INDUSTRIAL HEAT PUMPS

DEVELOPMENT PERSPECTIVES AND DEMONSTRATION ACTIVITIES

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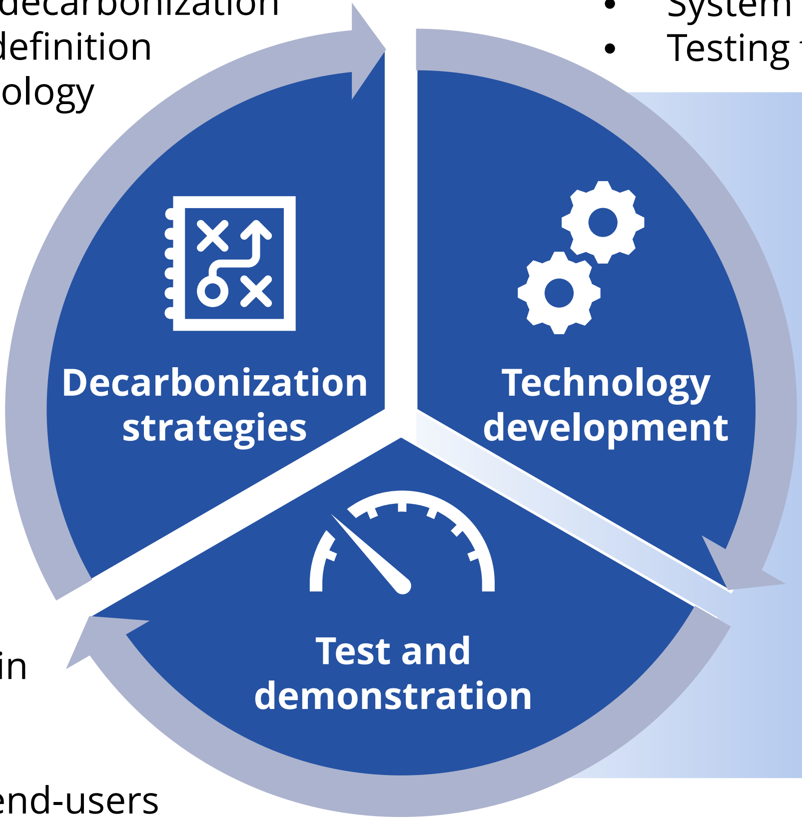
DECARBONIZATION OF INDUSTRIES AT DTI

- Holistic consultancy approach supporting process industries in their decarbonization
- Process Analysis & Target definition
- Conceptualization & Technology Overview
- Roadmap development
- Support during implementation

- Component development
- System design and optimization
- Testing function and performance



- Validation of technologies in full scale
- Industrial heat pump lab
- On-site demonstration at end-users

Technologies
- Heat pumps
- Thermal storage
- Thermal networks
- Biogas & green fuels
- Unit operations
- Electric systems
- Water recovery

Scope
- Energy
- GHG emissions
- Water
- Economy

Collaboration partners
- Technology suppliers (system manufacturers, OEMs, …)
- Process equipment manufacturers
- End-users from various industries (Food & beverage, Pulp & paper, chemicals, minerals, utilities, industry symbioses, …)

HTHP APPLICATION POTENTIAL

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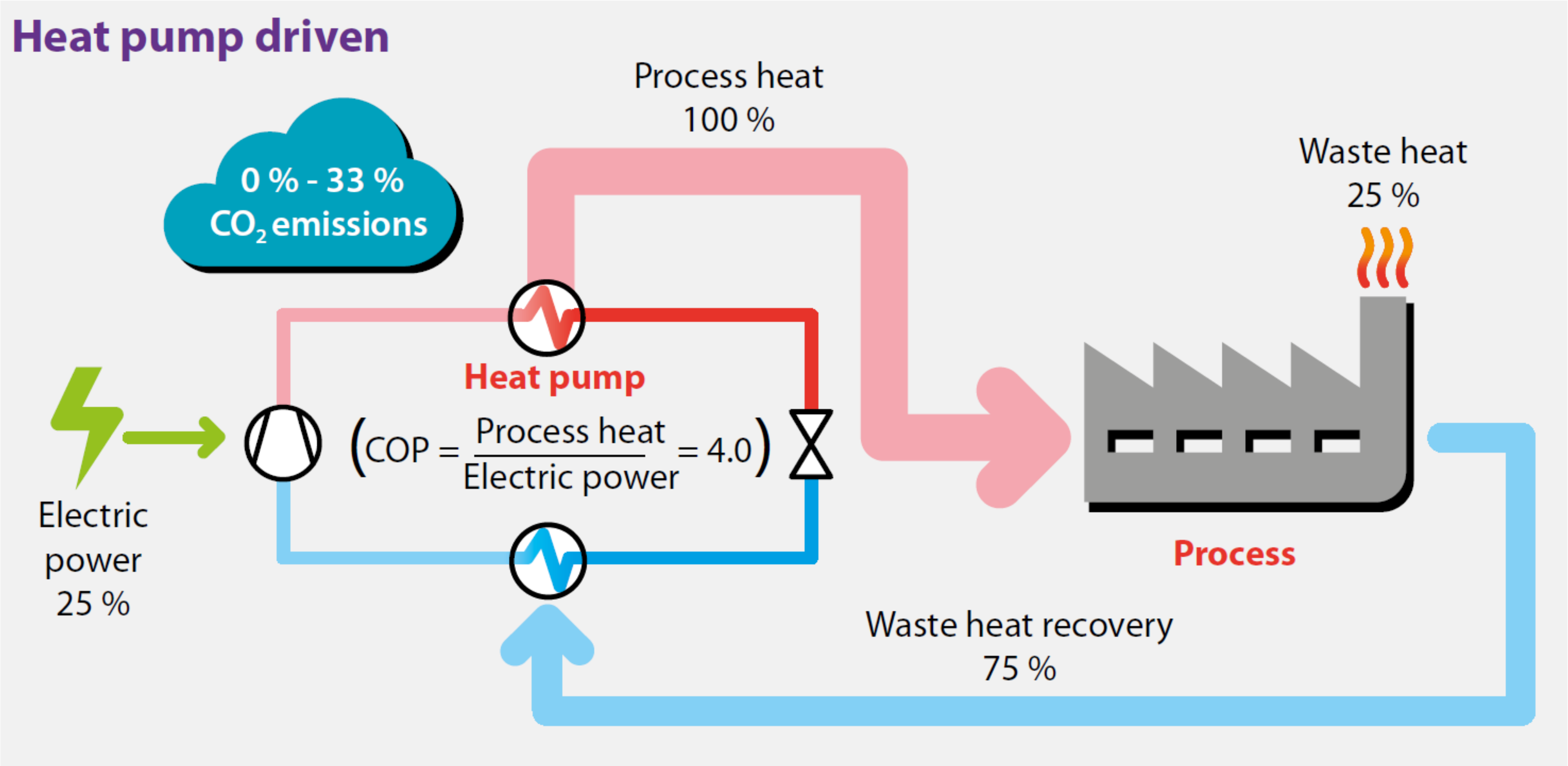
INDUSTRIAL HEAT PUMPS FUNCTIONING PRINCIPLE



