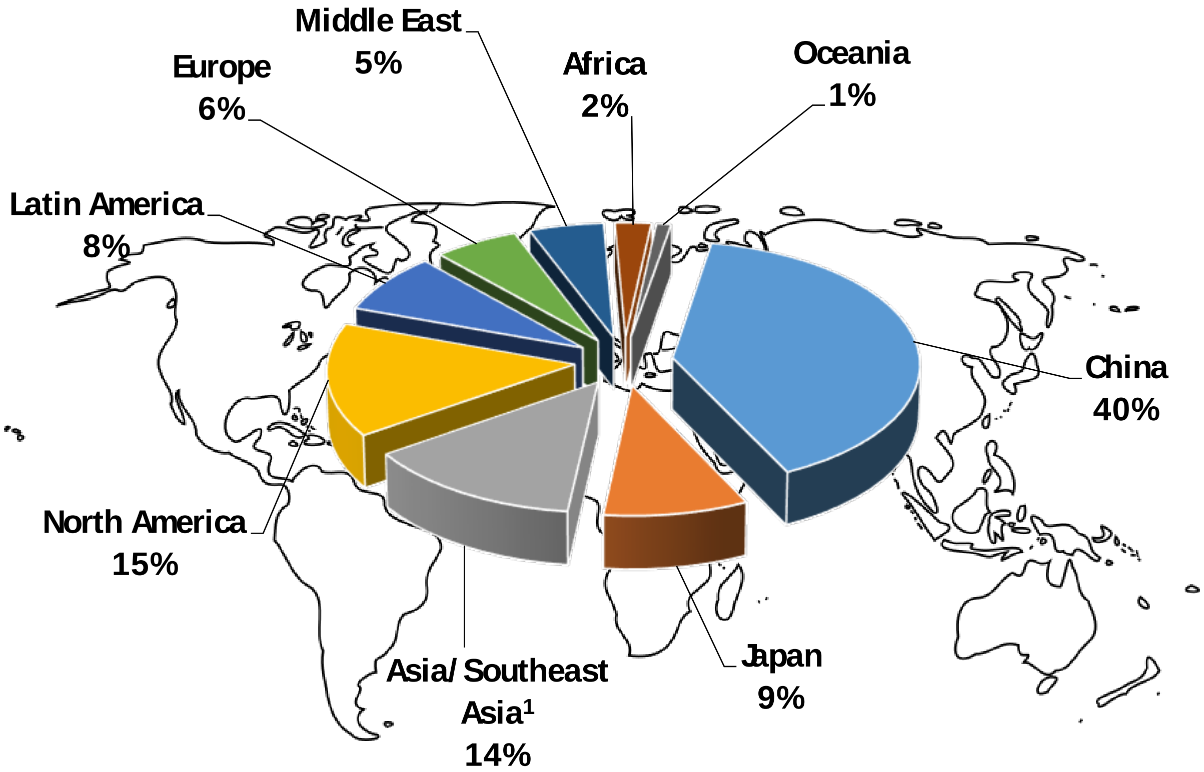
CO_2 TC STORES GROWING GLOBALLY (FEB 2018)

