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AND ARCHITECTURE

INDUSTRIËLE WARMTEPOMPEN,

TOEKOMSTMUZIEK OF NU AL RELEVANT?

Steven Lecompte, Elias Vieren, Kenny Couvreur

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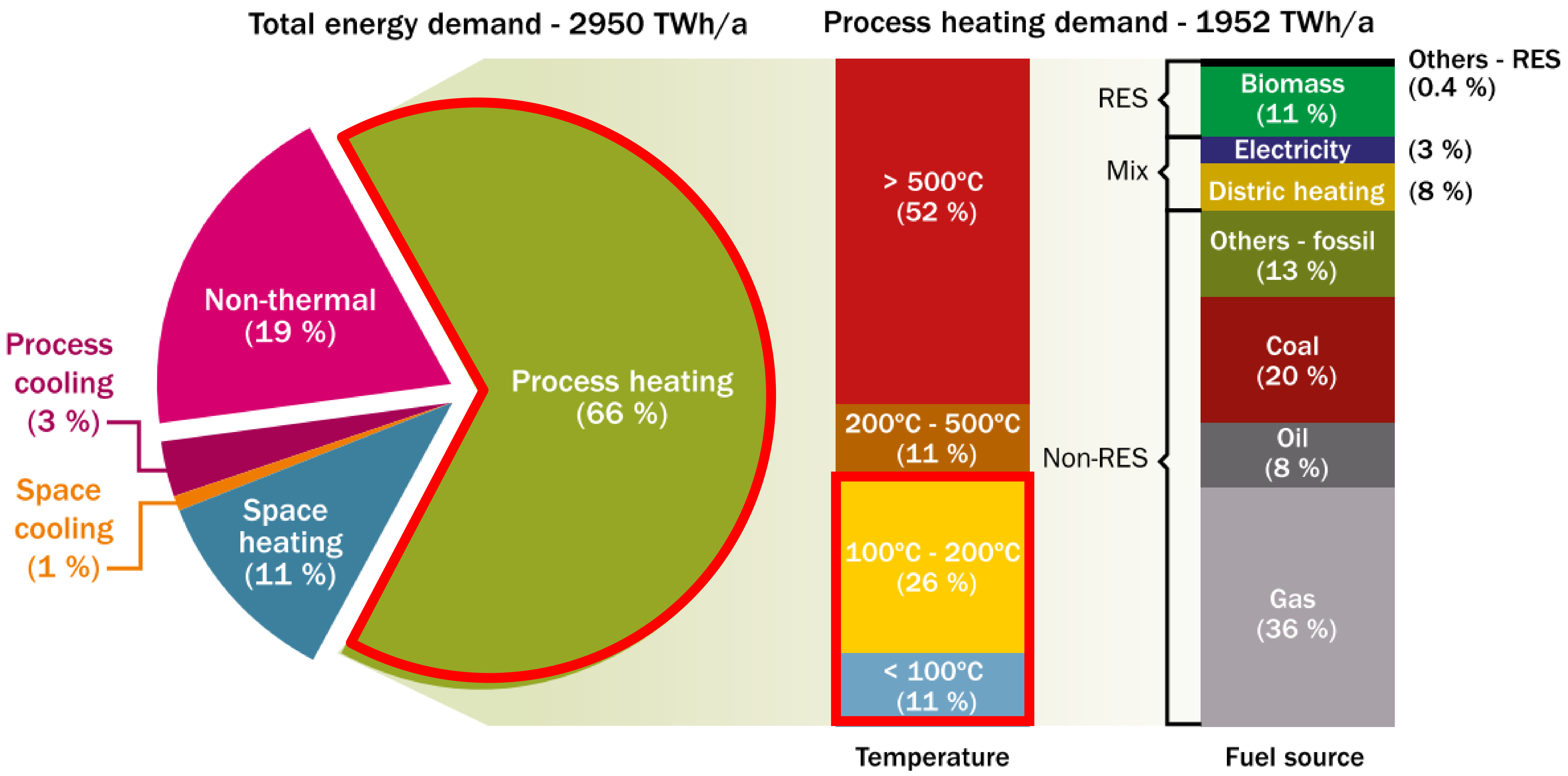
INDUSTRIAL ENERGY DEMAND IN EUROPE



De Boer et al. (2020)
HeatRoadMap (EU 2015)

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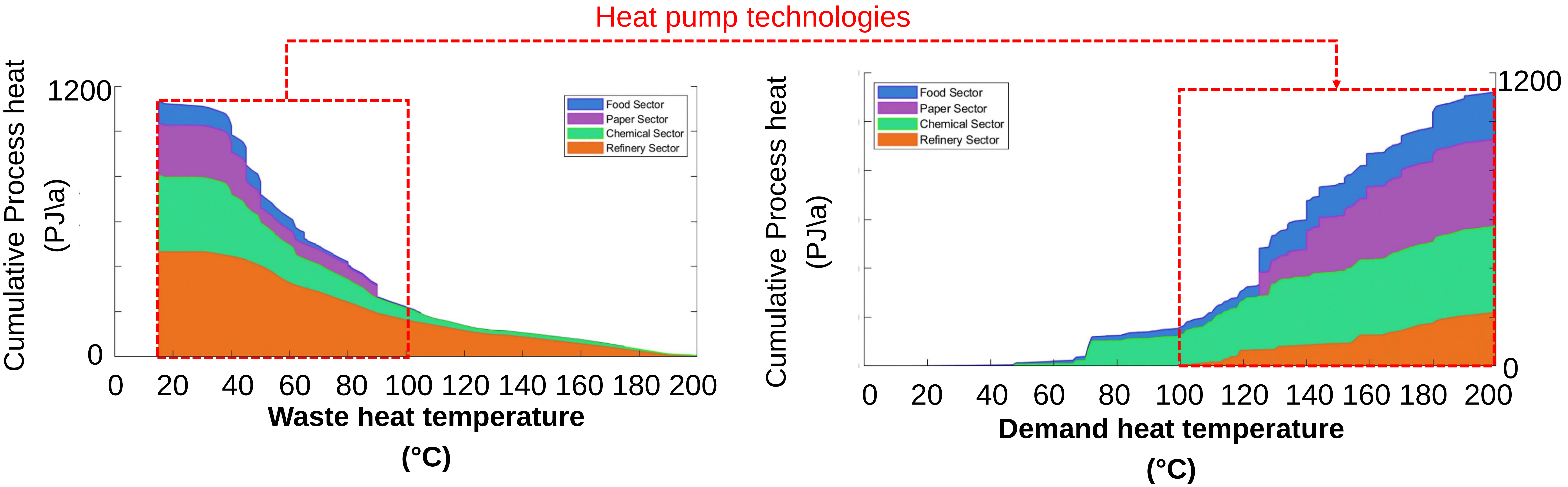
MATCHING COOLING (RESIDUAL HEAT) AND HEATING



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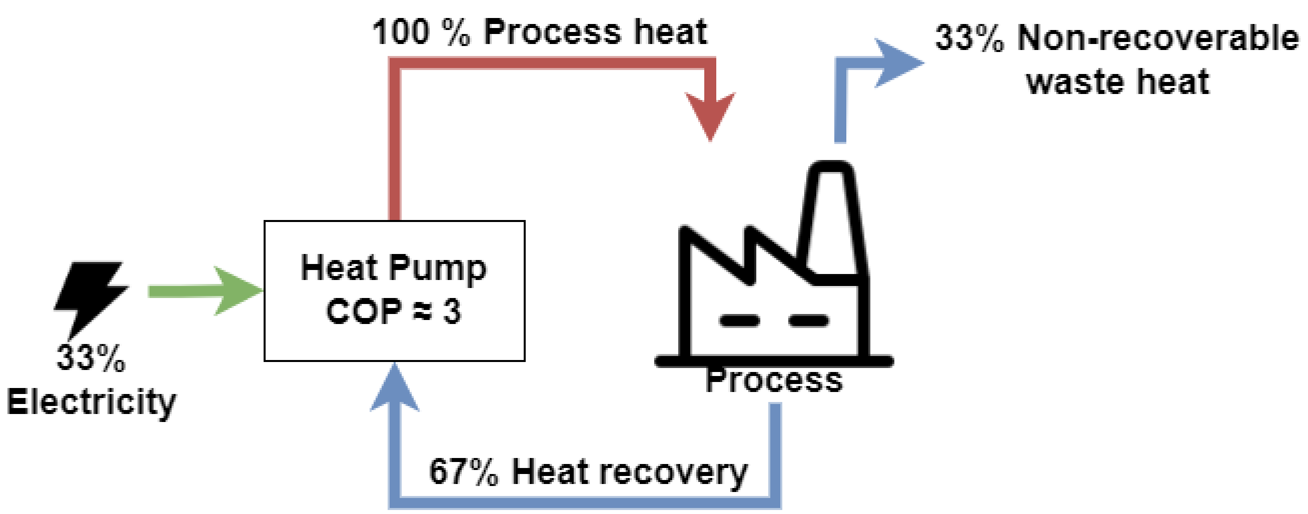
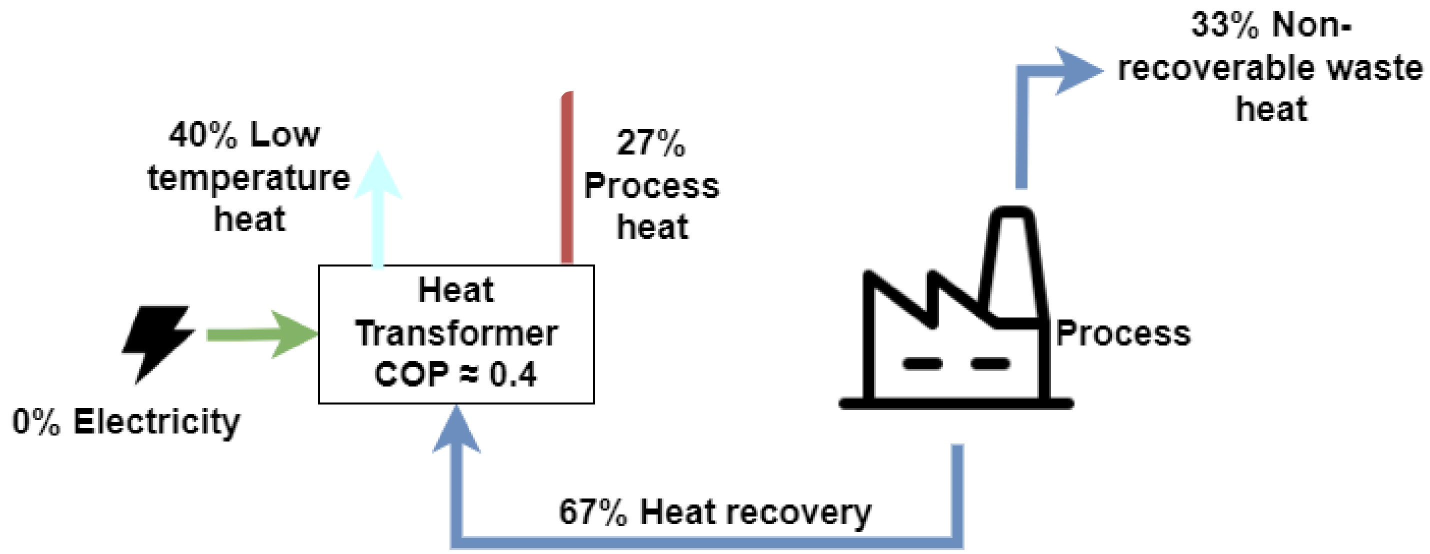
Marina et al. (2021)