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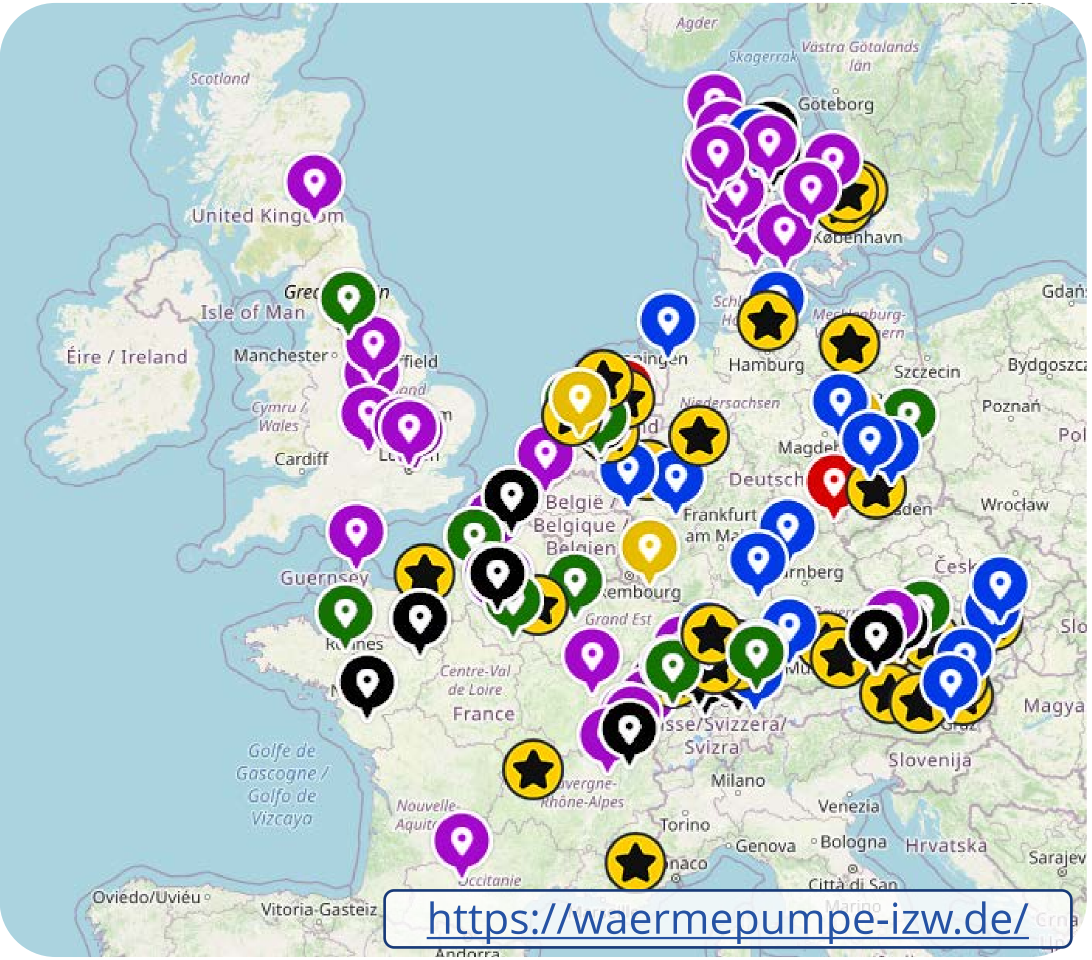
PROVEN PRINCIPLES



https://waermepumpe-izw.de/

- > 300 cases in IEA HPT Annex 48
- Proven technology < 100 °C
- Proven principles > 100 °C

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INDUSTRIAL PROCESS HEAT DEMAND – EU28

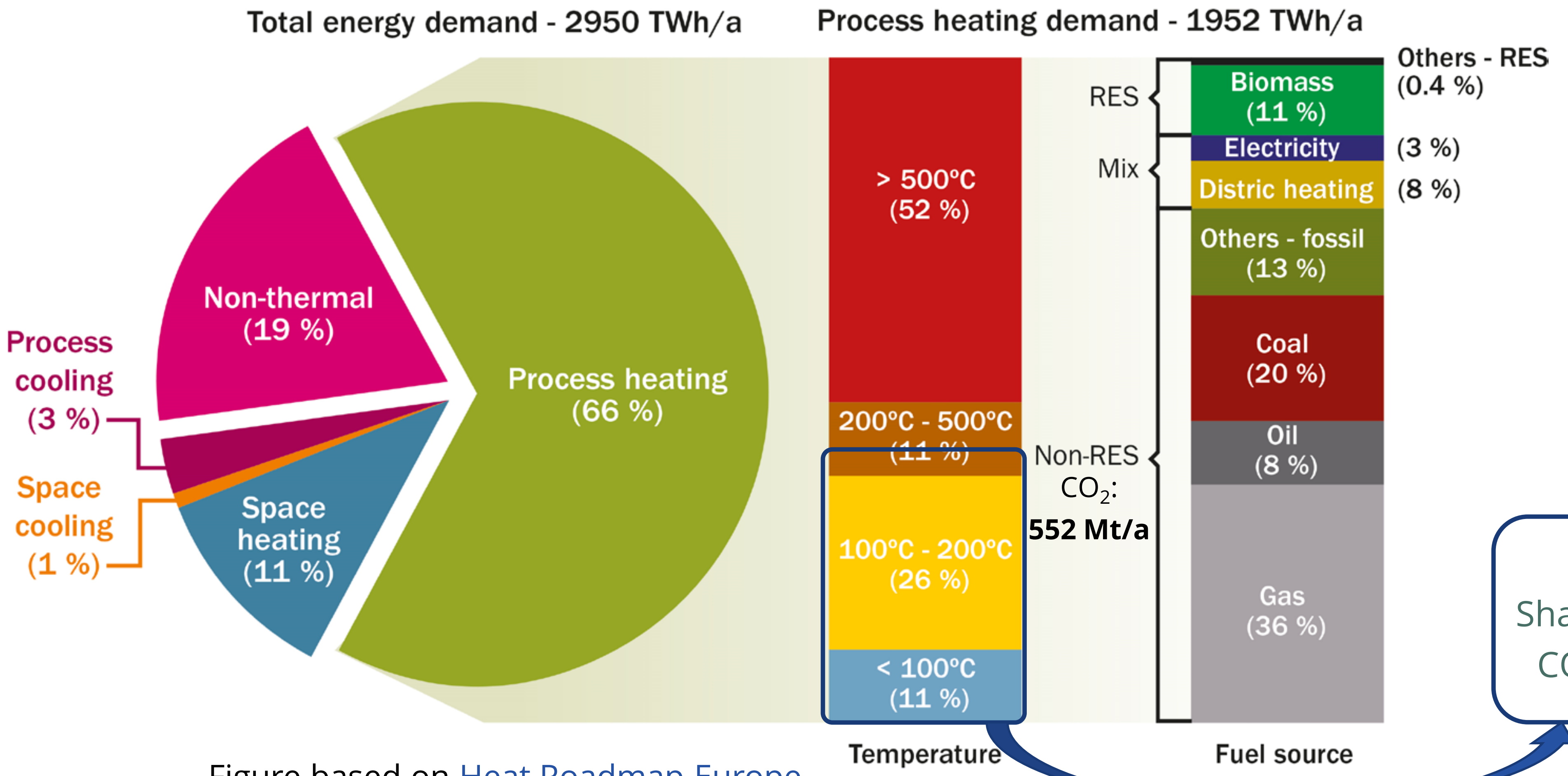
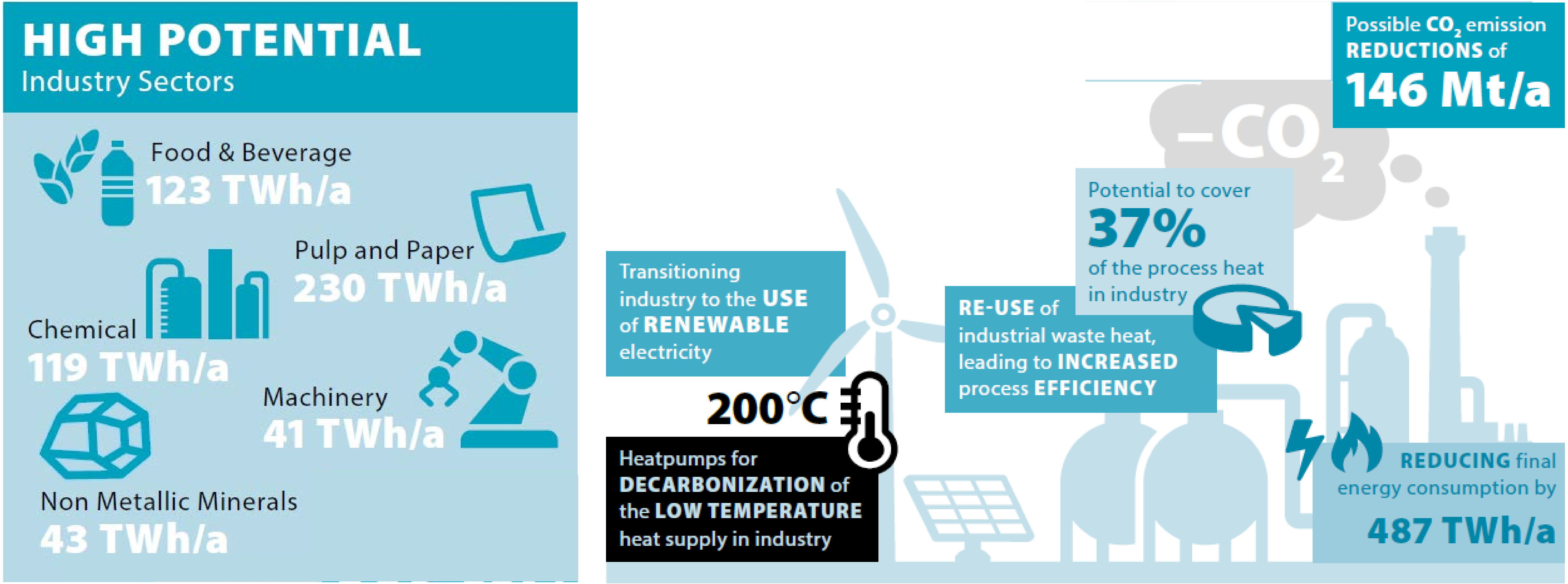