sheccoBase Webinar



sheccobase.com

Air Conditioning: Global 105 Mio/a, installed > 2 billion

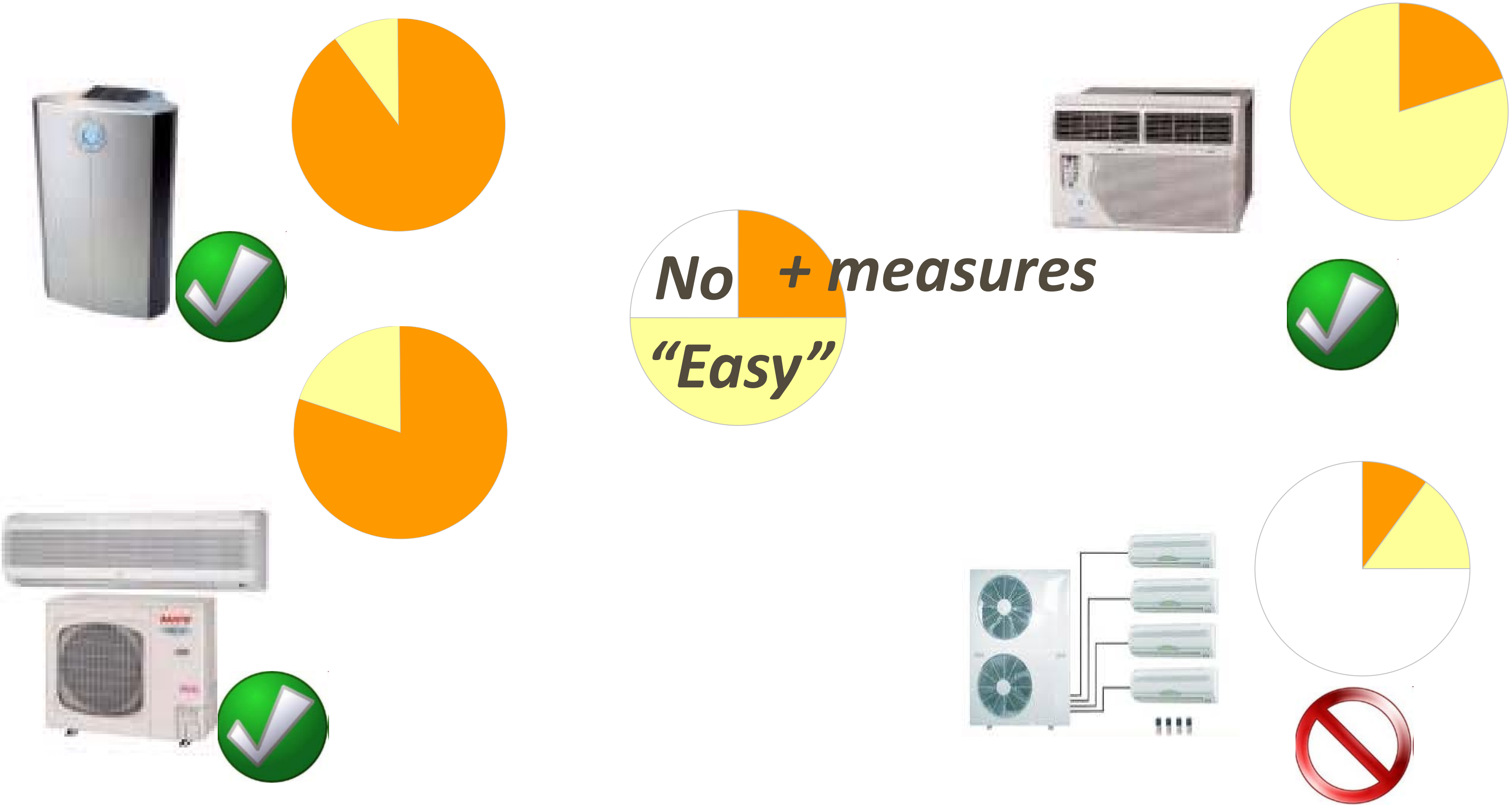


~105m units

[1] excl. China and Japan

Sources: JRAIA, JARN, BSRIA (2015)