HEAT PUMP TECHNOLOGIES POTENTIAL

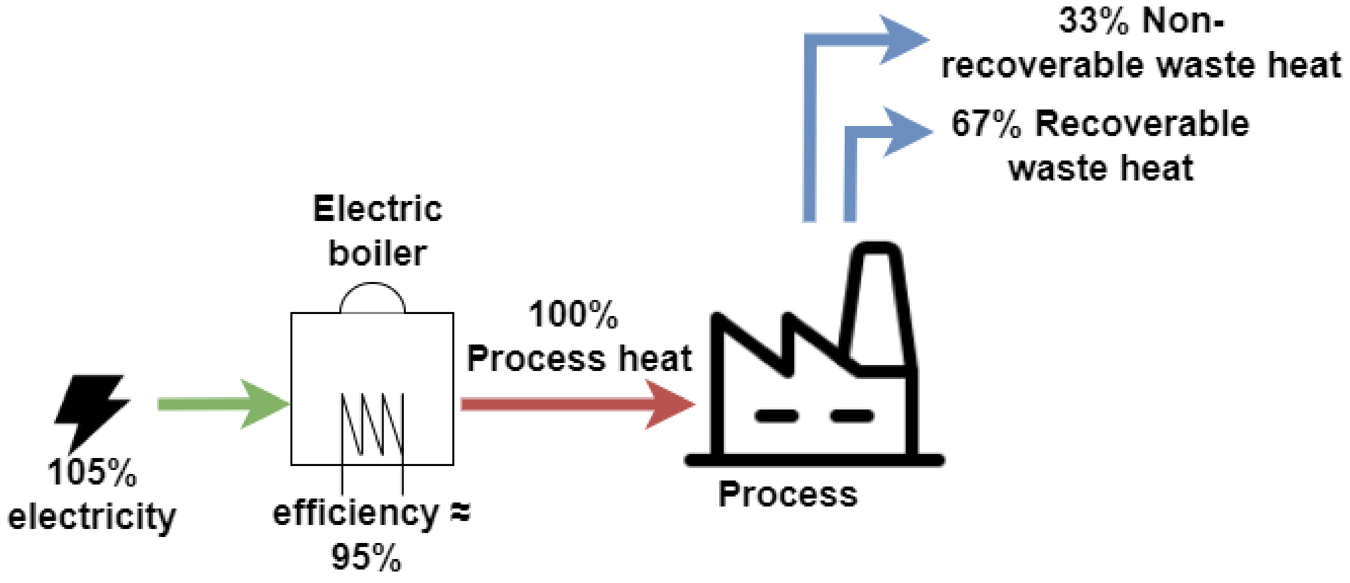
Vapour compression heat pump (CAPEX: $$$)



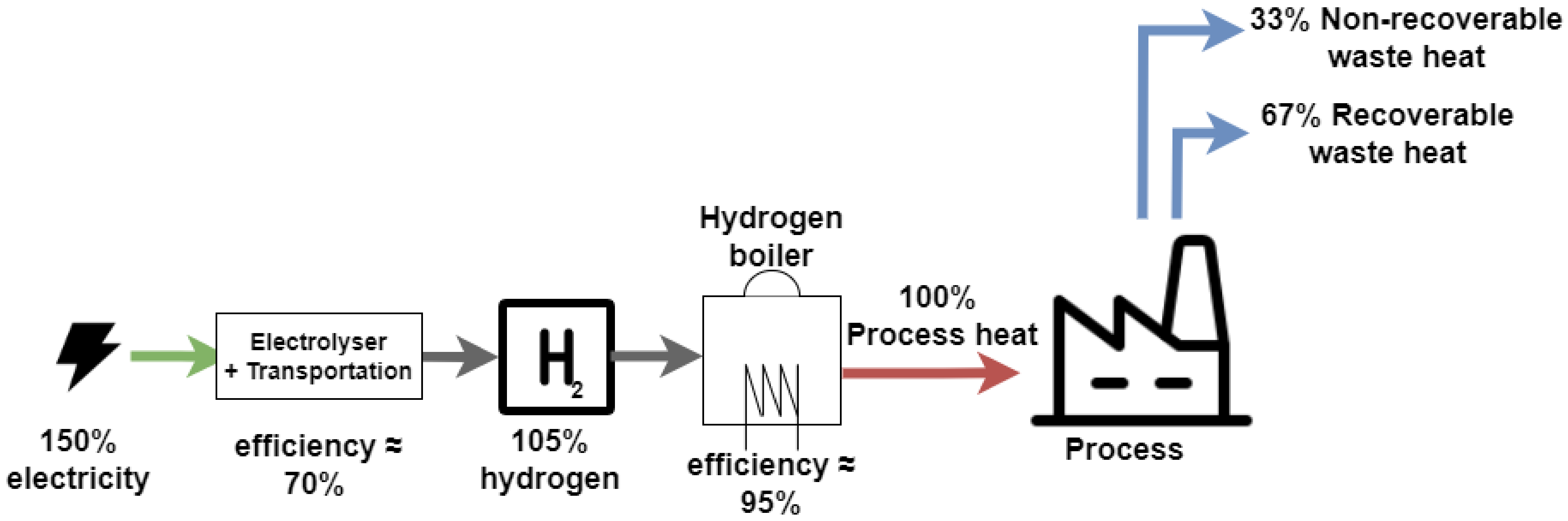
Heat transformer (CAPEX: $$$$)