Figure based on Heat Roadmap Europe

Heat Pumps:
Share of process heat: 37 %
CO_2 emissions: 146 Mt/a

INDUSTRIAL HP APPLICATION POTENTIAL



White Paper: *Strengthening Industrial Heat Pump Innovation – Decarbonizing Industrial Heat* & *Webinar*

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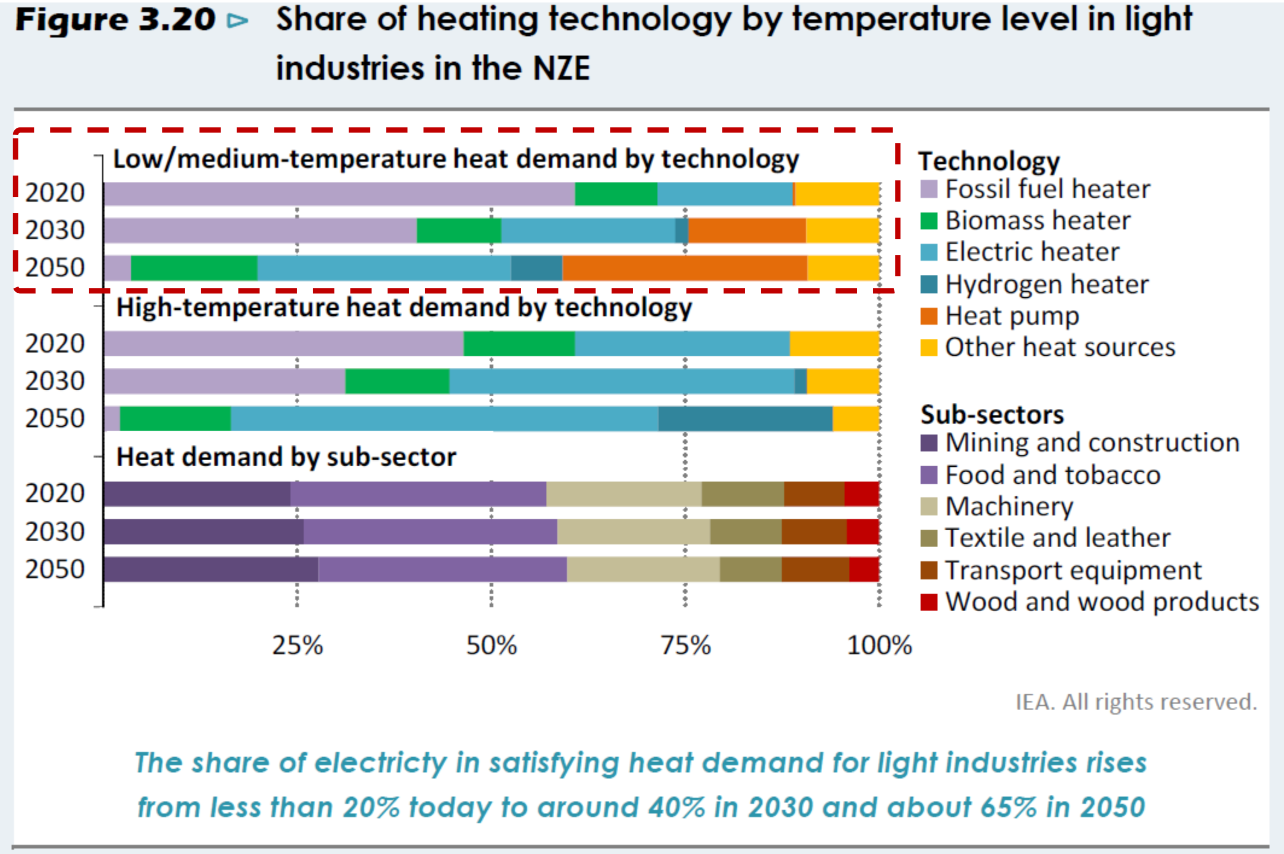
ELECTRIFICATION AND ENERGY EFFICIENCY ARE KEY FOR REACHING SUSTAINABILITY TARGETS



Source: "*Net Zero by 2050 – A Roadmap for the Global Energy Sector*, International Energy Agency, 05/2021, https://www.iea.org/reports/net-zero-by-2050