Viable application of HCs in air conditioners



Summary

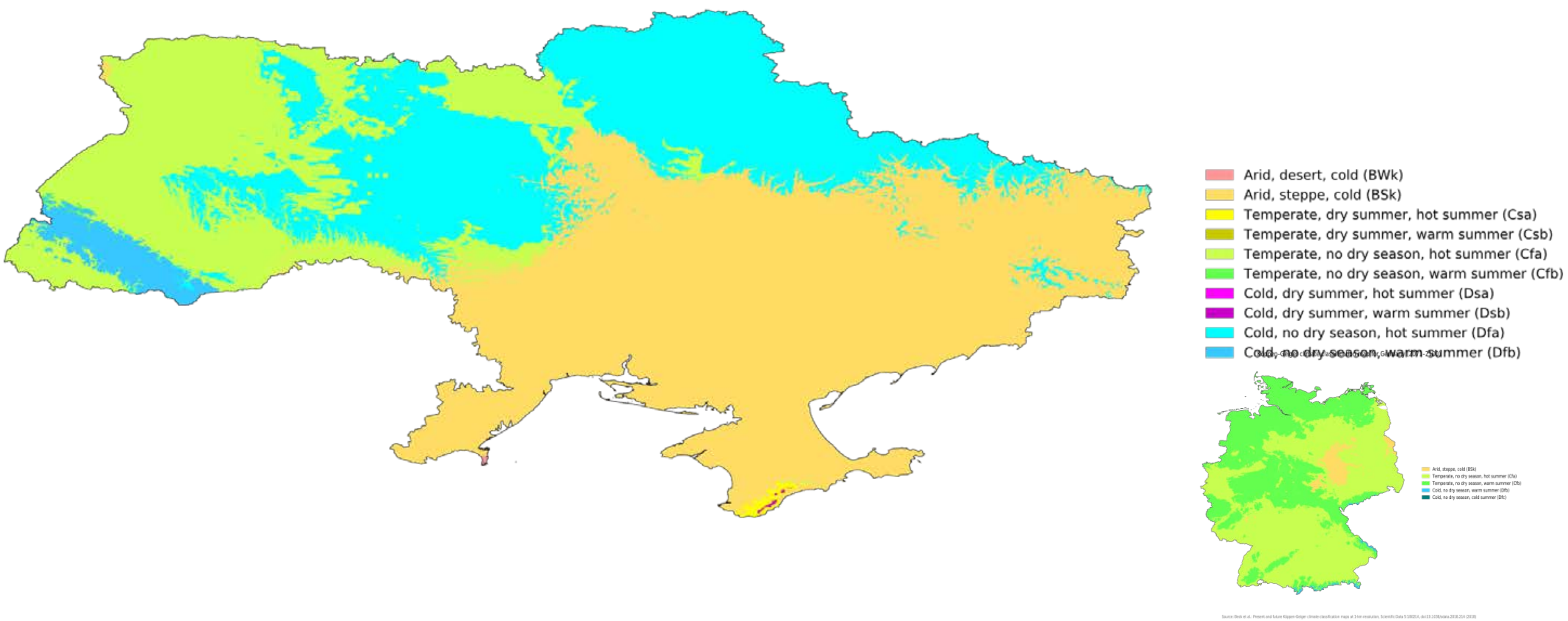
- Fighting climate changes requires RES and green technologies
- Most RES are electrical
- HPs most favourable to RES heating
- Green technologies available for RAC&HP
- AND for UA: HP LCC < Boiler

Summary LCC

	Boiler	New EE HP
Heating capacity (kW) (Tedsign at - -10 °C)	15	15
Unit price (USD)	1.000	8.000
Installation price (USD)	1.800	200
Maintenance cost (USD/year)	20	20
Total investment (USD)	**2.820**	**8.220**
SCOP		4
Total input power (kW)		
Energy consumption (kWh/year)	**27.409**	**6.781**
Annual electricity cost (USD)	**19**	**237**
Gas price (USD/year)	1.654	-
Total energy cost (USD/year)	1.674	237
LCC (USD)	**14.875**	**9.912**