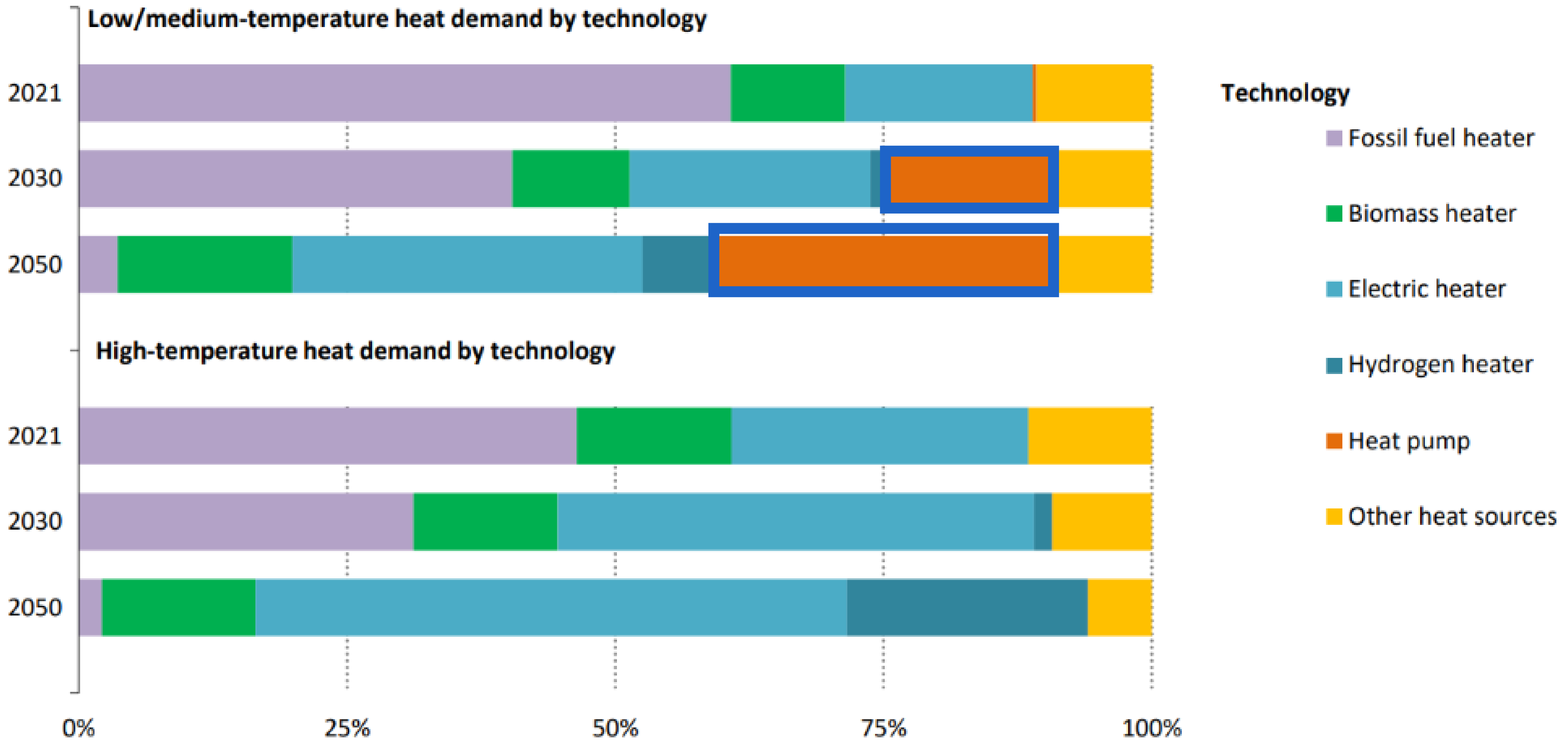
Electric boiler (CAPEX: $)



Hydrogen boiler (CAPEX: $$)



POSSIBLE SCENARIO (IEA)



Net Zero By 2050, IEA

Additional 500 MW installed capacity each month
over the next 30 years!

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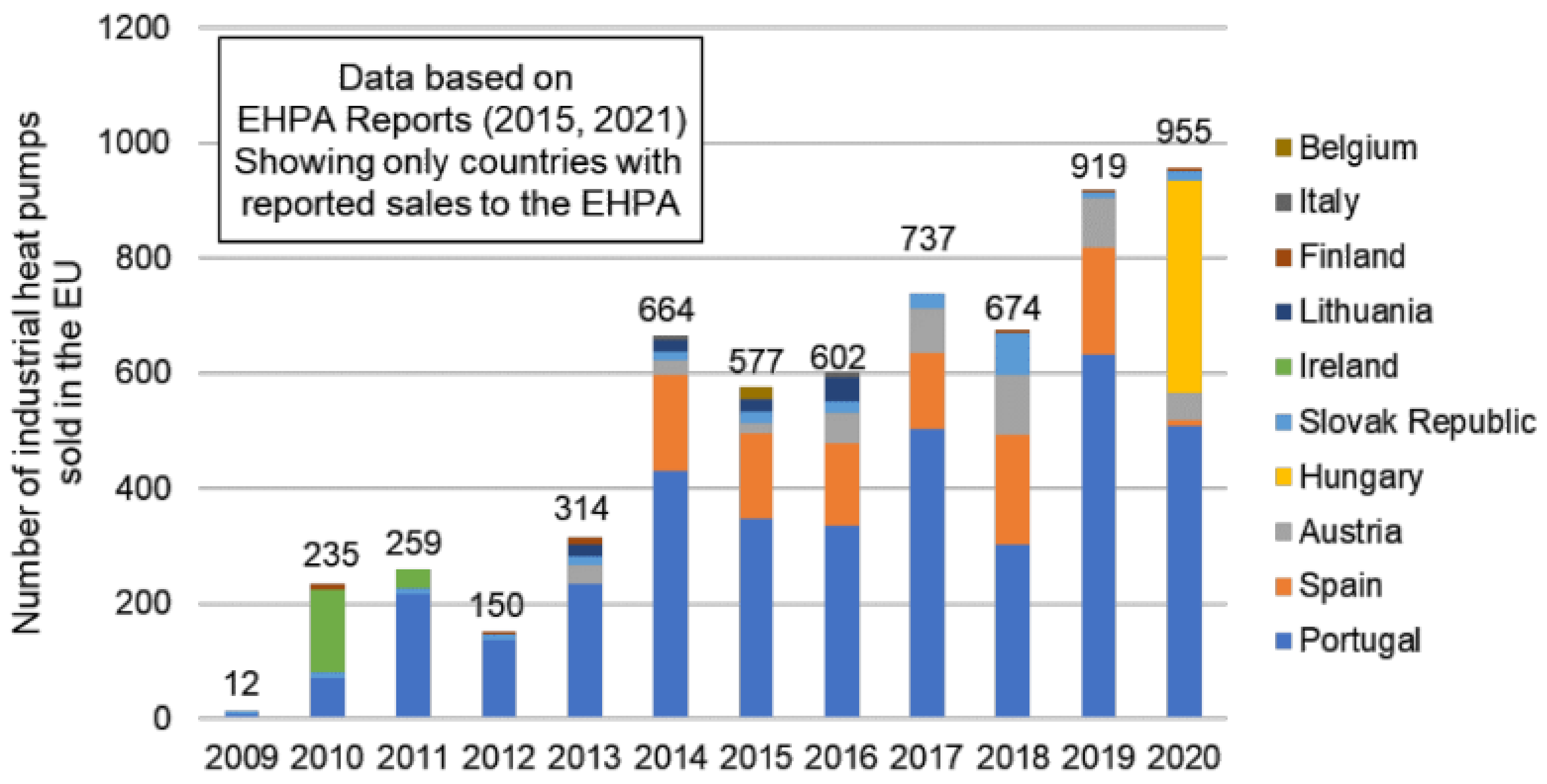
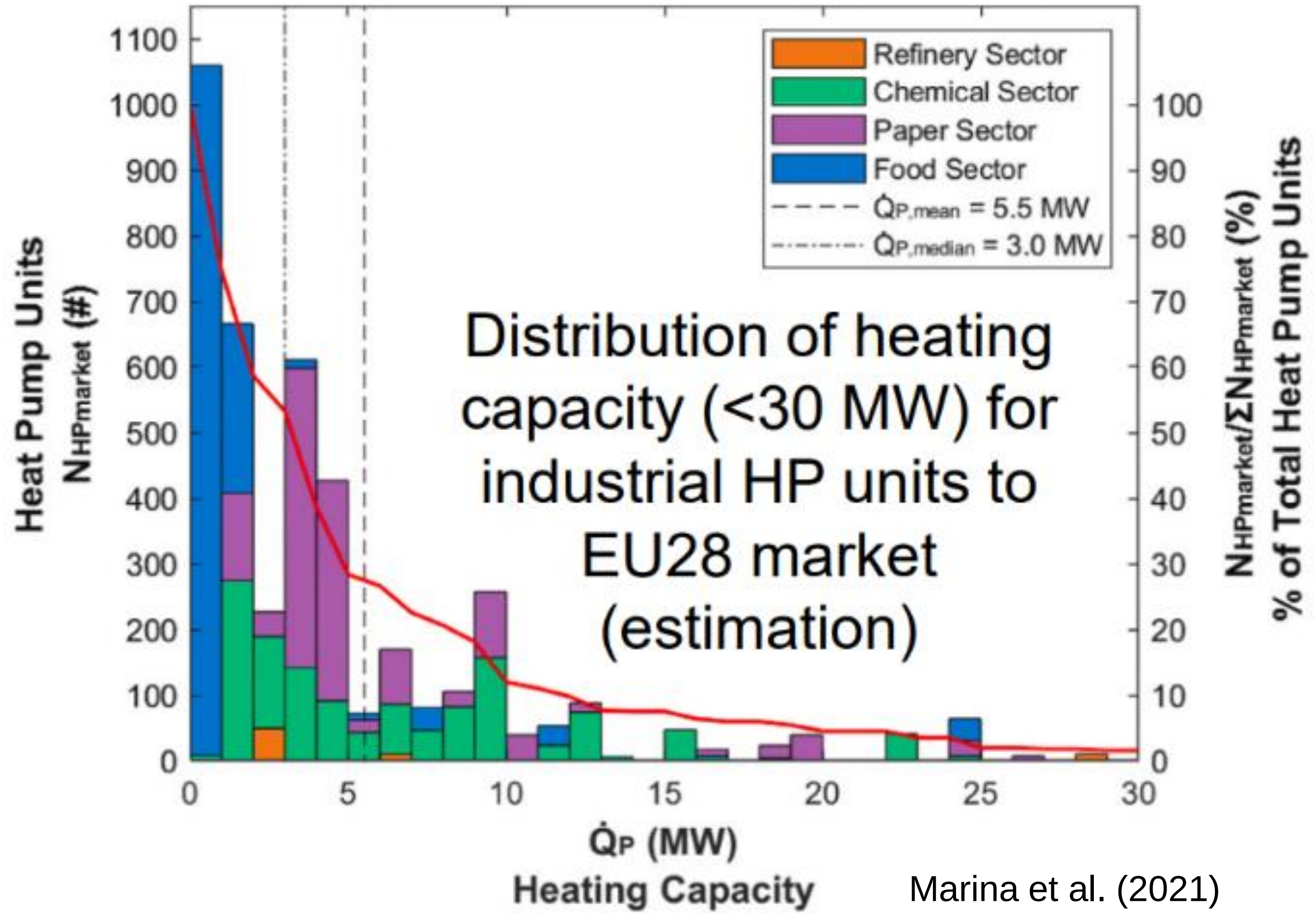
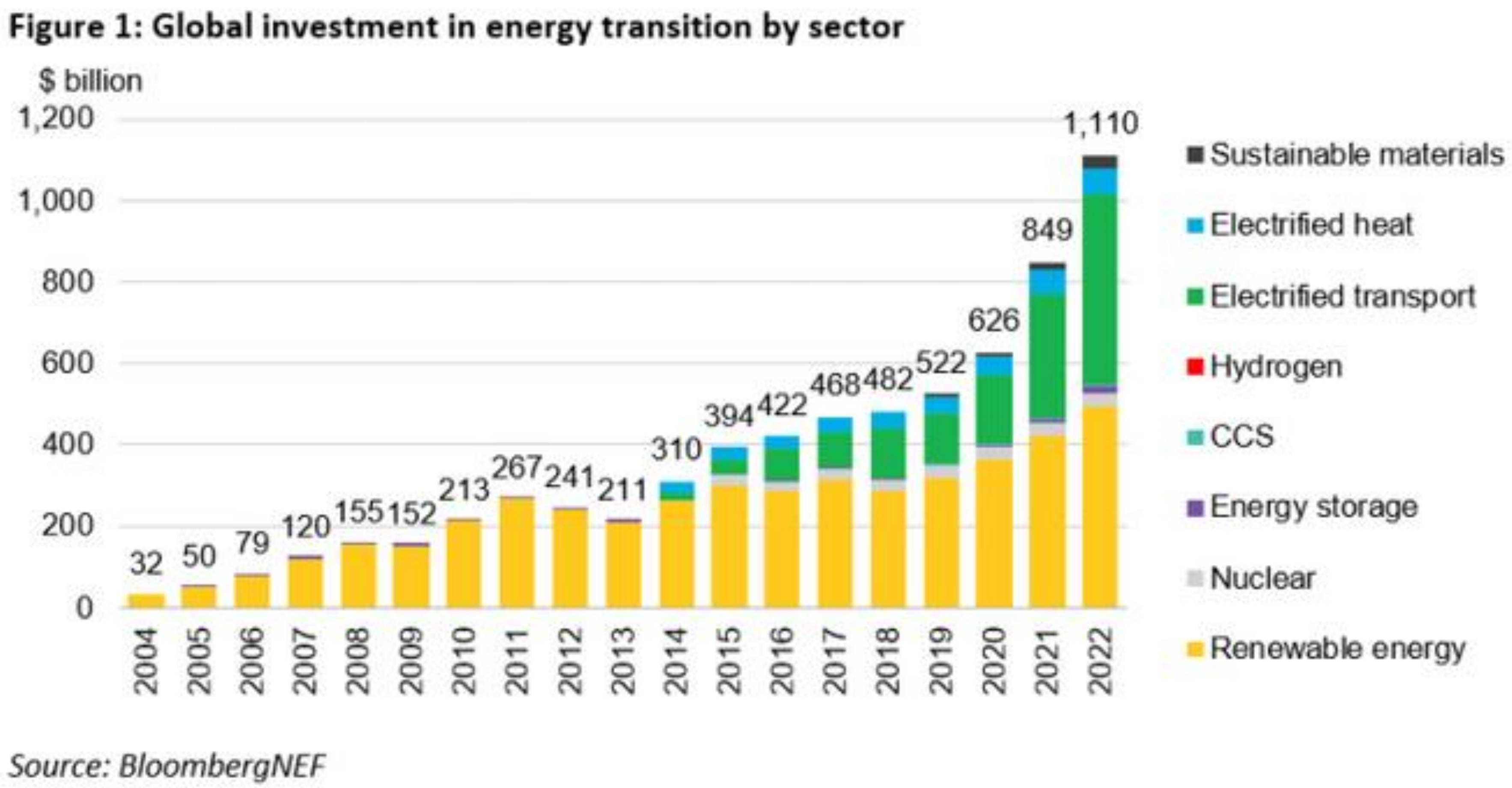
SALE STATISTICS