- IEA estimates that natural gas will be steadily phased out by heat pumps and electric heaters, especially for temperatures up to 200 °C to 250 °C
- Developed countries must go first and be front runners
- The Danish industry should reduce emissions by 1.9 mio. tons of CO2 per year. **25 %** are to be obtained by "**Electrification and heat pumps**", mainly implemented between 2025 to 2030 (Klimarådet)
- EU discusses an end of fossil fuel use for processes <200 °C by 2027 in the RED III, art. 21

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THE ROAD TOWARDS IMPLEMENTATION

Technology Awareness

- Commitment to sustainability and decarbonization
- Potentials, limitations and characteristics of the technology
- How to exploit the potentials?
- Variety of stakeholders involved

Technology Development

- Component and system development
- Testing and demonstration
- Variety of technologies
- Collaborative effort

End-user adoption

- Technology adoption life cycle
- Retrofitting of industries for HP-based heat supply
- Decarbonization strategies

Boundary conditions

- Cost for fuels and GHG
- Regulatory frameworks
- Subsidies & incentives
- Market developments

Market deployment

- Technology implementation within commercial projects
- Learning curve for operators and suppliers
- Supply chain covering considerable volumes
- Business models

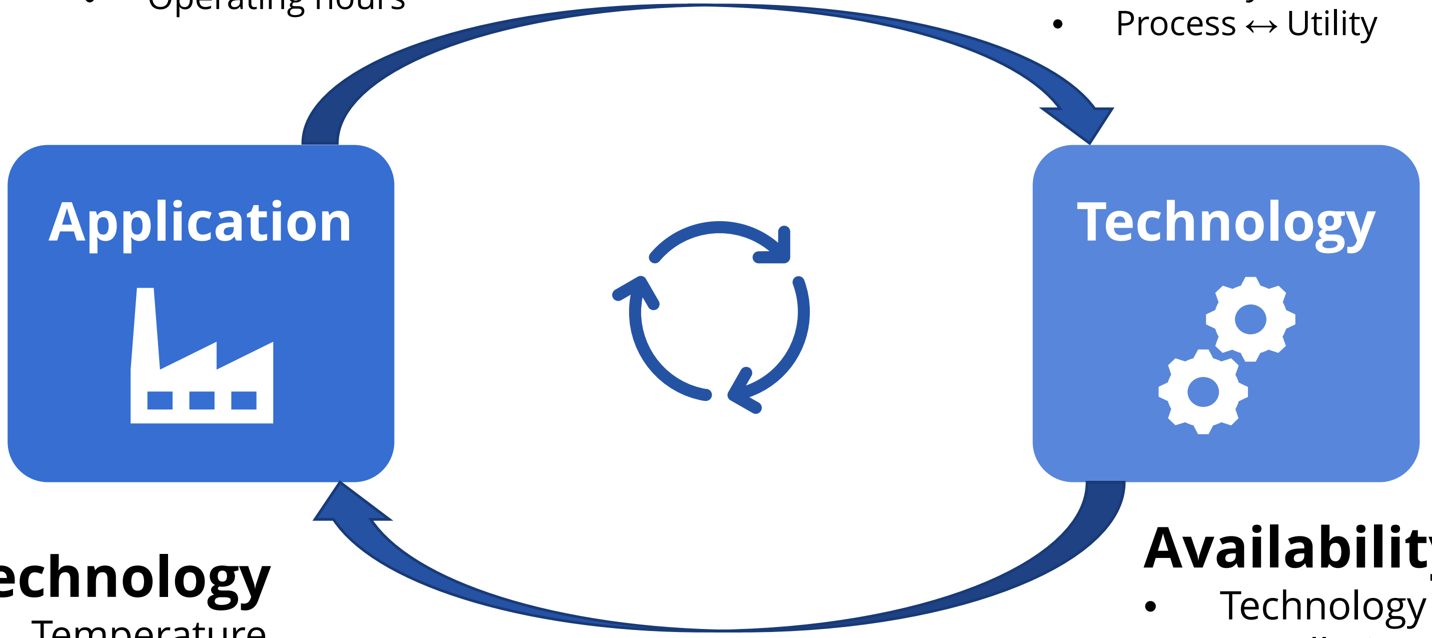
POTENTIAL & TECHNOLOGY AVAILABILITY

Capacity
- Heat supply
- Heat source
- Operating hours

Temperatures
- Supply temperature
- Temperature glides
- Temperature lift

Integration
- Open cycle
- Closed cycle
- Process ↔ Utility

Application potential based on technology availability



Development perspectives based on application potential

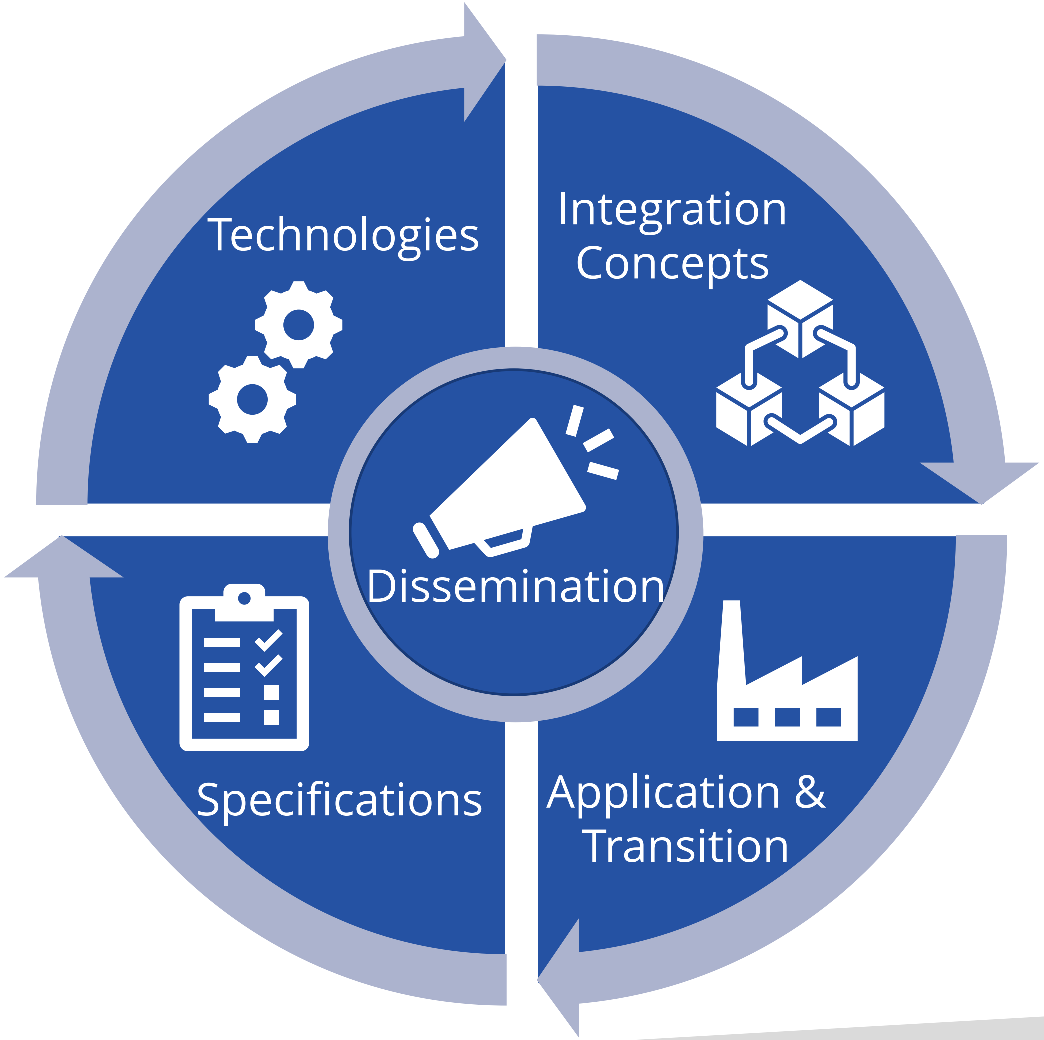
Technology
- Temperature limitations
- Working fluid
- …