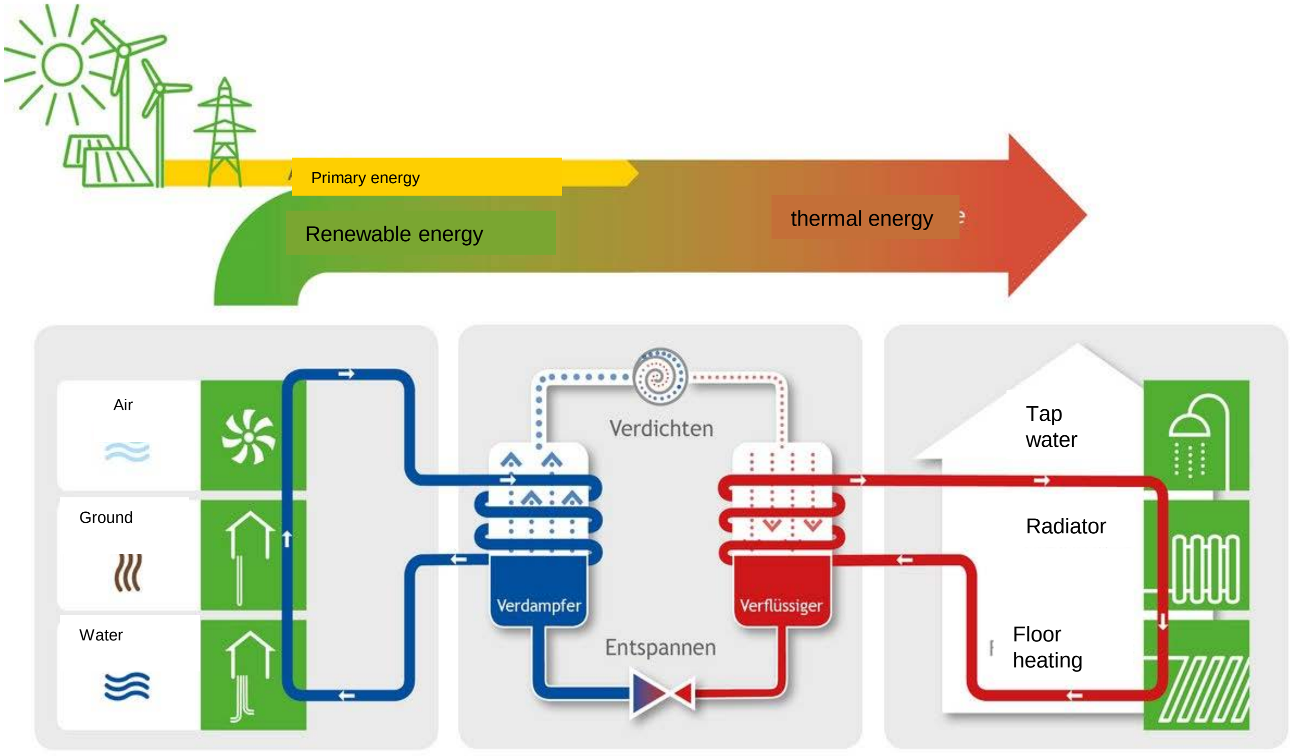
Climate Conditions for Heating (and cooling?)

Köppen–Geiger climate classification map for Ukraine (2071–2100)



Source: Beck et al.: Present and future Köppen-Geiger climate classification maps at 1-km resolution, Scientific Data 5:180214, doi:10.1038/sdata.2018.214 (2018)