Marina et al. (2021)

WHAT'S THE MARKET POTENTIAL?



The Next Half-Trillion-Dollar Market

Electrification of Heat

[BloombergNEF]

2030

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ZOOMING IN ON APPLICATIONS

Sector	Process	Temperature [°C]
Paper	Drying	90 -240
	Boiling	110 - 180
	Bleaching	40 - 150
	De-inking	50 - 70
Food & beverages	Drying	40 - 250
	Evaporation	40 - 170
	Pasteurization	60 - 150
	Sterilization	100 - 140
	Boiling	70 - 120
	Distillation	40 - 100
	Blanching	60 - 90
	Scalding	50 - 90
	Concentration	60 - 80
	Tempering	40 - 80
	Smoking	20 - 80
Chemicals	Destillation	100 - 300
	Compression	110 - 170
	Thermoforming	130 - 160
	Concentration	120 - 140
	Boiling	80 - 110
	Bioreactions	20 - 60
Automotive	Resin molding	70 - 130
Metal	Drying	60 - 200
	Pickling	20 - 100
	Degreasing	20 - 100
	Electroplating	30 - 90
	Phosphating	30 - 90
	Chromating	20 - 80
	Purging	

Sector	Process	Temperature [°C]
Plastic	Injection modling	90 - 300
	Pellets drying	40 - 150
	Preheating	50 - 70
Mechanical engineering	Surface treatment	20 - 120
	Cleaning	40 -90
Textiles	Coloring	40 - 160
	Drying	60 - 130
	Washing	40 - 110
	Bleaching	40 - 100
Wood	Glueing	120 - 180
	Pressing	120 - 170
	Drying	40 - 150
	Steaming	70 - 100
	Cocking	80 - 90
	Staining	50 - 80
	Pickling	40 - 70
Several sectors	Hot water	20 - 110
	Preheating	20 - 100
	Washing/Cleaning	30 - 90
	Space heating	20 - 80

Technology Readiness Level (TRL):

- conventional HP < 80°C, established in industry
- commercial available HP 80 - 100°C, key technology
- prototype status, technology development, HTHP 100 - 140°C
- laboratory research, functional models, proof of concept, VHTHP > 140°C

Deep Dive Application Potential by C. Arpagaus

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RECENT REPORTS

Decarbonizing Low-Temperature Industrial Heat In The U.S.

October 20, 2022

ENERGY INNOVATION
POLICY & TECHNOLOGY LLC®

Share

Industrial facilities use low-temperature heat (up to 165 degrees Celsius) in numerous manufacturing processes, contributing 3.5 percent of U.S. energy-related carbon emissions. New Energy Policy Simulator modeling finds shifting from fossil fuel combustion to industrial heat pumps for low-temperature process heat would reduce industry emissions by 5 percent in 2030 and 16 percent in 2050, while adding $42 billion to the economy in 2030 and $8 billion in 2050 and creating 275,000 jobs in 2030 and around 75,000 jobs in 2050. This report recommends federal policies to accelerate the deployment of industrial heat pumps in the U.S., including financial support for research and development and efficiency standards.

Breaking free from fossil gas

A new path to a climate-neutral Europe

STUDY

Agora Energiewende

Heat pumps are considered to be the major pillar for the supply of low temperature process heat to industry, and the major lever in decarbonising the less energy-intensive industries, which in most cases are not integrated into heavy industry clusters. This

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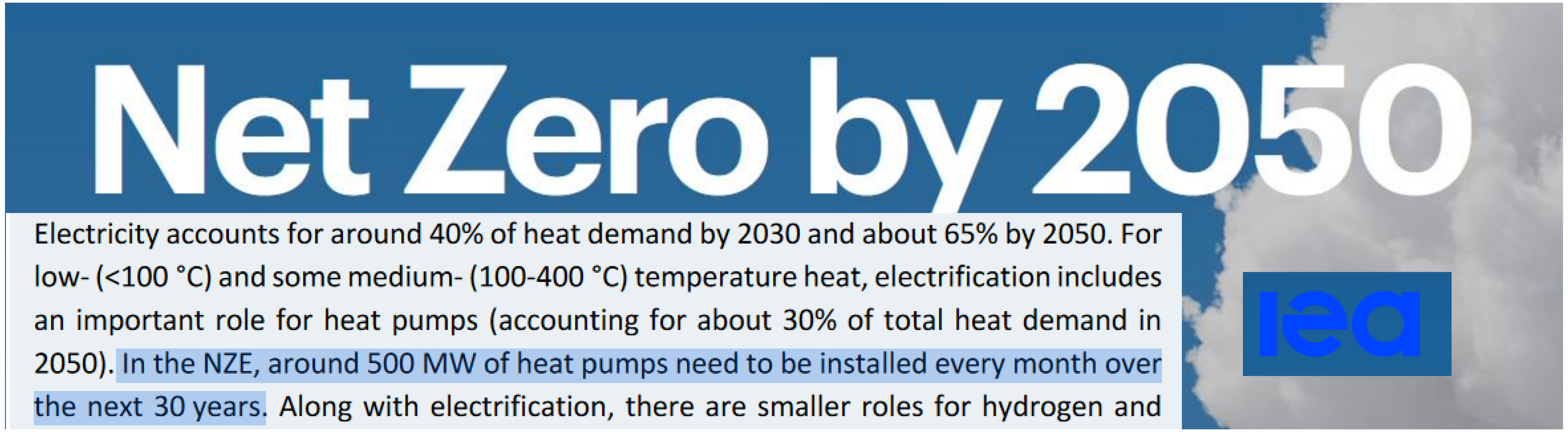
RECENT REPORTS

wbcsd

Heat pumps are a great starting point for decarbonizing industrial heat because they are easily scalable and have superior efficiencies, particularly in light industry, where there are typically lower temperature heating requirements.