Maturity
- TRL and perspectives
- References

Cost
- CAPEX
- OPEX

Availability
- Technology availability
- Installation, Service & Maintenance
- Number of installations

IEA HPT ANNEX 58 ABOUT HTHP



- Heat pump technologies with supply temperatures above 100 °C
- Participants: **Denmark (Operating Agent),** Austria, Belgium, Canada, China, France, Japan, Germany, Netherlands, Norway, South Korea, Switzerland, US
- 01/2021 – 12/2023
- https://heatpumpingtechnologies.org/annex58/

HTHP TECHNOLOGY DEVELOPMENT PERSPECTIVES

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ANNEX 58 – TECHNOLOGY REVIEW

- 34 Technology descriptions
- Key information includes:
  - Performance data
  - Capacity range
  - Max. temperatures
  - Working fluid
  - Compressor type
  - Spec. investment cost
  - TRL
  - Expected lifetime
  - Size & footprint
- Project examples

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ANNEX 58 – TECHNOLOGY REVIEW

IEA HPT

GEA Engineering for a better world.
enertime
HybridEnergy HIGH TEMPERATURE HEAT PUMPS
enerin ENERGY ENGINEERING
Combitherm APPARATE- UND ANLAGENBAU

EPCON Evaporation Technology AS
ecop
MAN Energy Solutions
ANEO
OLVONDO TECHNOLOGY

QPINCH
PILLER Blowers & Compressors
Weel & Sandvig ENERGY AND PROCESS INNOVATION
Fuji Electric
SPH Sustainable Process Heat

SPILLING Technologies
TURBODEN clean energy ahead
KOBELCO
MAYEKAWA MYCOM
FENAGY FUTURE ENERGY SOLUTIONS

Rank®
EMERSON
SIEMENS energy
SRM
toCircle INDUSTRIES

SABROE Johnson Controls
:skala fabrikk
MITSUBISHI HEAVY INDUSTRIES THERMAL SYSTEMS
HEATEN
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ANNEX 58 – TECHNOLOGY REVIEW

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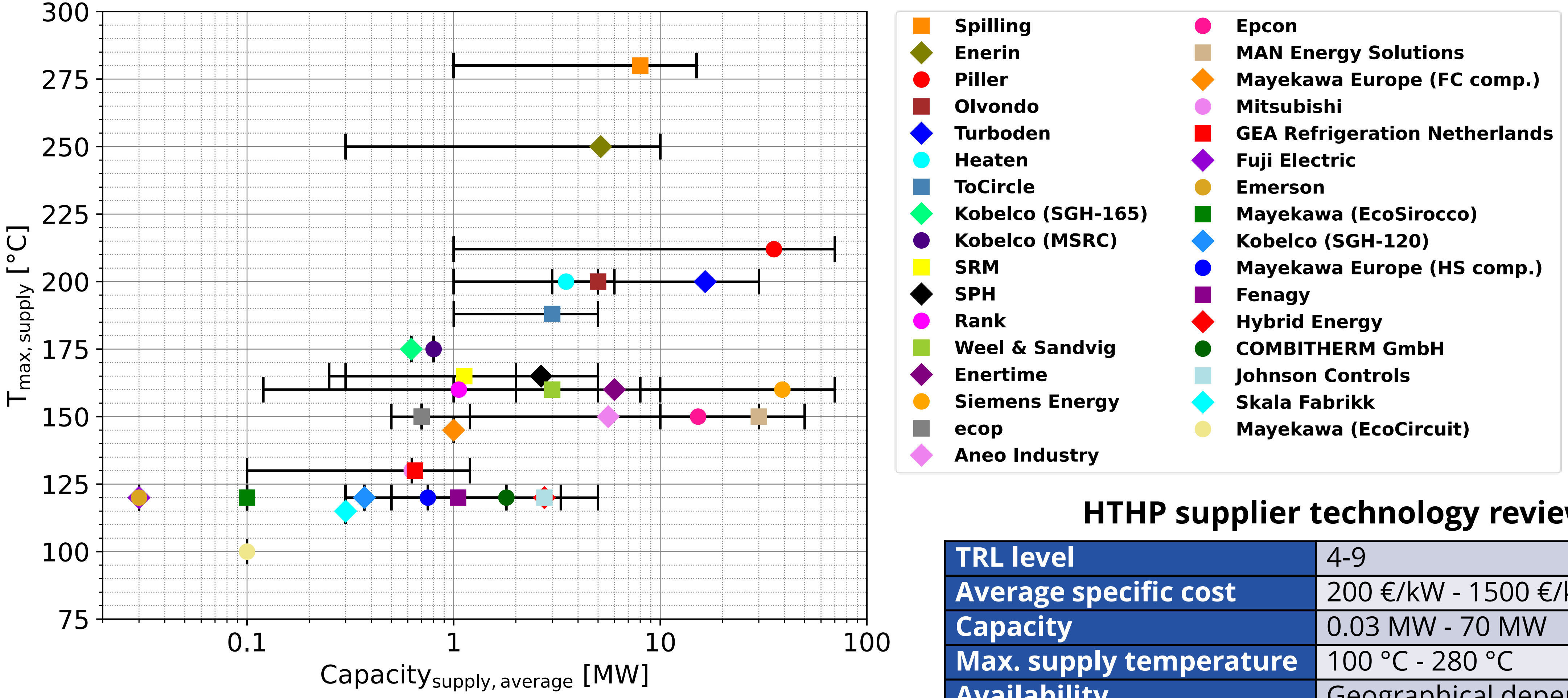
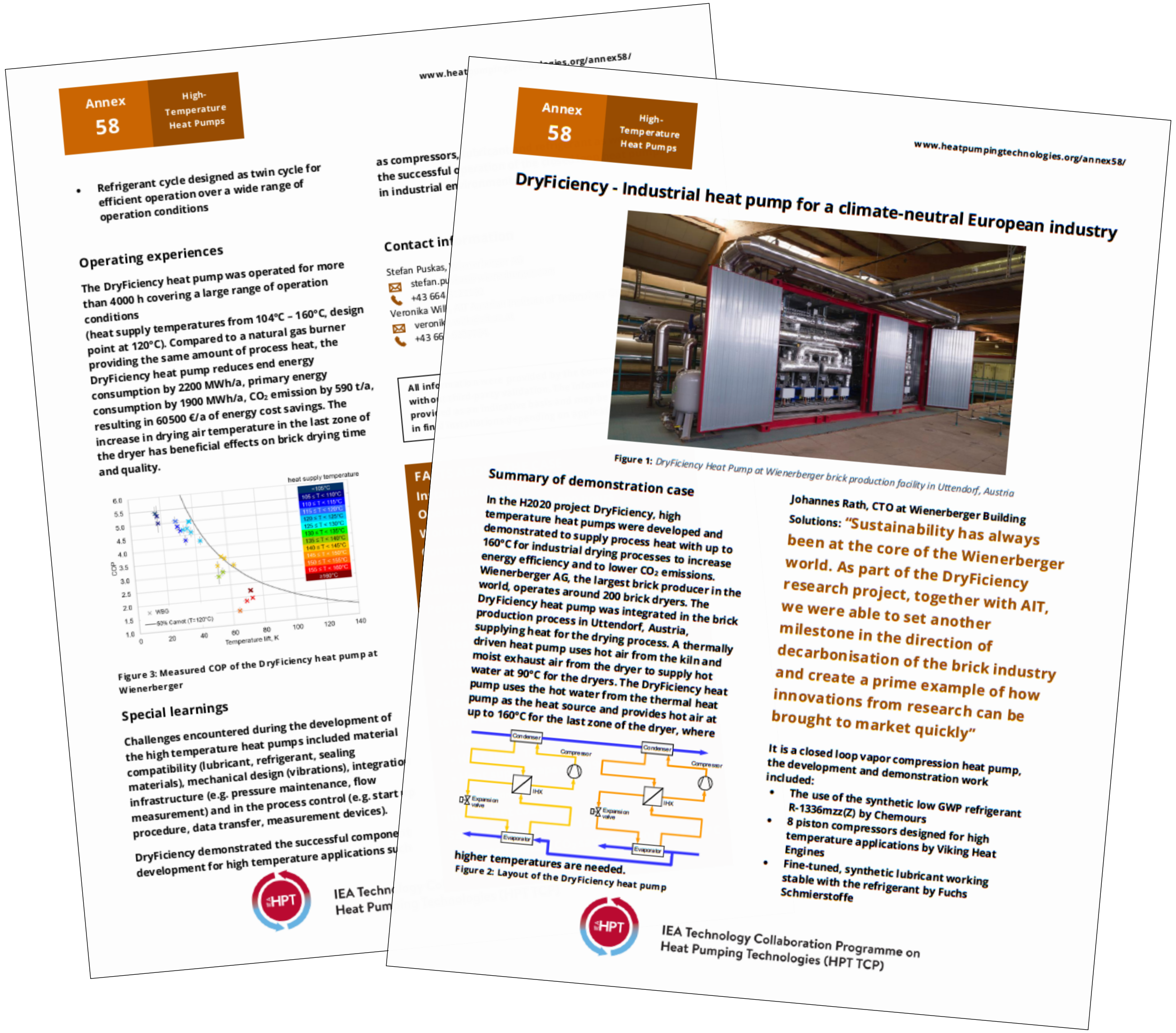
MAXIMUM TEMPERATURE AS A FUNCTION OF CAPACITY



HTHP supplier technology review

TRL level	4-9
Average specific cost	200 €/kW - 1500 €/kW
Capacity	0.03 MW - 70 MW
Max. supply temperature	100 °C - 280 °C
Availability	Geographical dependent, e.g. between Europe and Japan
Size of HTHP technology review	34 different technologies with 85 performance use cases

ANNEX 58 – DEMONSTRATION CASES



- 16 two-paged descriptions of HTHP demonstration cases prepared.
- Includes key information on:
  - Performance in design point
  - Operating hours
  - System manufacturer
  - Installation year
  - Working fluid
  - Compressor technology
  - Investment cost
  - Energy savings
  - Estimated annual CO_2 savings

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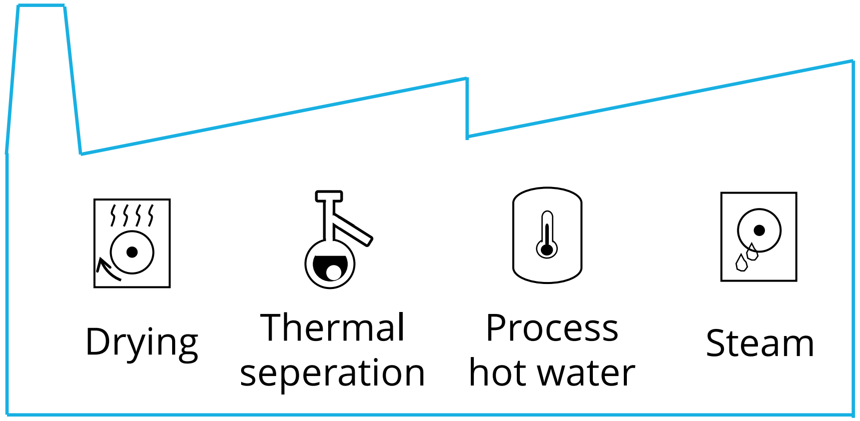
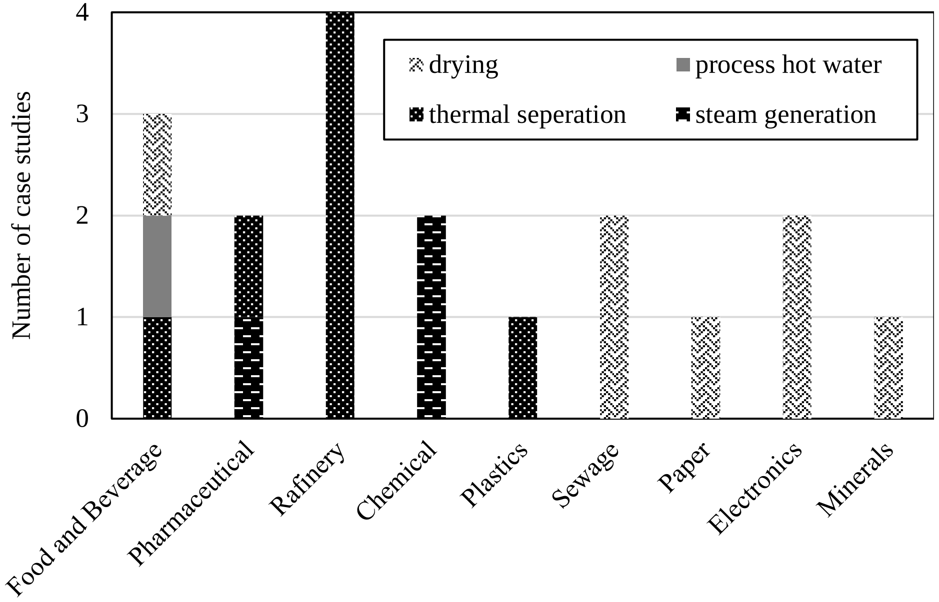
DEMONSTRATION CASES OVERVIEW

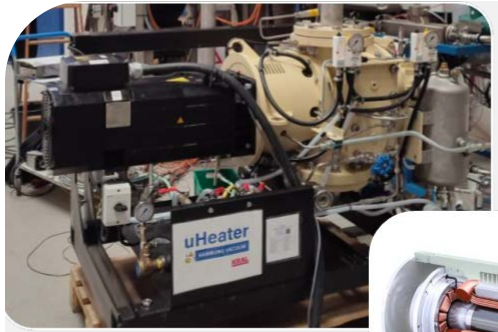




No.	Supplier	Industry	Process	Heat source			Heat sink			HP Type	Refrigerant	Compressor	Capacity	COP_H	Op. hours	Ref.
				Unit Operation	T_{out} [°C]	T_{in} [°C]	Unit Operation	T_{out} [°C]	T_{in} [°C]				[kW]		[h/a]	
1	n. a.	beverage	alcoholic distillation	product cooling	75	78.3	distillation	140	n. a.	MVR	n. a.	n. a.	350	5.2	n. a.	[1]
2	**Mayekawa**	electronic	coil drying	electro-painting cooling	25	30	drying	120	20	CCHP	R744	piston	89	3.1	n. a.	[1]
3	**AMT/AIT**	food	starch drying	waste heat	72	76	drying	138	96	CCHP	R-1336mzz(Z)	screw	374	3.2	4,000	[2]
4	**Olvondo**	pharma-ceutical	recooling	recooling heat	34	36	steam generation	183	178	Stirling HP	R704	piston	2,250	1.7	6,100	[2]
5	**Kobelco**	sewage	sludge drying	exhaust drying air	93	93	steam generation	160	160	MVR	R718	twin-screw, roots blower	675	2.9	n. a.	[2]
6	**Kobelco**	refinery	bioethanol distillation	process cooling	60	65	distillation	115	110	CCHP + Flash Tank	R245fa	twin-screw	1,850	3.5	n. a.	[2]
7	**MHI**	electronic	coil drying	waste heat	50	55	drying	130	70	CCHP	R134a	centrifugal	627	3.0	n. a.	[2]
8	**Piller**	plastics	thermal seperation	exhaust vapour	60	60	steam generation	131	126	MVR	R718	turbo (8 blowers)	10,000	4.4	8,000	[2]
9	**AMT/AIT**	minerals	brick drying	exhaust drying air	80	84	drying	121	96	CCHP	R-1336mzz(Z)	piston (8 compr.)	296	5	4,000	[2]
10	**Spilling**	pulp and paper	pulp drying	exhaust vapour	105	133	steam generation	201	n. a.	MVR	R718	piston (4 LT-, 2 HT-cylinders)	11,200	4.2	7,500	[2]
11	**Spilling**	chemical	chemical	exhaust vapour	105	152	steam generation	211	n. a.	MVR	R718	piston (4 LT-, 2 HT-cylinders)	12,000	5.3	7,500	[2]
12	**Rotrex, Epcon**	sewage	sludge drying	surplus steam	100	n. a.	steam generation	146	n. a.	MVR	R718	turbo (2 stages)	500	4.5	n. a.	[2]
13	**SkaleUP**	dairy	process hot water	(re)cooling	12, 0	20, 5	process hot water	115	95	CCHP	LT-C: R290, HT-C: R600	piston	300	2.5, 2.3	6,500	[2]
14	**QPinch**	chemical	steam production	exhaust vapour	120 - 145		steam generation	140 - 185		heat trans-former	H_2PO_4	heat-driven	2,900	0.45	2,500	[2]
15	**Huayuan Taimeng**	refinery	ethyl-benzene	waste heat	95	120	steam generation	152	n. a.	heat trans-former	LiBr-H_2O	heat-driven	7,553	0.48	n. a.	[2]
16	**Shanghai Nuotong**	beverage	alcoholic distillation	air	n. a.	18.9	steam generation	120	90	CCHP + Flash Tank + MVR	LT-C:R410a, HT-C:R245fa	screw	180	1.85	n. a.	[2]
17	**Huayuan Taimeng**	refinery	alkyl-benzene	waste heat	86	127	steam generation	150	n. a.	heat trans-former	LiBr-H_2O	heat-driven	5,100	0.48	n. a.	[2]
18	**Shandong Zhangqiu Blower**	refinery	ethanol distillation	exhaust vapour	76	n. a.	steam generation	116	n. a.	MVR	R718	centrifugal	n. a.	7.68	7,000	[2]

ONGOING DEVELOPMENT & DEMONSTRATION ACTIVITIES BY DTI

SuPrHeat



Steam compression system

- Spindle compressor: High pressure ratio and T_{Lift}
- 2-stage turbo compressor: high flows and T_{lift} up to 50 K
- Full-scale test: 2023
- On-site demo: 2024

Hydrocarbon system

- Butane (R600) → 120 °C
- Isopentane (R601a) → 160 °C
- Bock piston compressors
- Full-scale test: 04/2023
- On-site demo: Early 2024

CO_2 system

- CO_2 (R744) → 180 °C
- Bock piston compressors
- Single-stage with ejectors
- Full-scale test: 2023
- On-site demo: Early 2024

http://suprheat.dk/

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ONGOING DEVELOPMENT & DEMONSTRATION ACTIVITIES BY DTI

HC cascade system

- Iso-Butane (R600a) → 120 °C
- Iso-Pentane (R601a) → 160 °C
- Frascold screw compressors
- 500 kW in drying process
- Full-scale test: 2023
- On-site demo: 2024
- https://interheat.dk/

HC & steam system

- Butane (R600) → 120 °C
- Water (R718) → 160 °C (steam)
- SRM screw compressors
- 1 MW process heat (source DH)
- Full-scale test: 2023
- On-site demo: 2024
- https://interheat.dk/

Pentane system

- Pentane (R601) → 145 °C (steam)
- GEA screw compressors
- Single-stage
- 4 MW for sugar production
- On-site demo: 2024
- https://spirit-heat.eu/

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END-USER ADOPTION

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BUSINESS CASES

Fossil-fuel based process heating

Cost for process heating ≈ Fuel consumption

Heat pump-based process heating

Cost for process heating ≈

- Electricity consumption
- Time of operation
- Installed capacity
- Temperature

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TEMPERATURE DEAMDS & LEVEL OF INTEGRATION

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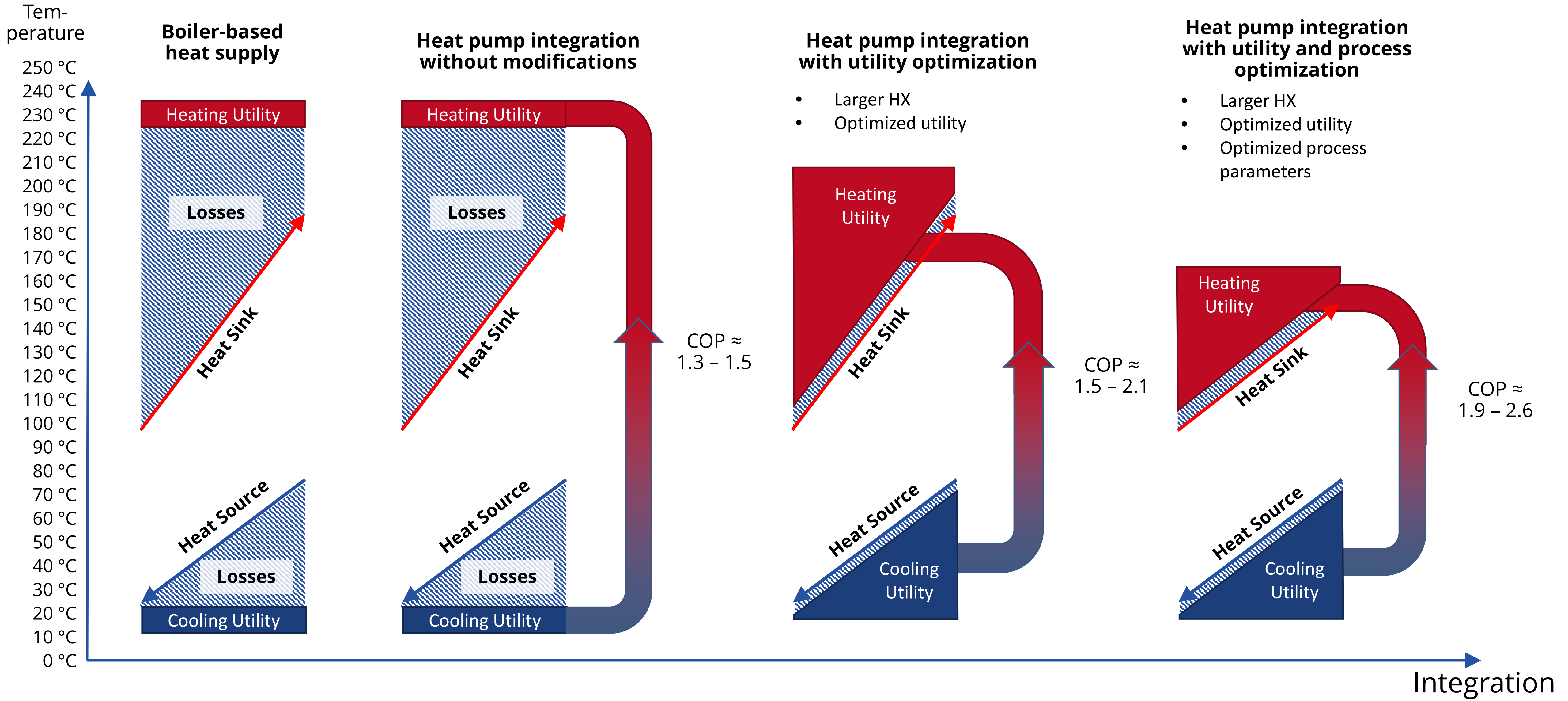

DEVELOPMENT OF DECARBONIZATION STRATEGIES

Mapping of existing processes

Definition of SMART **sustainability targets**

Development of **concept solutions**

Analysis of **technology availability and perspectives**

Development of **decarbonization roadmap**

Implementation of decarbonization roadmap

PERSPECTIVES

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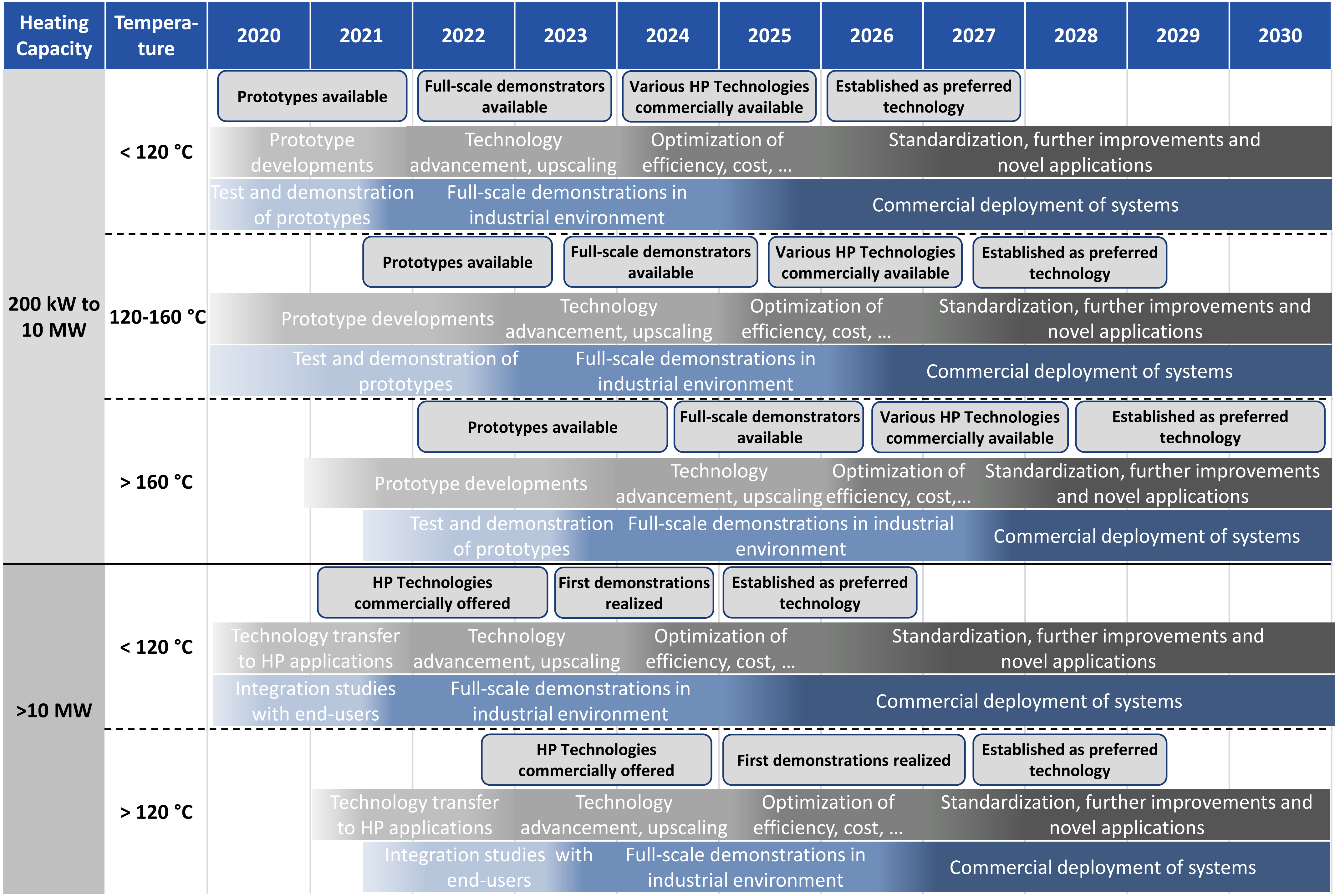

CONCLUSIONS, OUTLOOK & TAKE-AWAYS

Conclusions

- High-temperature heat pumps have a considerable potential
- Variety of technologies and manufacturers required
- Process integration and decarbonization strategies are key

Outlook

- Large up-take of heat pumps in industry & district heating < 100 °C
- Establishing HTHPs as reference technology for heat supply up to 150/160 °C
- Advancing the state of the art for technologies >150 °C
- Creating awareness at variety of stakeholders

Take-aways

- **Technologies must be developed and demonstrated at scale**
- **Industrial decarbonization is a long-term process and requires holistic strategies**
- **The HTHP technology supply and the market are global.**

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HTHP SYMPOSIUM

High-Temperature Heat Pump Symposium

- Focus on:
  - Technology developments and trends
  - Successful demonstration cases
  - Integration concepts
  - Market potential and demand
- Presentations & Exhibition area
- Save the date:

  23rd & 24th of January 2024
- http://hthp-symposium.org/

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