Heat pumps basics



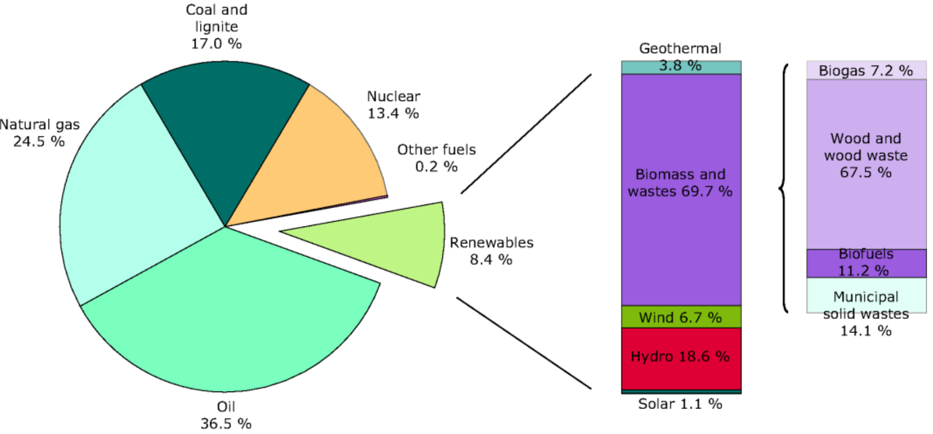
Heat Source

Heat Pump

Heat Sink, distribution and storage

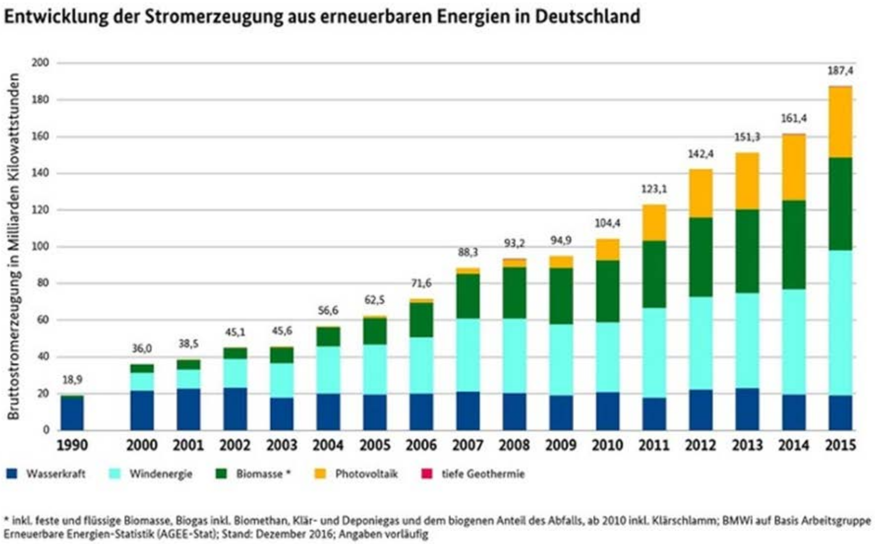
Energy sources and renewables

EU 28: 2008
Primary energy sources



Source: eea

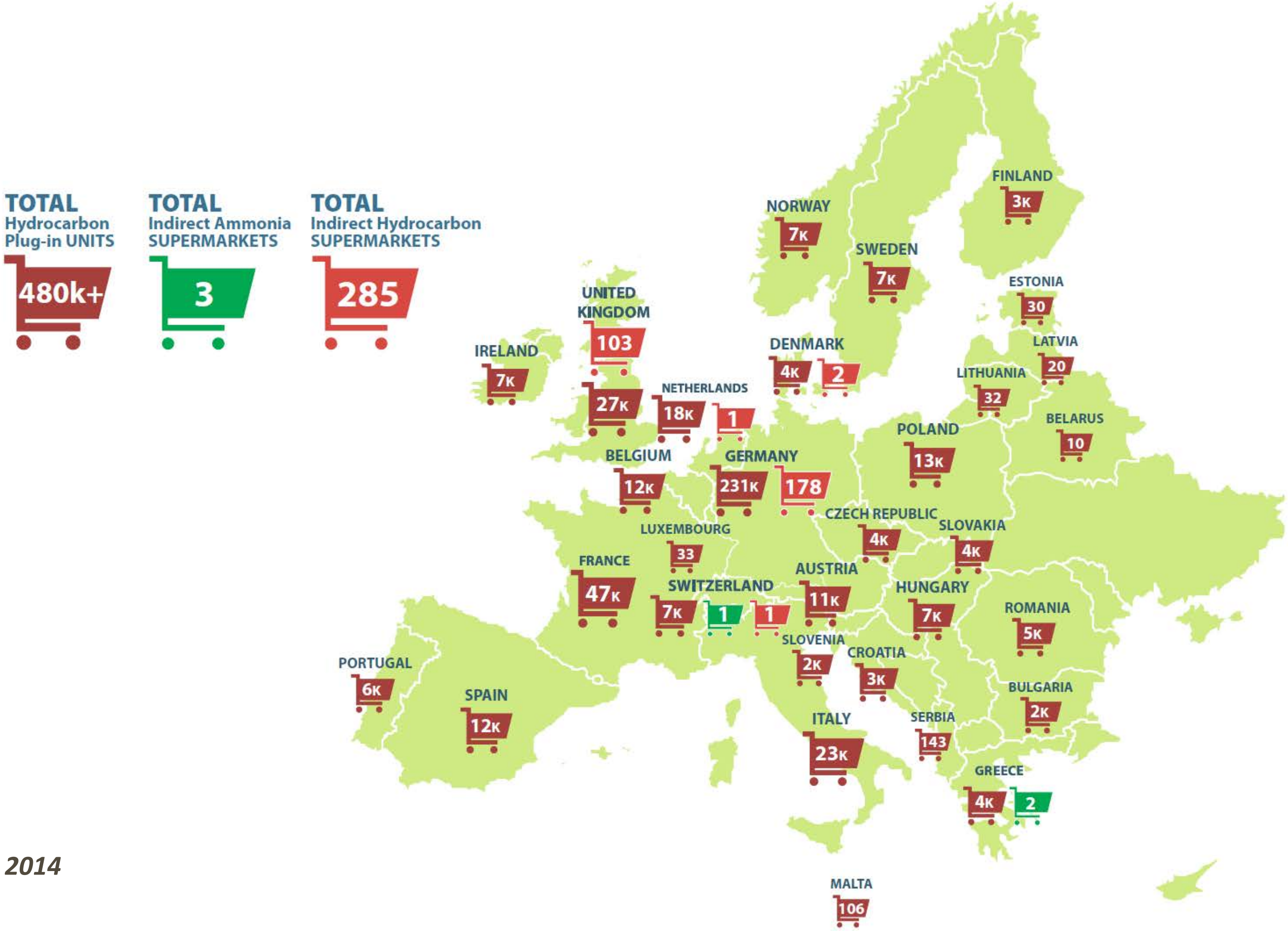
DE: 1990 – 2015
Electricity production from RES


Entwicklung der Stromerzeugung aus erneuerbaren Energien in Deutschland