Electricity accounts for around 40% of heat demand by 2030 and about 65% by 2050. For low- (<100 °C) and some medium- (100-400 °C) temperature heat, electrification includes an important role for heat pumps (accounting for about 30% of total heat demand in 2050). In the NZE, around 500 MW of heat pumps need to be installed every month over the next 30 years. Along with electrification, there are smaller roles for hydrogen and

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WHAT'S THE CATCH?

- Unfavorable electricity / fossil-fuel price ratio
  - To be competitive: US: $10/MWhe, EU: $24/MWhe [BloombergNEF]
  - Large variability!
- Insufficient grid capacity
  - Storage solutions
  - Projected growth similar as between 1990 and 2007 [Transformation of Europe's power system until 2050, McKinsey]
- Low technology readiness
  - Technology status and perspectives, Jonas Lundstedt Poulsen
- Insubstantial policy incentives

ELECTRICITY / FOSSIL-FUEL PRICE RATIO

	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**

Deep Dive Application Potential by C. Arpagaus

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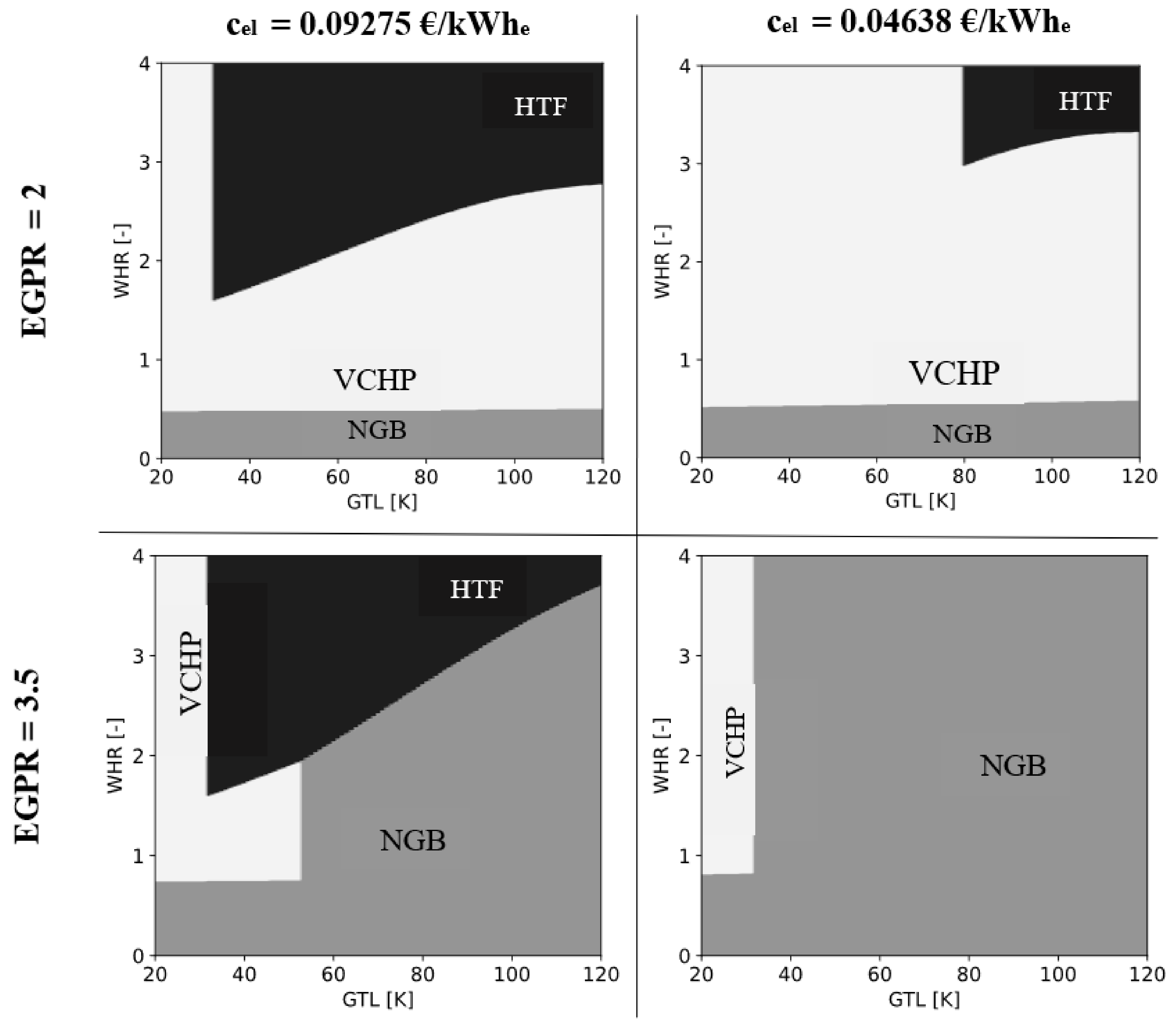
ELECTRICITY / FOSSIL-FUEL PRICE RATIO



HTF: Heat transformer
VCHP: Vapour compression heat pump
NGB: Natural gas boiler
EGPR: Electricity to gas price ratio = $\frac{c_{el}}{c_{ng}}$
WHR: Waste heat ratio = $\frac{\dot{Q}_{residual}}{\dot{Q}_{process}}$
Study considers electric heater when not sufficient waste heat available

Vieren et al. (2023), accepted for International Congress of Refrigeration

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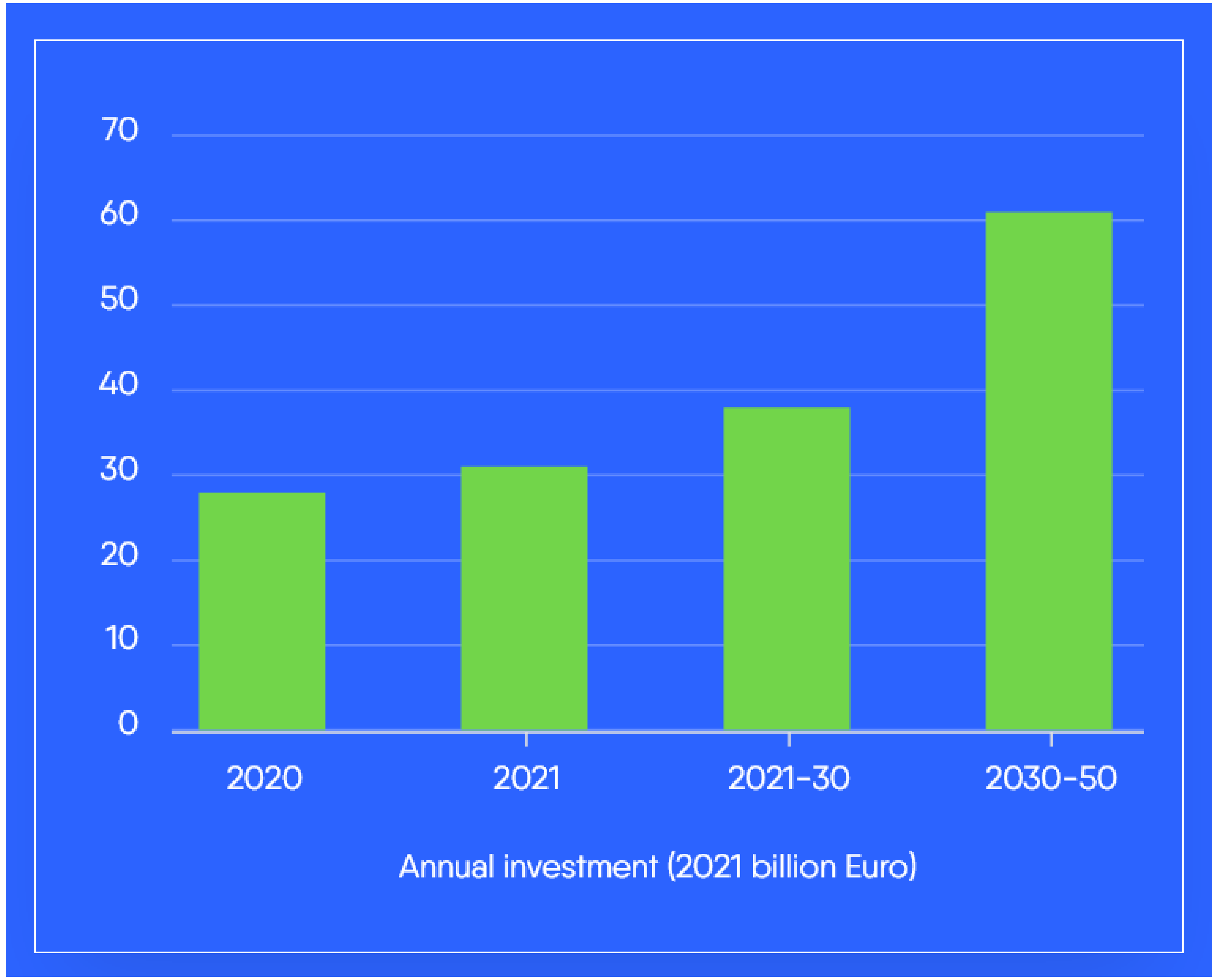
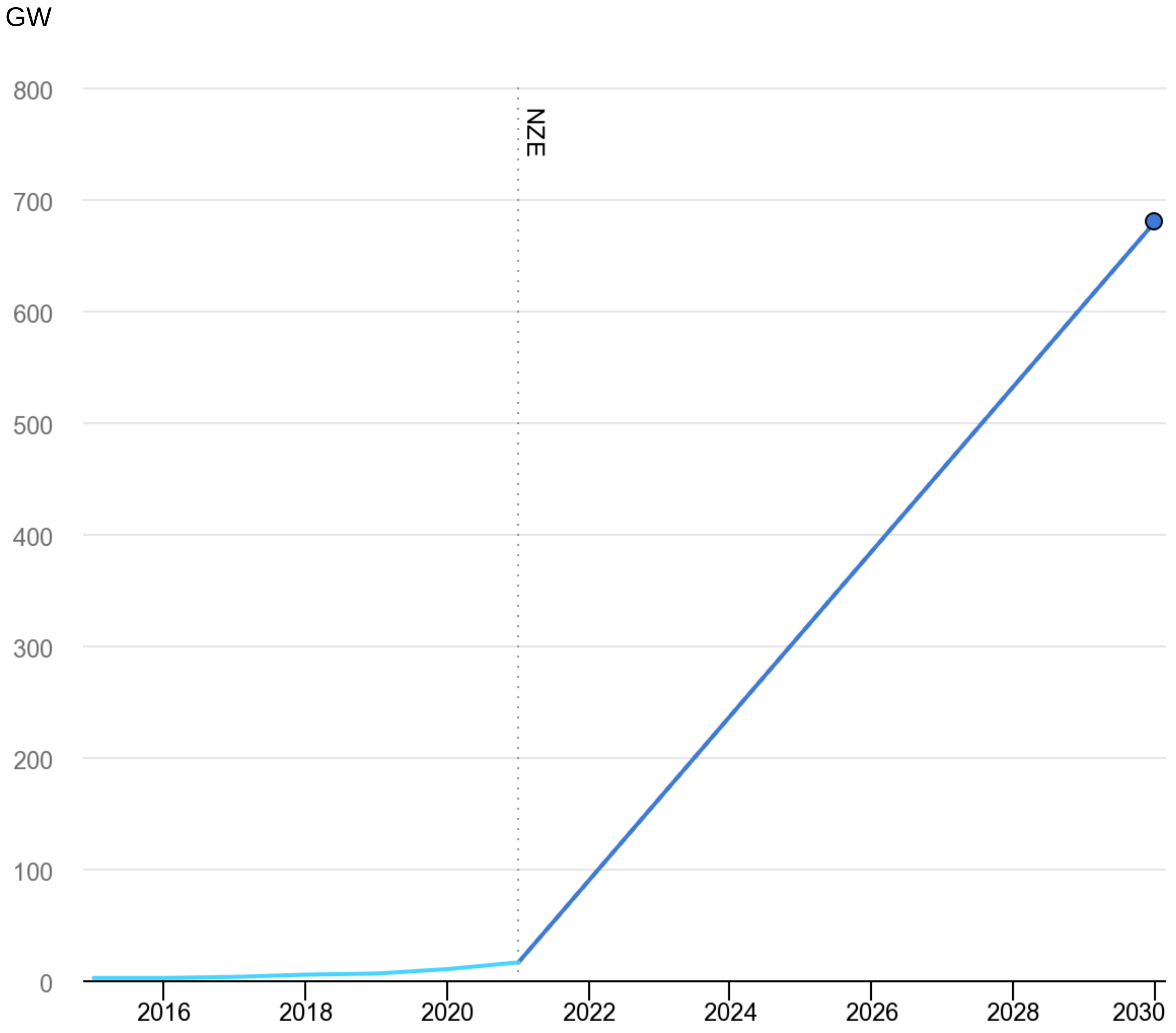
GRID CAPACITY AND RE AVAILABILITY



Powerbarometer 2022

Installed grid-scale battery storage capacity in the Net Zero Scenario



IEA

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TECHNOLOGY READINESS

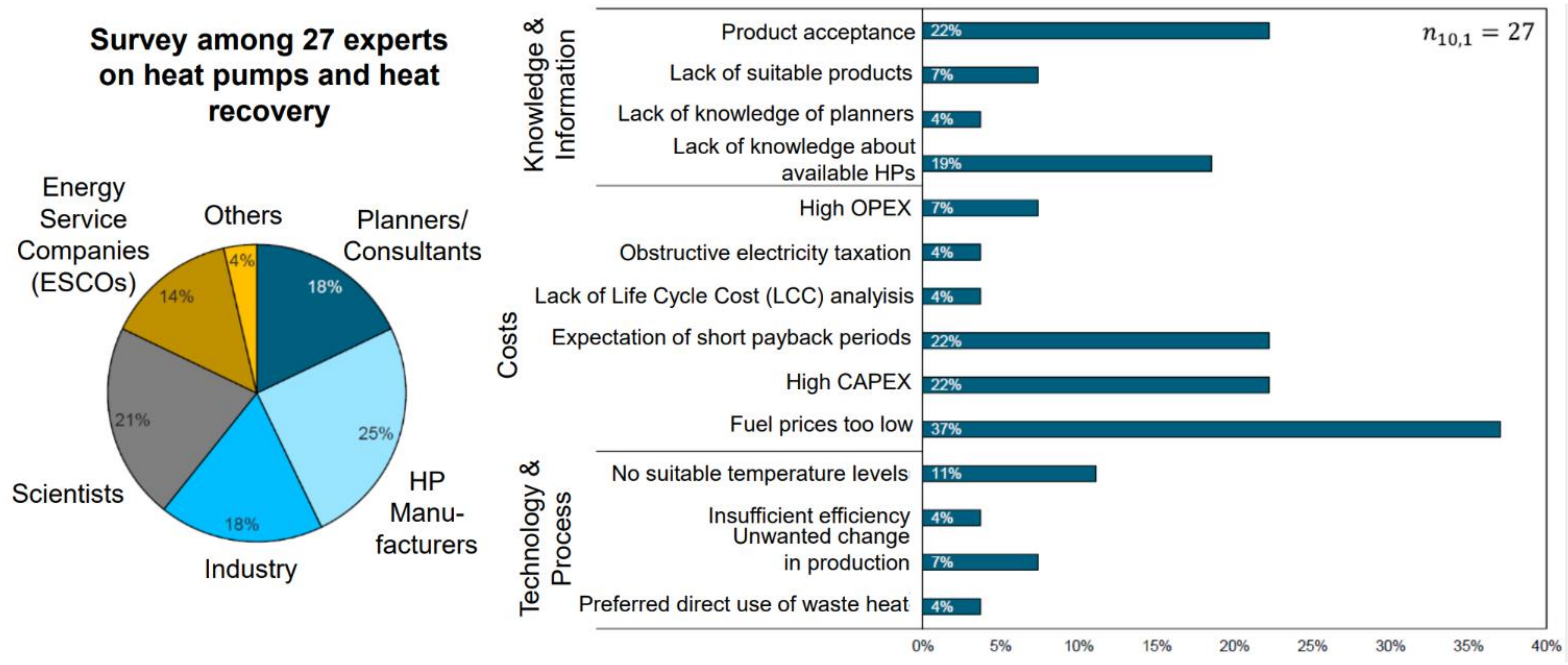
Temperature range	Technology readiness level (TRL)	Example process
<80 °C	TRL 11: Proof of market stability	Paper: De-inking Food: Concentration Chemical: Bio-reactions
80 °C to 100 °C	TRL 10: Commercial and competitive, but large-scale deployment not yet achieved	Paper: Bleaching Food: Pasteurisation Chemical: Boiling
100 °C to 140 °C	TRL 8-9: First-of-a-kind commercial applications in relevant environment	Paper: Drying Food: Evaporation Chemical: Concentration
140 °C to 160 °C	TRL 6-7: Pre-commercial demonstration	Paper: Pulp boiling Food: Drying Chemical: Distillation Various industries: Steam production
160 °C to 200 °C	TRL 8-9: First-of-a-kind commercial applications for small-scale MVR systems and heat transformers TRL 4-5: Early to large prototype	Various industries: High-temperature steam production
>200 °C	TRL 4: Early prototype	Various industries: High-temperature processes

Readiness level: TRL 1 to 5 TRL 6 to 7 TRL 8 to 11

Notes: MVR = mechanical vapour recompression. TRLs can vary for specific processes or different heat pump capacities.

Sources: Representation using the IEA extended TRLs (IEA, 2020b) based on Maruf et al. (2022).