* inkl. feste und flüssige Biomasse, Biogas inkl. Biomethan, Klär- und Deponiegas und dem biogenen Anteil des Abfalls, ab 2010 inkl. Klärschlamm; BMWi auf Basis Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat); Stand: Dezember 2016; Angaben vorläufig

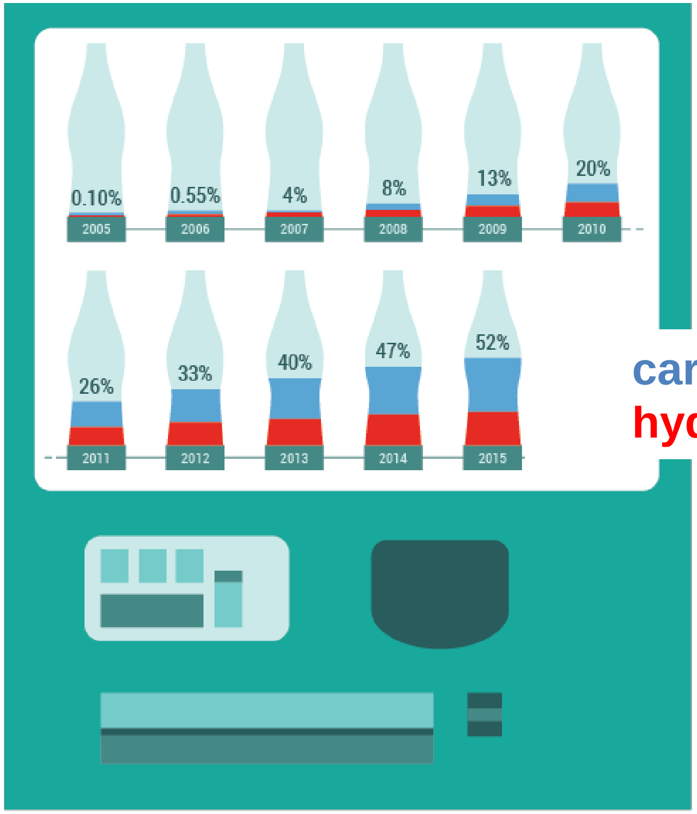
Source : *BMWi nach Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat)*