OTHER MARKET BARRIERS



Wolf et al (2017, 2020), Deep Dive Application Potential by C. Arpagaus

POLICY

European Commission

EU Heat Pump Action Plan

There is an urgency to switch to renewable efficient heating and cooling technologies in buildings, industry, and networks. The 2022 Commission report on the competitiveness of clean energy technologies indicates that the deployment of all kinds of heat pumps (from single-family houses to large multi-apartment, tertiary buildings and heat network heat pumps to high-temperature heat pumps for industrial applications) is necessary to meet our reinforced climate objectives. However,

- EU RED III: art. 22:
  Increase alternatives to fossil-fuel based energy use in industry
  End fossil fuel use for processes up to 200°C by 2027
- EU EED: Member States shall remove regulatory barriers
  for waste heat utilization and data centers with a total
  rated energy input exceeding 100 kW shall use waste heat
  or waste heat recovery applications
- EU EED 2022, art. 23: heating and cooling plans

CONCLUSION

‘There is a huge potential, but that it requires an immediate, common and interdisciplinary effort to exploit the full potential’

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MARKET POTENTIAL EU

Market potential up to 200°C

	Cumulative Heating Capacity (GW)	EU28 Heat Pump Units (#)	Heat Pump Process Heat Coverage (PJ/a)	Electricity Requirement (PJ/a)
Paper	7.9	1351	245	94
Chemical	9.1	1291	283	65
Food	5.5	1463	98	31
Refining	0.5	69	14	6
	23	4174	641	195

An estimation of the EU industrial heat pump market potential, TNO, 2022

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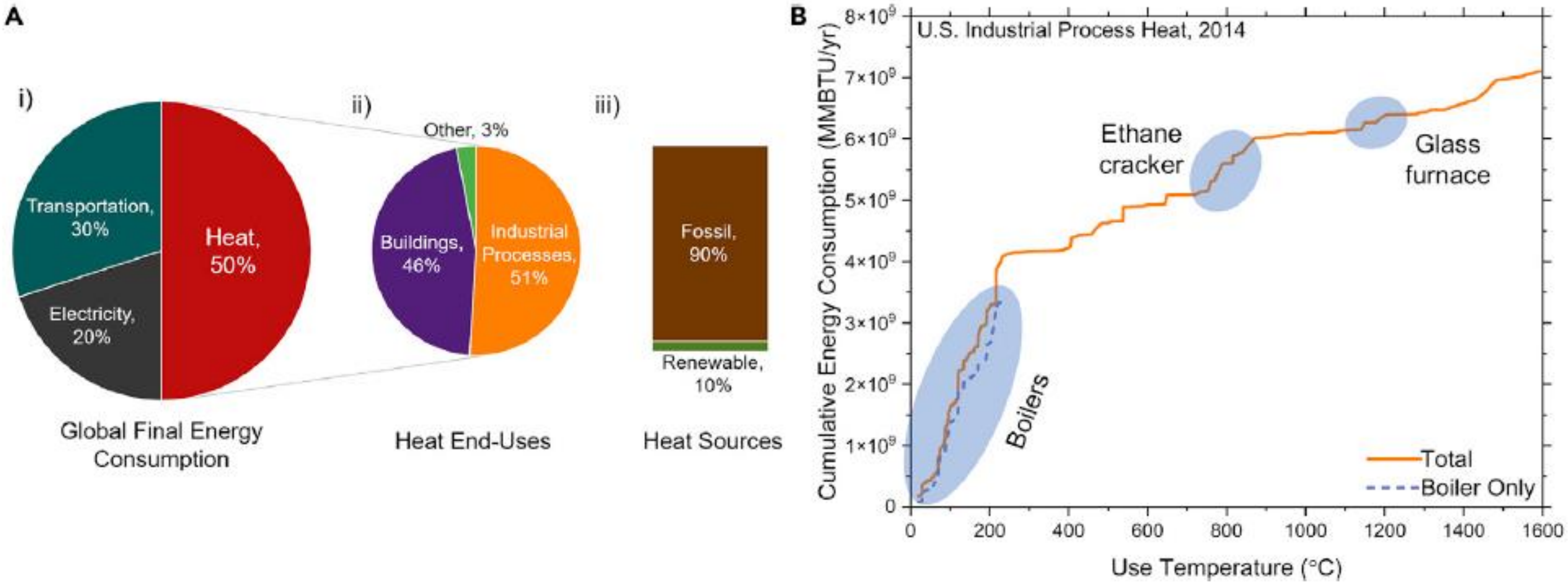
GLOBAL FINAL ENERGY USE US



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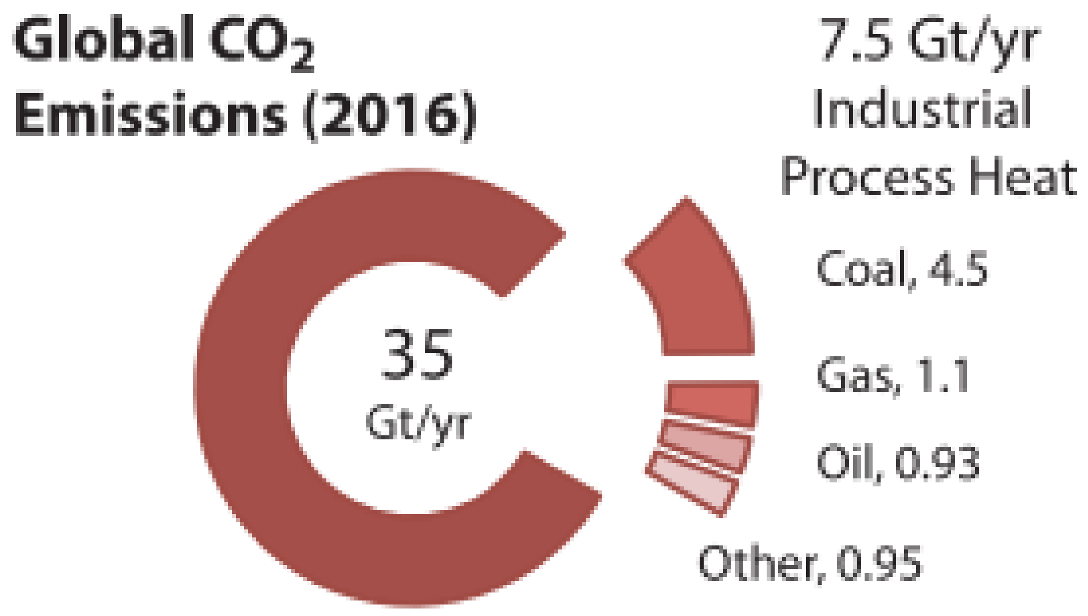
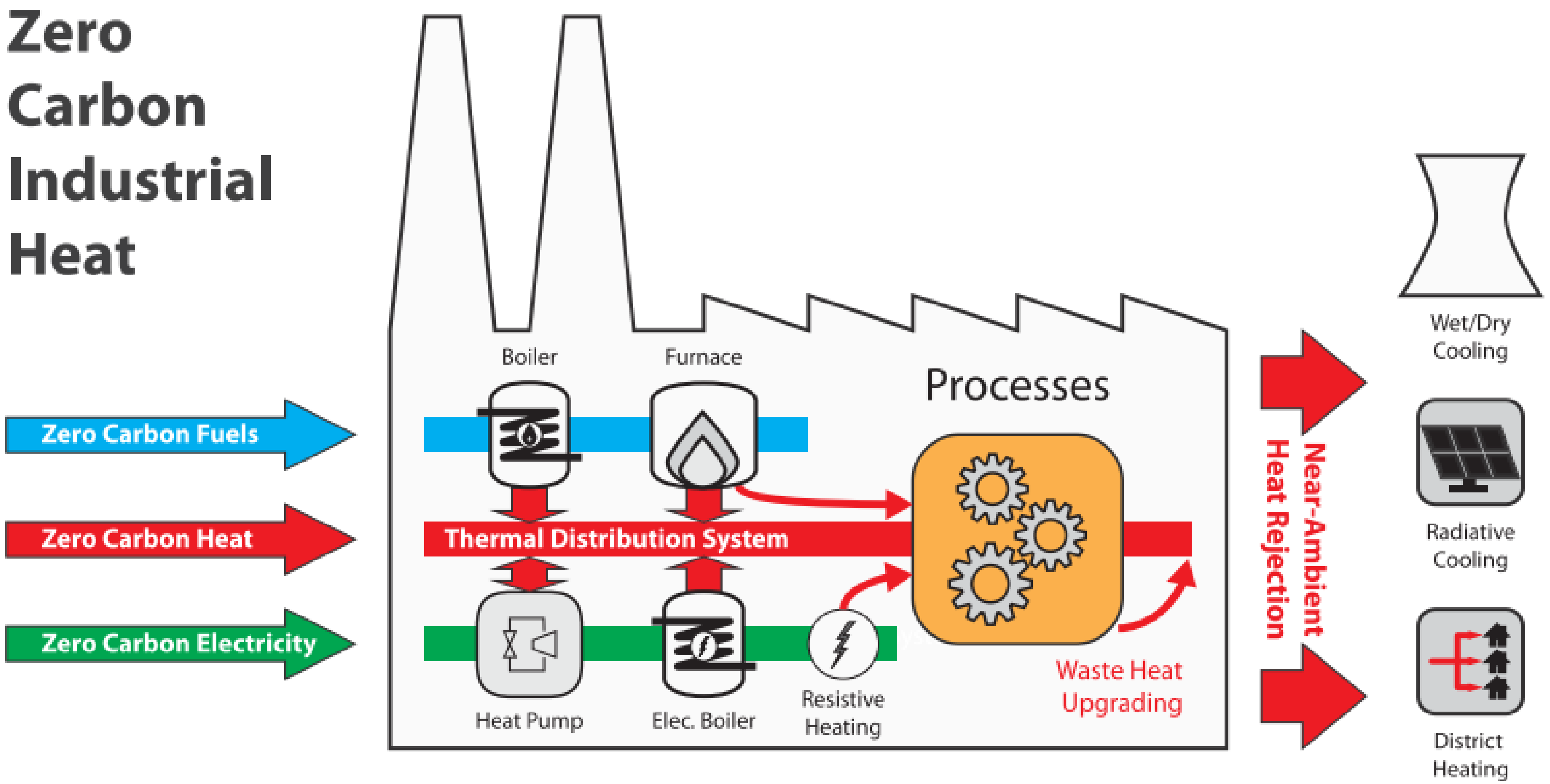

Global CO_2
Emissions (2016)
35
Gt/yr
7.5 Gt/yr
Industrial
Process Heat
Coal, 4.5
Gas, 1.1
Oil, 0.93
Other, 0.95

The decarbonize industry: we must decarbonize heat.
Pathways to decarbonize heat
(1) zero-carbon fuels,
(2) zero-carbon heat sources,
(3) electrification of heat,
(4) better heat management.