Commercial: Supermarkets (plug-ins and centralised) Europe



Source: Shecco, 2014

Light commercial in Japan



carbon dioxide
hydrocarbons

- 1.35 million beverage vending machines in Japan use either hydrocarbons or CO2
- natural refrigerants make up over 50% of the market
- from 0.1% to 52% market share in just 10 years ! = a clear Japanese success story

Alternative Refrigerants (selection)

Refrgerant	ODP	GWP (AR4/AR5)	NBP/NDP /°C	Critical Temp. / °C	Critical Pressure / MPa	Klasse ISO 817	CLP classification	LFL Kg/m³	LFL Vol%	S_u^* burning velocity / cm/s	H_c Verbrenn.-wärme / MJ/kg	ATEL / ODL / kg /m³
R32	0	675/677	-52	78	5,8	A2L	H220/H280	0,307	14,2	6,7	9,5	0,300
R152a	0	124/138	-25	113	4,5	A2	H220/H280	0,130	4,7	23	16,3	0,140
R290	0	3/3	-42	97	4,2	A3	H220/H280	0,038	2,1	46	46,3	0,090
R454B	0	698/676	-51/-50,2	77		A2L	H220/H280	0,298	7,3	5,2	9,9	0,47
R454C	0	148/146	-45,9/-39,9	82		A2L	H220/H280	0,289	6,1	<4	10,5	0,37
R466A	0,01-0,05	733	-51,7/-50,2	80,6	5,9	A1	H280	-	-	-	-	?
R600a	0	3/3	-12	135	3,6	A3	H220/H280	0,043	1,8	41	45,6	0,059
R717	0	0/0	-33	132	11,3	B2L	H221/H280/H331/H314/H410	0,116	16,7	7,2	18,6	0,00022
R718	0	0/0	100	374	22,1	A1	-	-	-	-	-	-
R744	0	1/1	-78	31	74	A1	H280	-	-	-	-	0,072
R1234ze(E)	0	4/1	-19	109	3,4	A2L	- /H280	0,303	6,4	1,2	10,1	0,28
R1234yf	0	7/1	-26	95	3,6	A2L	H220/H280	0,289	6,1	1,5	10,7	0,47

Primary Application Relevance

* ISO 817 Nominal Formulation or WCF

Relevant publications

Policy and market:

- GCI Market trends in selected refrigeration and air conditioning subsectors
- Promoting Food Security and Safety via Cold Chains
- RAC Inventory Vietnam
- RAC Inventory Philippines

Relevant publications

Technical:

- Good practices in refrigeration (primarily refrigerators)
- International Safety Standards in Air Conditioning, Refrigeration & Heat Pump
- Guidelines for the safe use of hydrocarbon refrigerants
- C4 resources guide for R290 Split Air Conditioners (as soon as published)
- Safe use of hydrocarbon refrigerants (focus on training, will be published)

Relevant publications

U4E publications:

- Country assessment

https://united4efficiency.org/country-assessments/ukraine/

Thank you for your attention !

Contact : regina.karakina@heat-international.de
www.heat-international.de
Twitter @HEAT_GmbH