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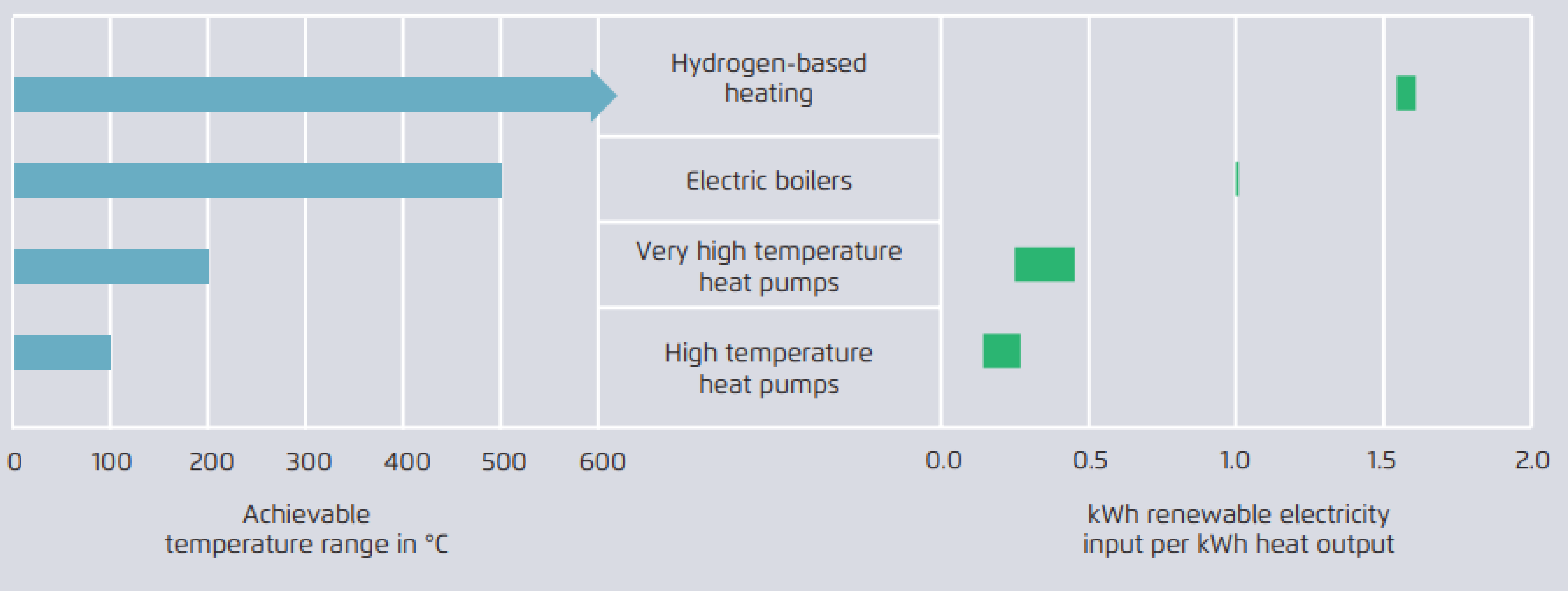

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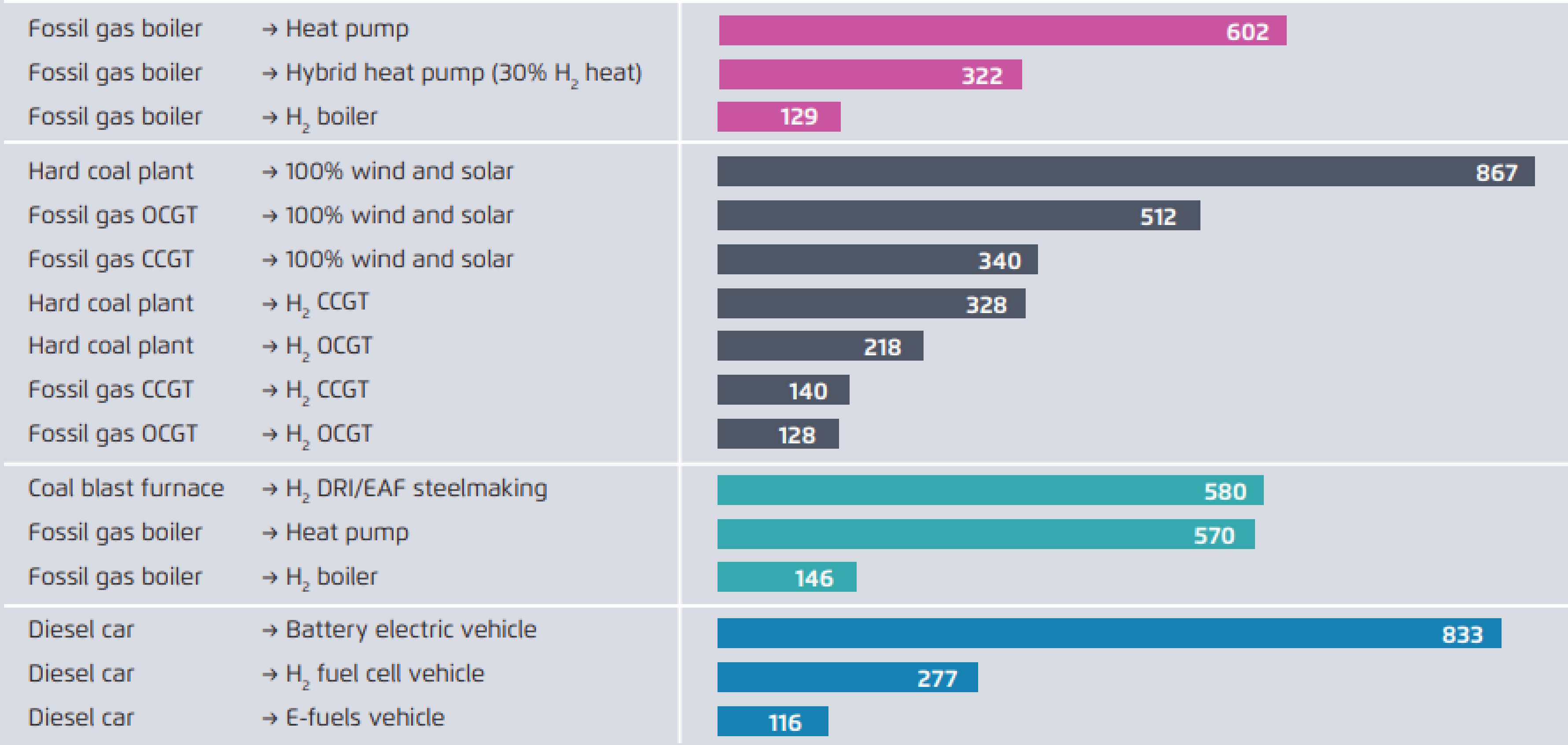
GHG emissions reductions in kg of CO_{2eq} when using 1 MWh* of renewable electricity to substitute fossil fuels in different applications

Figure 20

Technology switch | GHG savings [in kg $CO_{2 eq}$/MWh]



Efficiency assumptions

Buildings
Hybrid heat pump: 145%
(HP 450%, Boiler: 90%)
Heat pump: 300%
Boiler: 90%

Energy sector
Hard coal plant: 39%
OCGT: 39%
CCGT: 59%

Industry
BF: 2t CO_{2eq}/t steel
DRI/EAF: 3.4 MWh_{el}/t steel
Heat pump: 300%
Boiler: 95%

Transport
BEV: 18 KWh/100 km
Fuel cell: 0.89 kg/100 km
Diesel & E-fuels: 6 l/100km

* 1 MWh represents roughly the annual electricity production of 1 kWp solar PV
Emissions intensities (in g CO_2/kWhPE) = Hard coal (338.2), Fossil gas (200.8), Diesel (266.5)
HP = Heat pump, H_2 = Hydrogen, OCGT = Open cycle gas turbine, CCGT = Closed cycle gas turbine,
BF = Blast furnace, DRI = Directly reduced iron, EAF = Electric Arc Furnace, BEV = Battery electric vehicle

Agora Energiewende (2023)

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Why high-temperature heat pumps?

- The energy use in industry (2019): 40 % of the global CO_2 emission's
  - ➢ Mainly attributed to the demand in heat.
- Four pathways to decarbonize industrial heat [1]
  - ➢ Zero-carbon fuels
  - ➢ Zero-carbon heat sources
  - ➢ Electrification of heat
  - ➢ Better heat management

Heat pumps

Total energy demand European industry [2]: