DANISH TECHNOLOGICAL INSTITUTE

Decarbonizing Industrial Process Heating

Benjamin Zühlsdorf, DTI

June 24th 2024

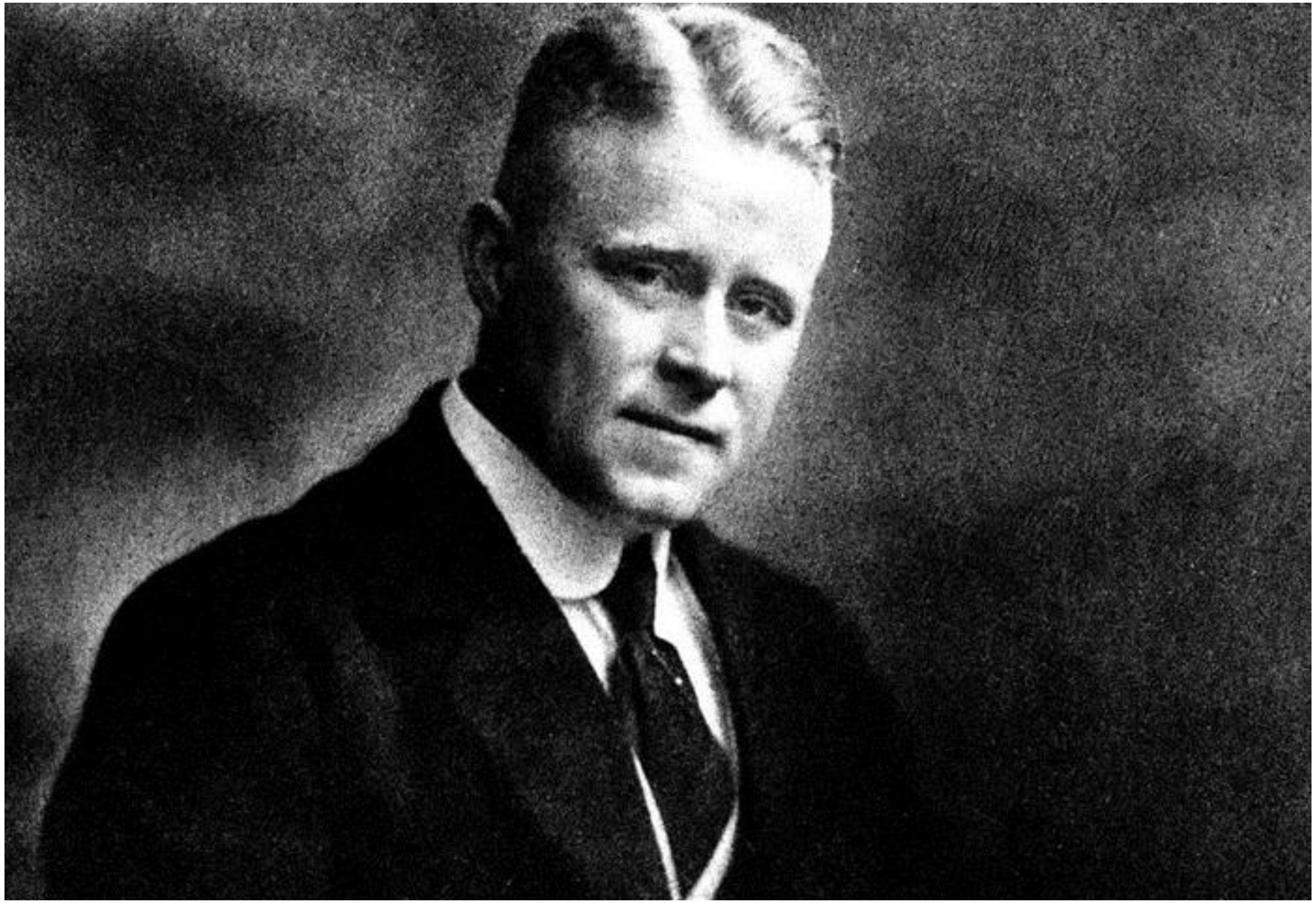
MONDAY, JUNE 24

TIME	ACTIVITY	LOCATION
08.00 – 08.15	Transport to Danish Technological Institute	
08.15 – 09.45	Welcome and Introduction • Round of introduction • Week program • DEA presentation of Danish industrial decarbonization	Kongsvang Alle 29, Aarhus C
09.45 – 12.30	Presentations and tour at Danish Technological Institute	Kongsvang Alle 29, Aarhus C
12.30 – 13.00	Lunch and Q&A	Kongsvang Alle 29, Aarhus C
13.00 – 13.30	Transport to Johnson Controls Denmark	
14.00 – 16.30	Visit at Johnson Controls Denmark	Christian X's Vej 201, Højbjerg

Agenda

- 09:45 – 10:00 Intro TI program – Benjamin Zühlsdorf
- 10:00 – 10:30 Industrial Heat Pumps – Status and perspectives – Benjamin Zühlsdorf
- 10:30 – 11:00 Electrification and batteries – Developments, trends and case – Anders Solberg Jensen
- 11:00 – 12:15 Lab tour and debate – We will split into two teams
- 12:15 Lunch
- 13:00 End of visit

Creating value since 1906



Danish Technological Institute was founded in 1906 by the visionary engineer, Gunnar Gregersen.

That makes us one of the oldest institutes of our kind.

We are approved as an RTO by the Danish Minister of Higher Education and Science.

We offer three types of services

Validation

We validate and document technological solutions through tests and trials in our state-of-the art technology infrastructures.

Development

We run extensive research projects and develop pioneering technological solutions.

Integration

We integrate and implement technological solutions aligned with market, organisation, environment and culture.

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Building & Construction

Materials

Environmental Technology

Energy & Climate

Board of representatives

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- Danish Technological Institute Spain, S.L
- Teknologisk Innovation A/S

STAFF

Refrigeration & Heat Pump Technologies

Validation

- Accredited testing of heat pumps
- From kW to MW

Integration

- Process integration & decarbonization strategies
- On-site testing
- Courses for industry

Development

- Technology development of components and systems
- Experimental testing
- Modelling and Simulation

Domestic HPs

Supermarket Systems

District Heating

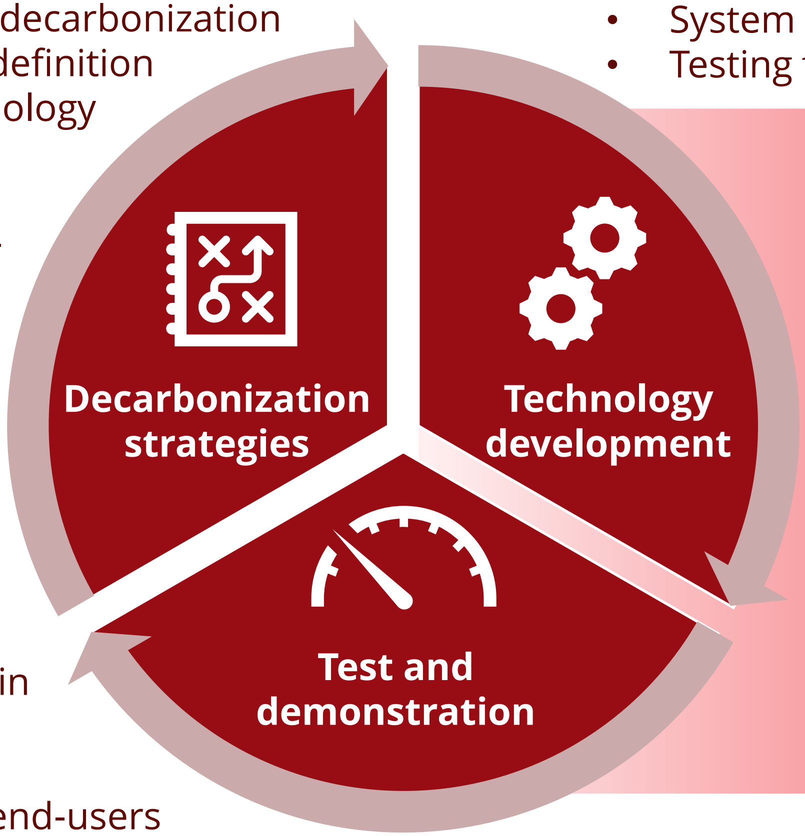
Unit Operations

High-Temperature HPs

Decarbonization of Industries

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

- 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, …)

Decarbonization of Industrial Process Heating

The bigger picture

Process Heating in EU 28

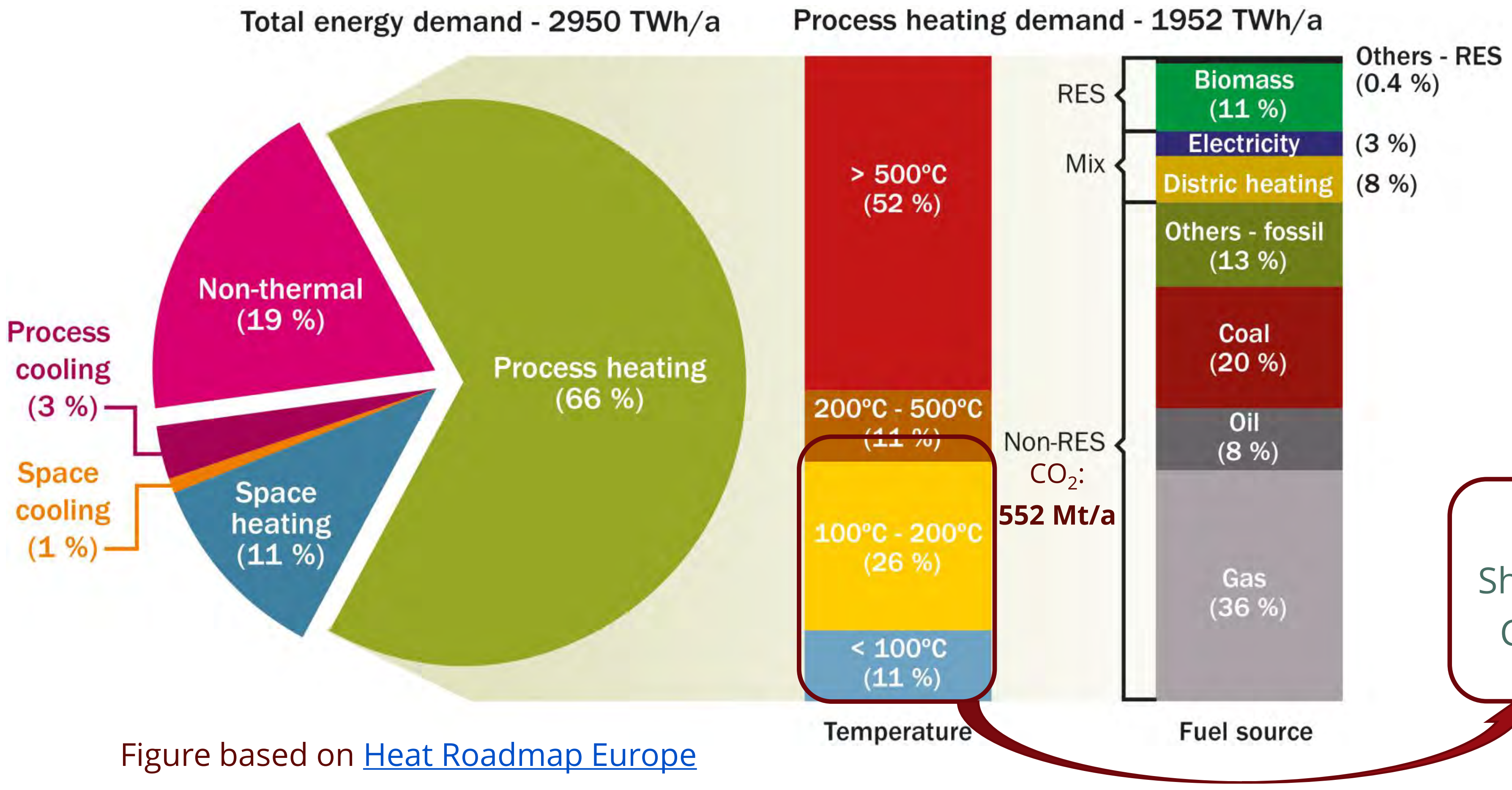


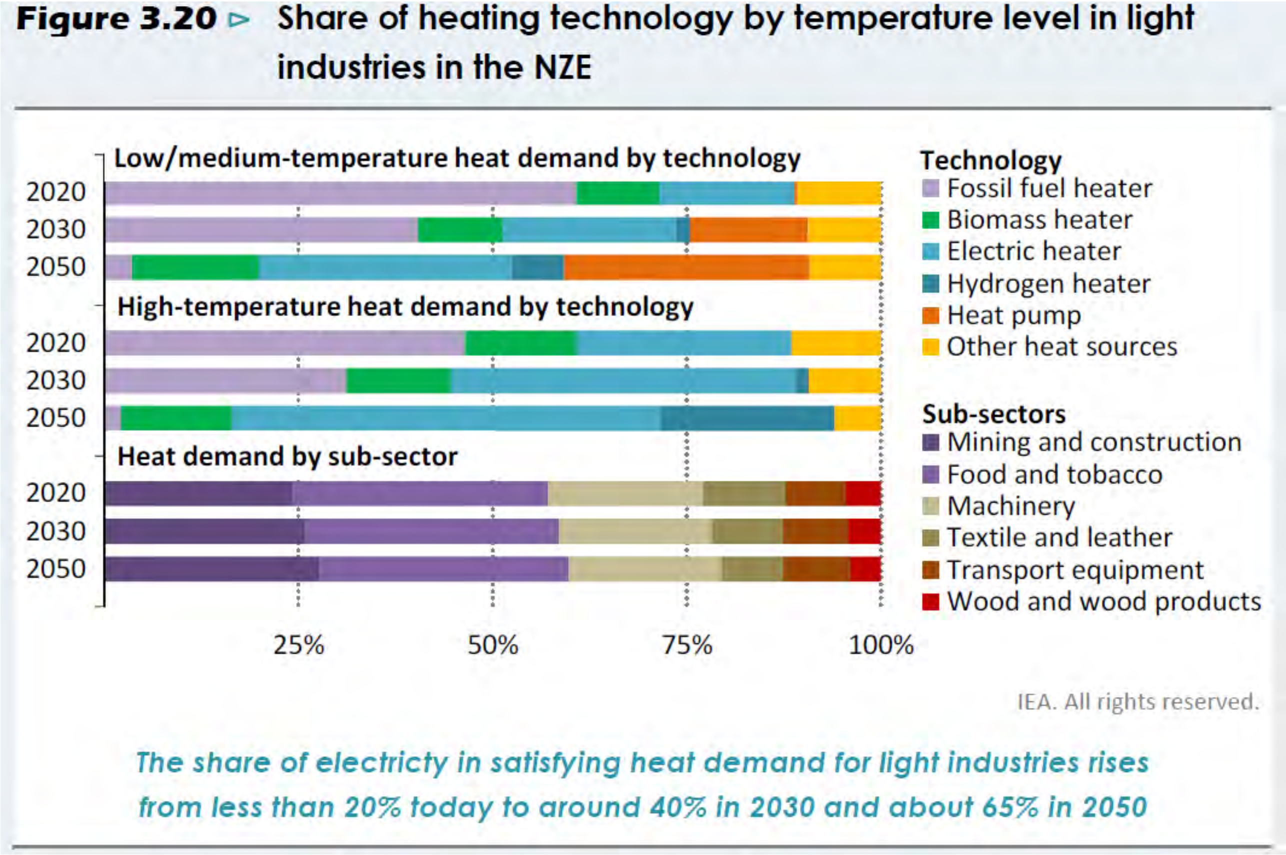
Figure based on [Heat Roadmap Europe]

Heat Pumps:

Share of process heat: 37 %

CO_2 emissions: 146 Mt/a

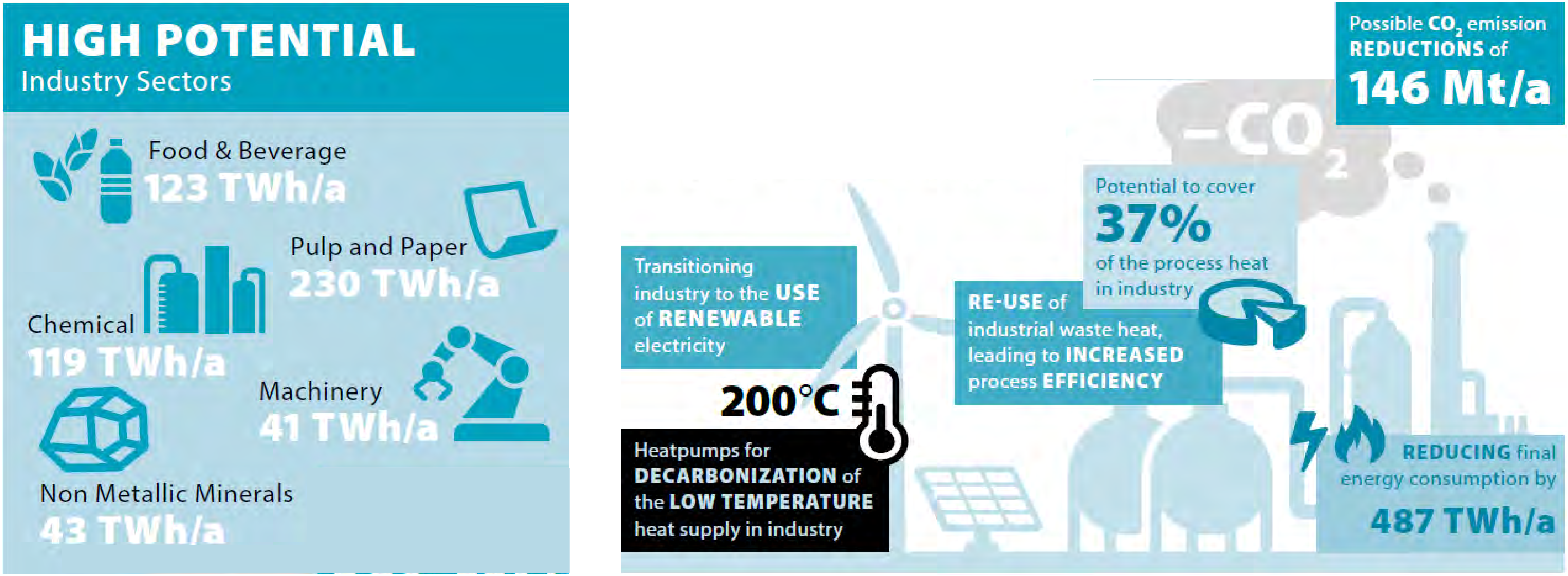
Electrification and energy efficiency are key for reaching sustainability targets



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

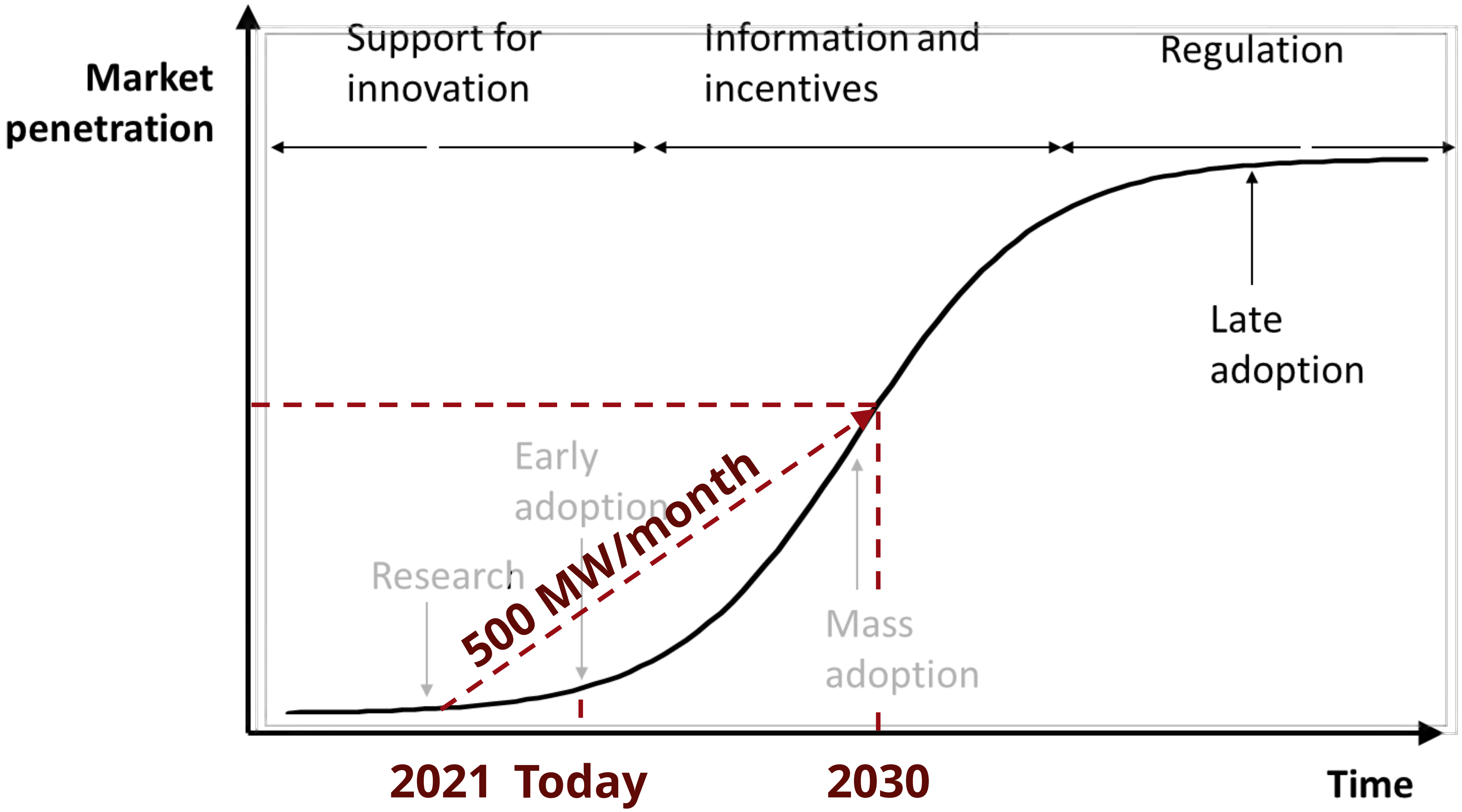
- IEA estimates that natural gas will be steadily phased out by heat pumps and electric heaters, especially for temperatures up to 200 °C to 250 °C
- Developed countries must go first and be front runners
- The Danish industry should reduce emissions by 1.9 mio. tons of CO_2 per year. **25 %** are to 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

Application Potential for HTHPs



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

From Early Adoption to Mass Adoption



Sources: Rosenow et al. 2015 & IEA, Net Zero by 2050 – A Roadmap for the Global Energy Sector, 2021

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

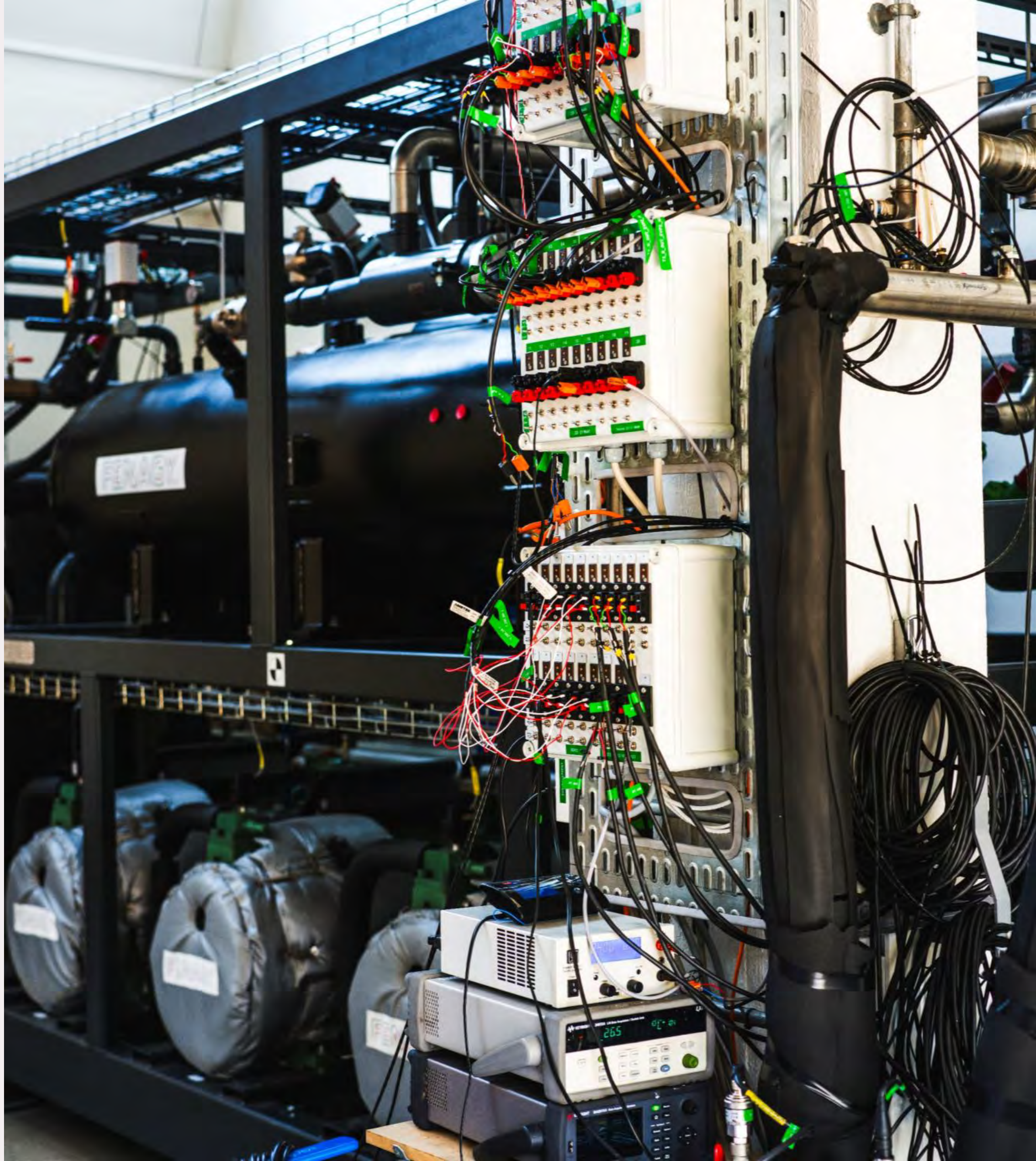
- Cost for fuels and GHG
- Regulatory frameworks
- Subsidies & incentives
- Market developments

Market deployment

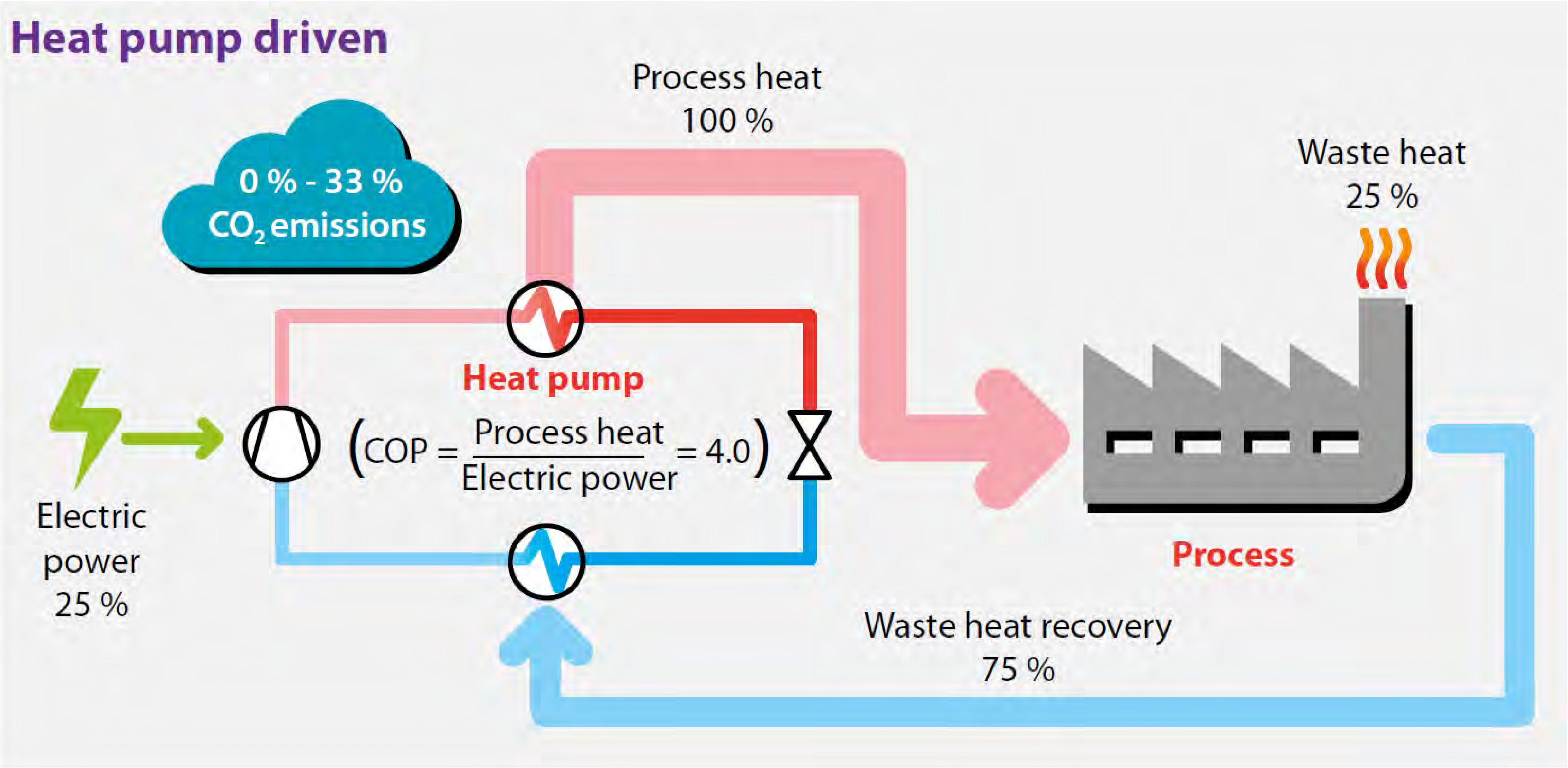
- Technology implementation within commercial projects
- Learning curve for operators and suppliers
- Supply chain covering considerable volumes
- Business models

Technologies

Ongoing developments and perspectives



Industrial HPs – Working Principle



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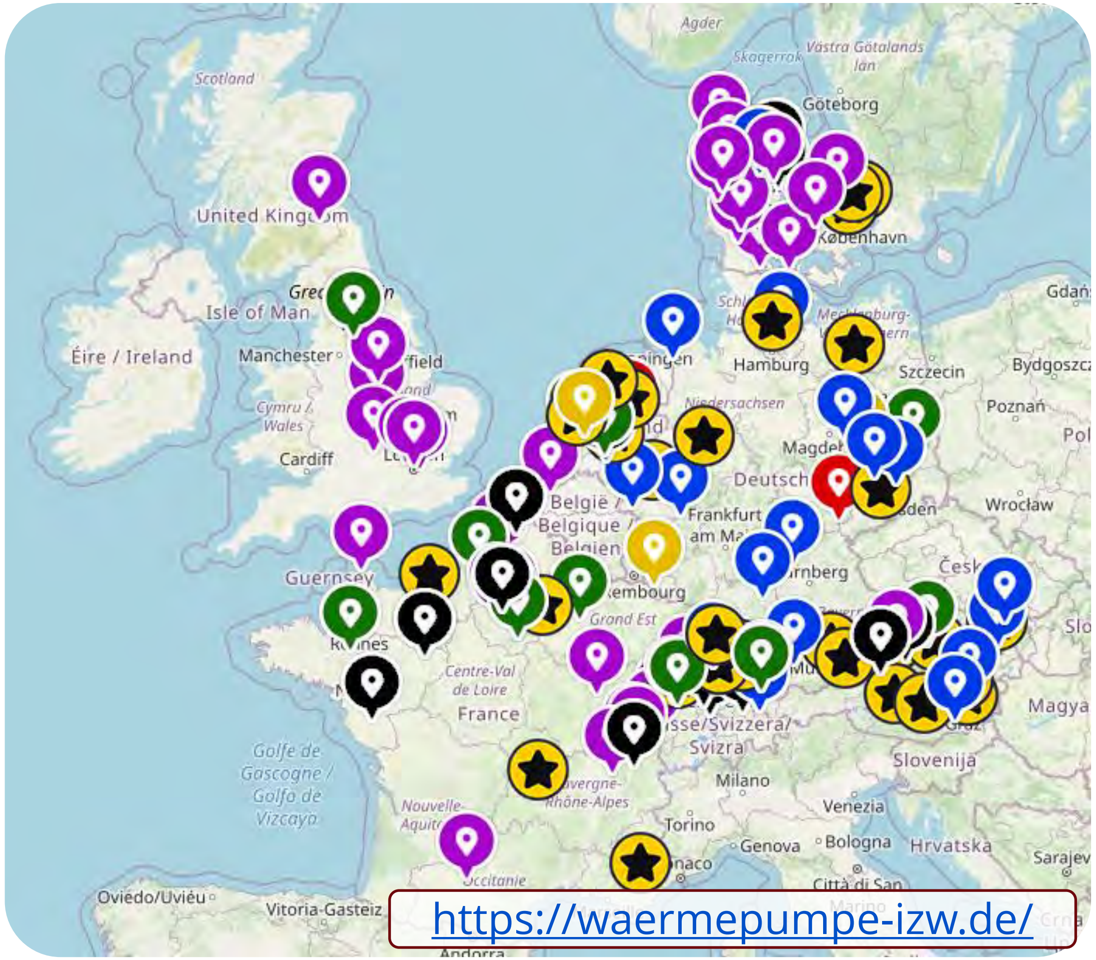
Proven Principles

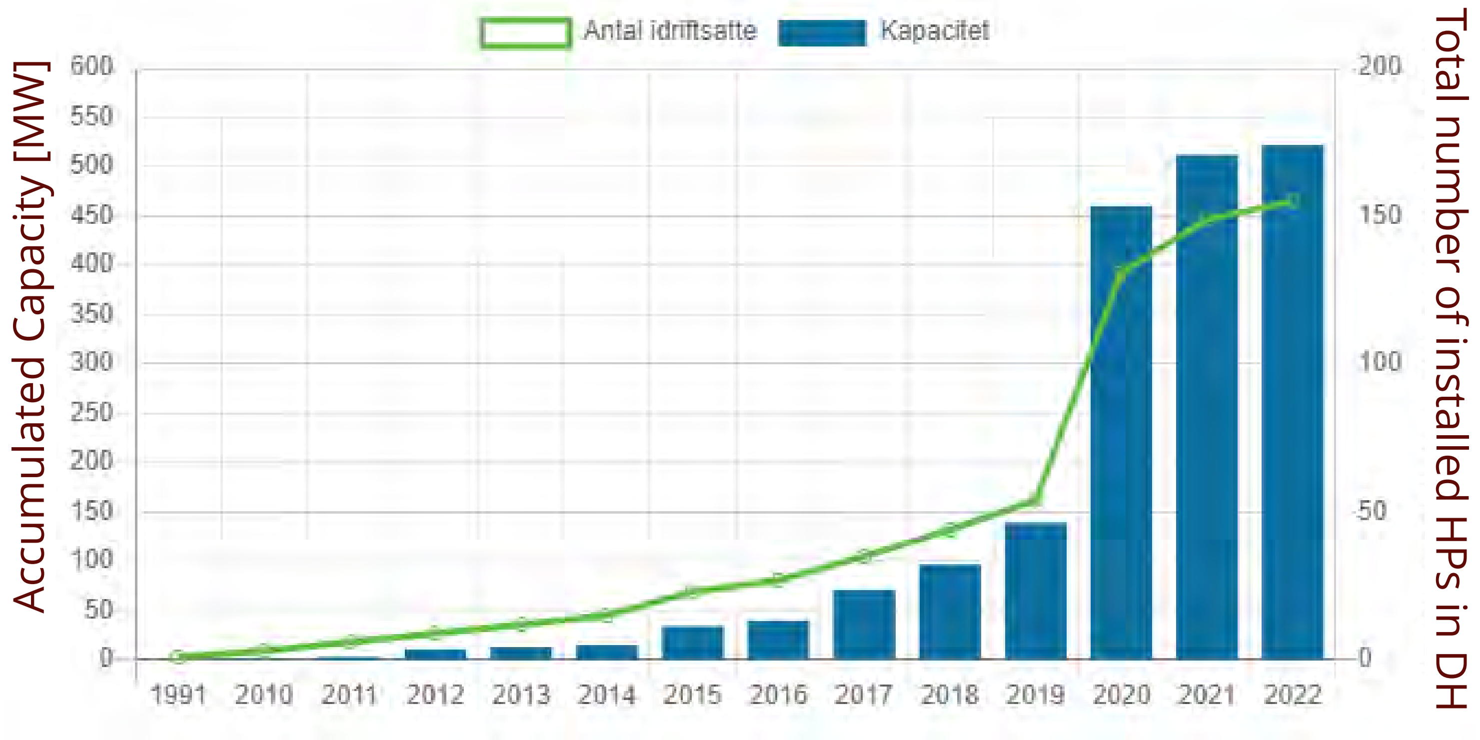


https://waermepumpe-izw.de/

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

HPs in District Heating in DK

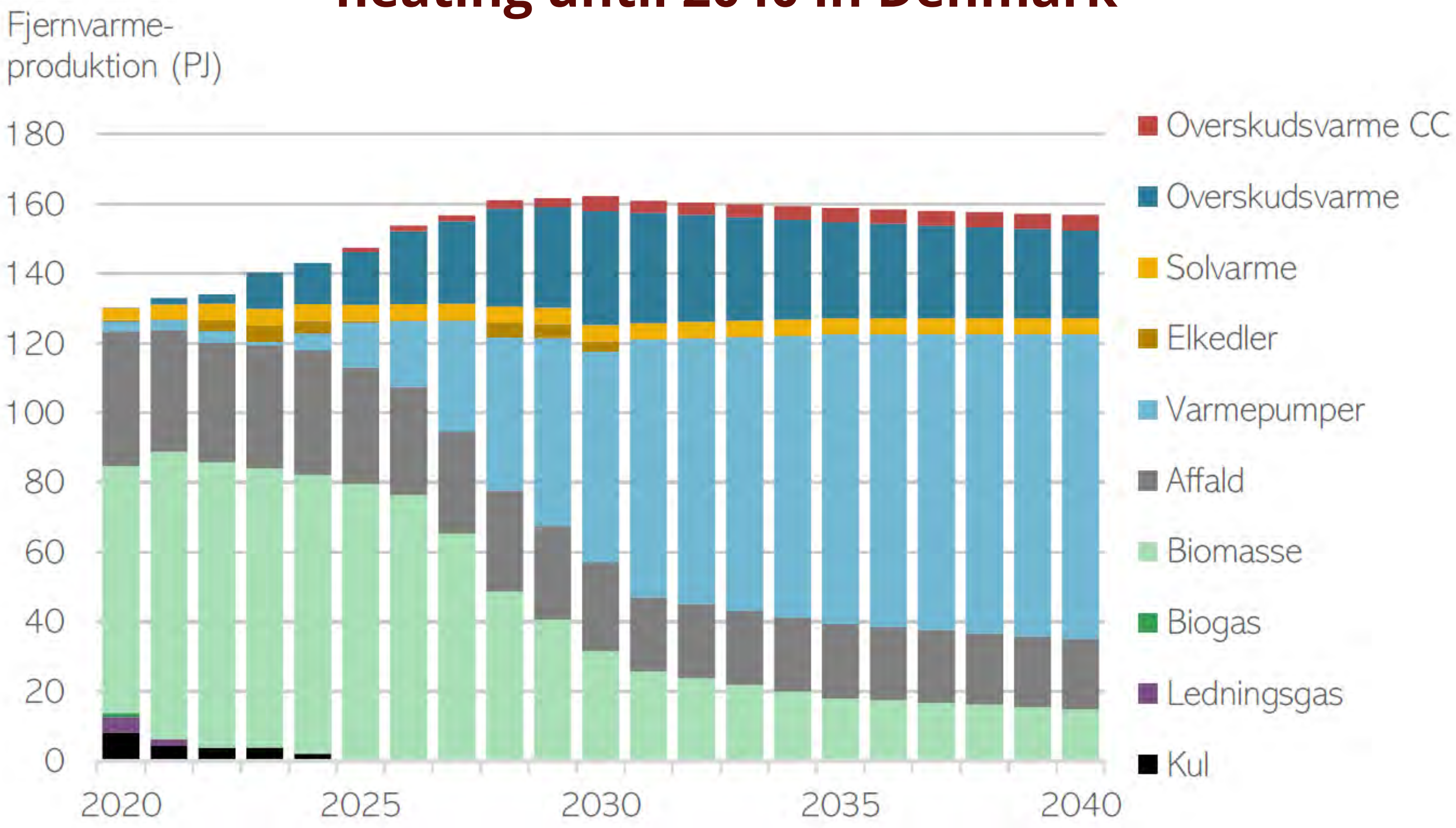
Installed HPs in District Heating in DK
https://varmepumpedata.dk/plants/



- Heat pumps are a preferred solution
- Technology is understood by all involved parties
- Solutions are becoming standardized
- Natural refrigerants are dominating (Ammonia | CO_2 | Hydrocarbons)

HPs in District Heating in DK

Expected development of heat supply to district heating until 2040 in Denmark



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- Technology is understood by all involved parties
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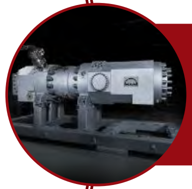
- Natural refrigerants are dominating (Ammonia | CO_2 | Hydrocarbons)

- **Phase out of biomass still to come**
- **HPs to become main heat source for district heating**

Udviklingen i kapacitet på termiske værker – Analyse frem mod 2040, 2022, Energy Modelling Lab, https://danskfjernvarme.dk/media/5tcb05ab/analyse-udviklingen-i-kapacitet-paa-termiske-vaerker.pdf

Large-scale HPs for DH – selected examples

50 MW (2 x ~25 MW) | CO_2 | Startup: 2024 | Esbjerg (DK) | MAN Energy Solutions [1]



132 MW (3 x ~44 MW) | CO_2 | Startup: 2027 | Aalborg (DK) | MAN Energy Solutions [2]

50 MW | R600a | Gothenburg (SE) | Atlas Copco & Strabag [3]

Rasmus Rubycz, Market Manager New Energy at Atlas Copco:

*"**Flammability was never really an issue** during the tendering phase, as **we have many examples for large processes plants with full ATEX / explosion protection. The key is a good ventilation concept and an open mind**" [4]*

[1] https://www.man-es.com/company/press-releases/press-details/2021/02/04/man-energy-solutions-liefert-erstes-sektor-%C3%BCbe
[2] https://www.man-es.com/company/press-releases/press-details/2023/09/28/man-energy-solutions-to-provide-climate-neutral-distr
[3] https://strabag-umwelttechnik.com/databases/internet/_public/content.nsf/web/DE-STRABAGUMWELTTECHNIK.COMN-NEWS-STRABAG pumpe%20in%20G%C3%B6teborg,%20Schweden#!
[4] https://www.linkedin.com/posts/strabag_strabag-workonprogress-construction-activity-7193844579572310016-yG15?utm_source=share&utm_medium=member_desktop

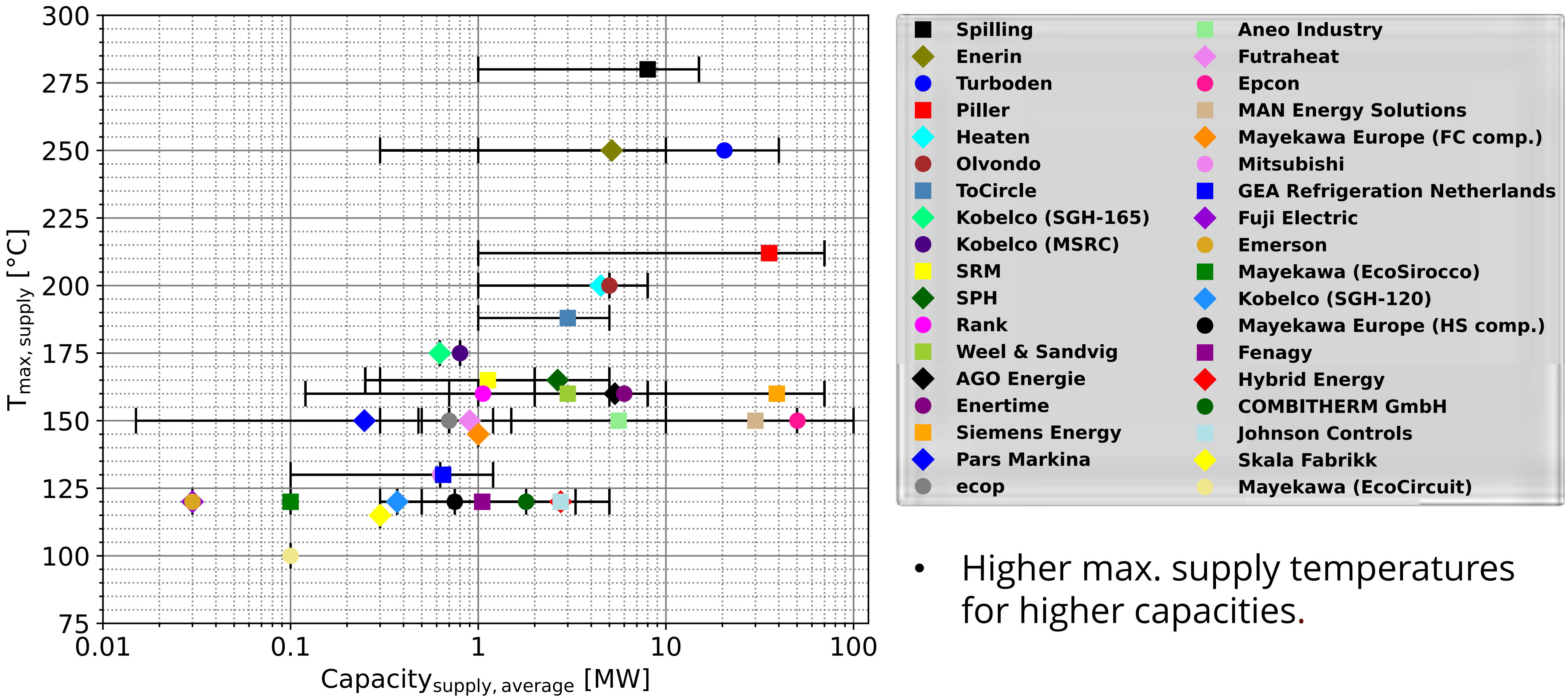
Review of High-Temperature Heat Pump Technologies – IEA HPT Annex 58

TRL level	4-9
Average specific cost	200 €/kW - 1500 €/kW
Capacity	0.02 MW - 100 MW
Max. supply temperature	100 °C - 280 °C
Availability	Geographical dependent, e.g. between Europe and Japan
Number of technologies	37 different technologies

MAN Energy Solutions, ecop, enertime, GEA Engineering for a better world., SPH Sustainable Process Heat, Combitherm Apparate- und Anlagenbau, QPINCH, EPCON Evaporation Technology AS, PILLER Blowers & Compressors, Weel & Sandvig Energy and Process Innovation, enerin Energy Engineering, FENAGY, toCircle Industries, SPILLING Technologies, TURBODEN, SIEMENS energy, MAYEKAWA MYCOM, Fuji Electric, ago, OLVONDO Technology, Rank®, EMERSON, KOBELCO, SABROE Johnson Controls, FUTRAHEAT High Temperature Heat Pumps, HEATEN, skala fabrikk, MITSUBISHI HEAVY INDUSTRIES THERMAL SYSTEMS, SRM, HybridEnergy, ANEO, pars makina power and rotary systems

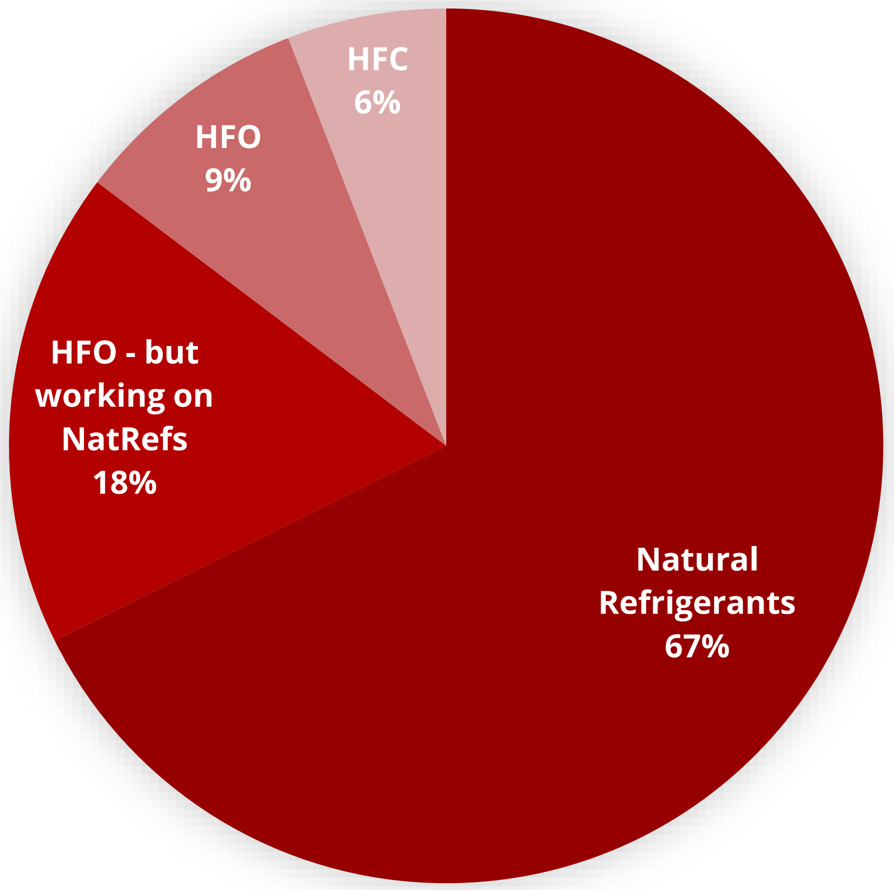
https://heatpumpingtechnologies.org/annex58/task1/

Maximum supply temperature as a function of capacity



- Higher max. supply temperatures for higher capacities.

Working Fluids in HTHP Technologies



Frequently used natural refrigerants:

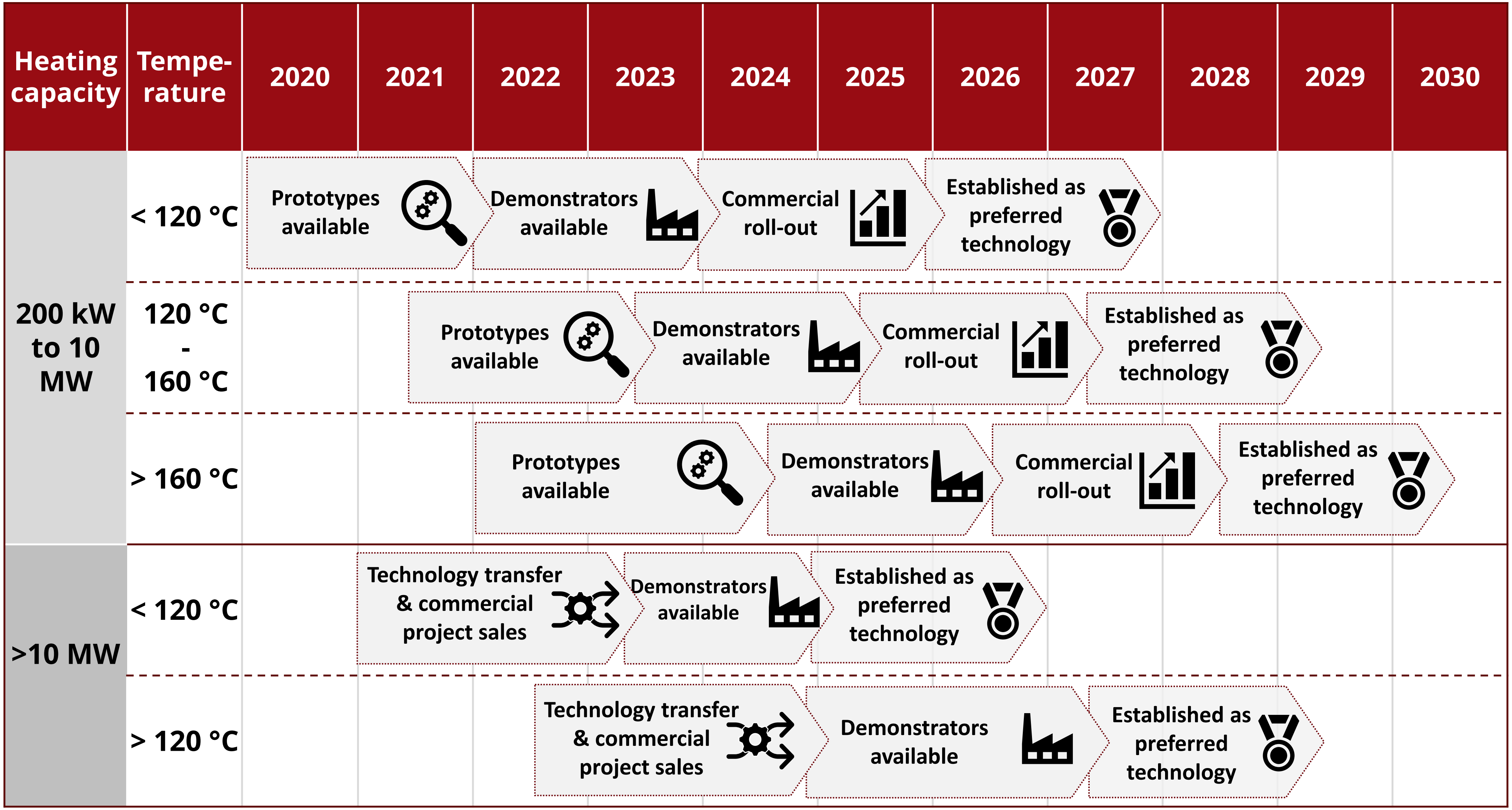
- CO_2 (R744)
- Steam (R718)
- Ammonia/Water (R717/R718)
- Hydrocarbons (R600, R600a, R601, R601a)

Frequently used HFOs:

- R-1233zd(E)
- R-1234ze(E)
- R1336mzz(Z)

Source: Information based on IEA HPT Annex 58 and other publicly available information

Development Perspectives for HTHPs towards 2030



Source: IEA HPT Annex 58, Task 1 Report – B. Zühlsdorf et al. 2023

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SuPrHeat Hydrocarbon System

SuPrHeat

- Cascade system
- **Butane (R600) → 120 °C**
- **Isopentane (R601a) → 150 °C**
- Heating capacity: **500 kW**
- Bock piston compressors
- Full-scale test at DTI: ongoing
- On-site demo: Q3-4/2024

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BOCK colour the world of tomorrow
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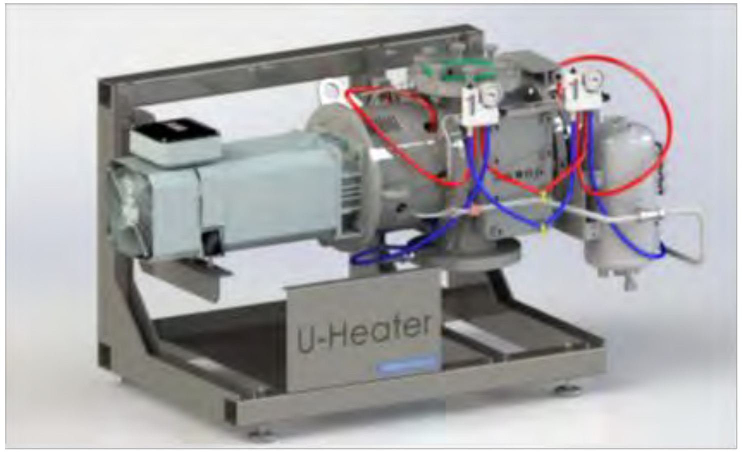
SuPrHeat Steam System



- Spindle compressor: High pressure ratio and T_{Lift} up to 60-80 K
- 2-stage turbo compressor: high flows and T_{Lift} up to 50 K
- Full-scale test at DTI: 08/2024
- On-site demo: 01/2025
- Currently in design and construction phase
- Direct integration in steam network possible

FORCO_2 – Fenagy CO2 System

FORCO2

- Hybrid air and water source system
- CO2 (R744) → 70 °C
- Heating capacity: 1800 kW
- Bitzer piston compressors
- Güntner hybrid air coil
- Full-scale test at DTI: ongoing
- On-site demo: 08/2024

EUDP CO2X Kelvion

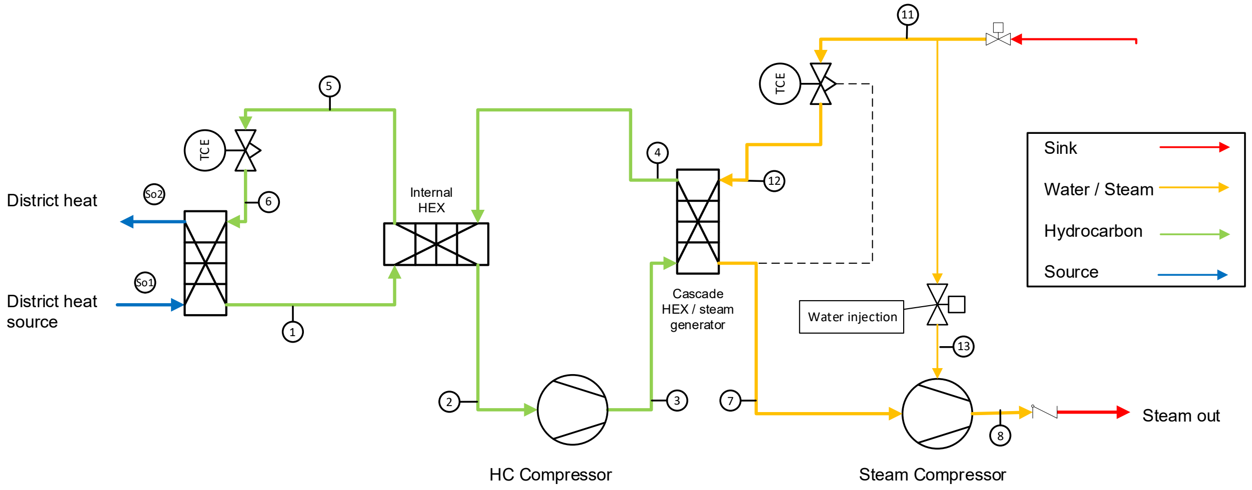
FENAGY FUTURE ENERGY SOLUTIONS Güntner Bitzer

Danmarks Tekniske Universitet DTU Danfoss echnological Institute

InterHeat Hydrocarbon System

- Cascade system
- **Isobutane (R600a) → 120 °C**
- **Isopentane (R601a) → 160 °C**
- Heating capacity: **500 kW**
- Frascold compressors
- Full-scale test at DTI: Q2/2024
- On-site demo: Q4/2024

InterHeat Hydrocarbon & Steam System



- Cascade system
- **Butane (R600) → 110 °C (steam)**
- **Steam (R718) → 160 °C**
- Heating capacity: **1000 kW**
- SRM screw compressors
- Full-scale test at DTI: Q2/2024
- On-site demo: Q1/2025

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SPIRIT Pentane System

- Refrigerant: **n-Pentane (R601)**
- Heat Sink: steam at T_{Sat} = **138 °C**
- Heat source: vacuum steam at T_{Sat} = **80 °C**
- Heating capacity: **4 MW**
- GEA Screw compressor
- On-site demo: Q4/2024

HTHP Symposium

High-Temperature Heat Pump Symposium

- Meeting place for HTHP Community
- 23. & 24.01.2024 – DGI Byen
- +80 presentations
- +25 exhibition stands
- +400 participants

SINTEF DTU DANISH TECHNOLOGICAL INSTITUTE

http://hthp-symposium.org/

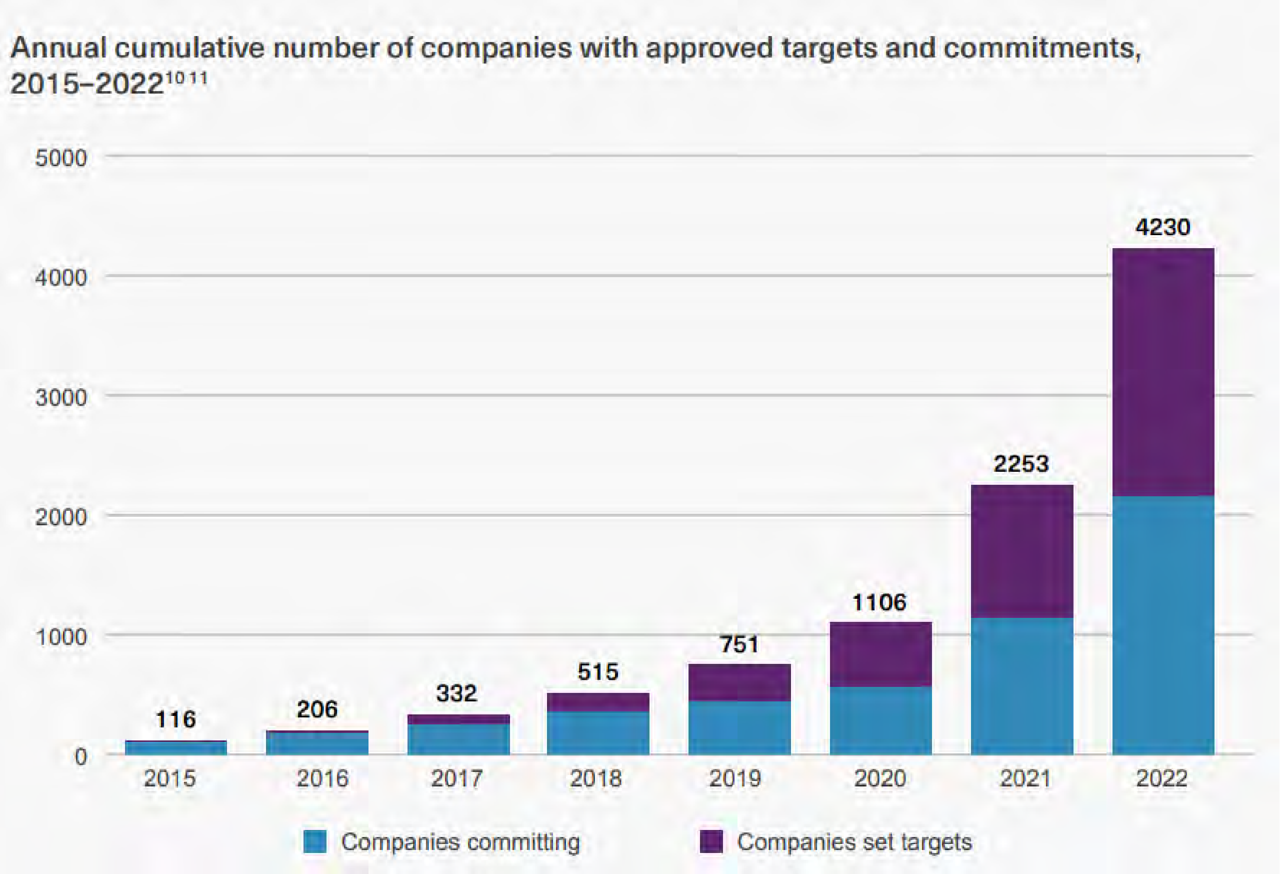
End-users

The transition towards HP-based process heating

Decarbonization is gaining traction

SCIENCE BASED TARGETS

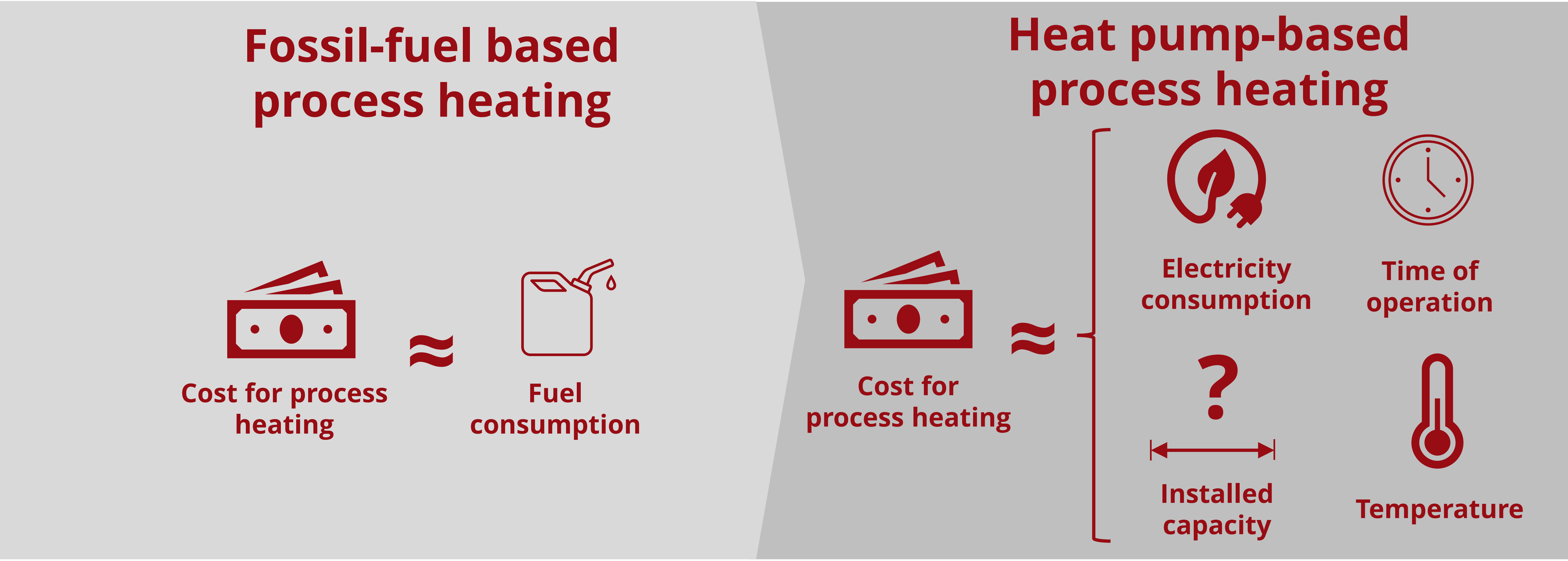
DRIVING AMBITIOUS CORPORATE CLIMATE ACTION



https://sciencebasedtargets.org/ [accessed: 21.01.2024]

Source: https://sciencebasedtargets.org/resources/files/SBTiMonitoringReport2022.pdf

Converting to HPs requires Shift of Mindset



Technology lock-in

Wrong investments = Slower decarbonization

- Process equipment designed for high pressures
- Waste-heat recovery with too large temperature differences
- Waste heat recovery from combustion processes
- Waste heat supply for external purpose
- Investments in process equipment not optimized for new energy supply
- Investments in energy utility based on wrong or short-sighted assumptions

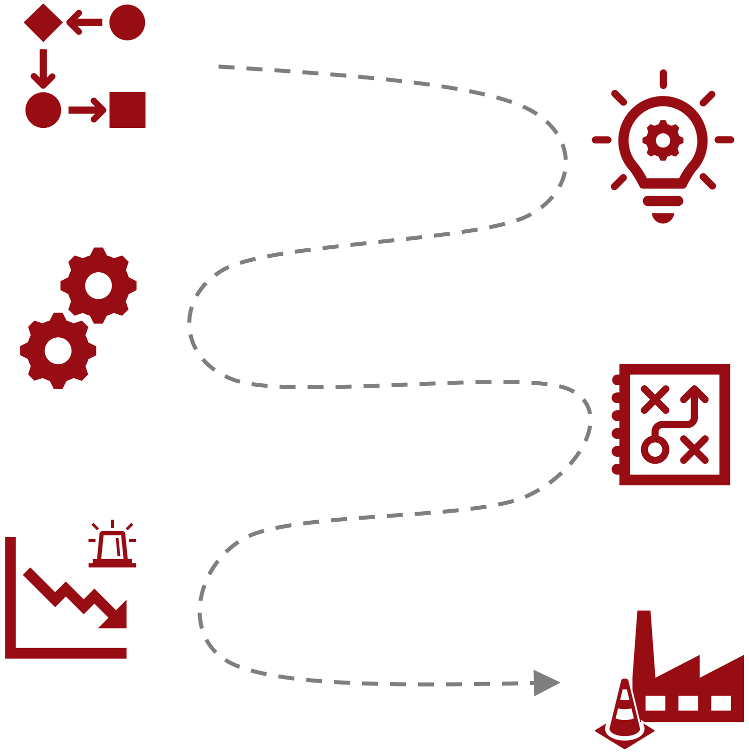
Icons from https://www.flaticon.com/

Long-term planning is key to success

Mapping of existing processes

Analysis of **technology availability and perspectives**

De-risking of decarbonization projects



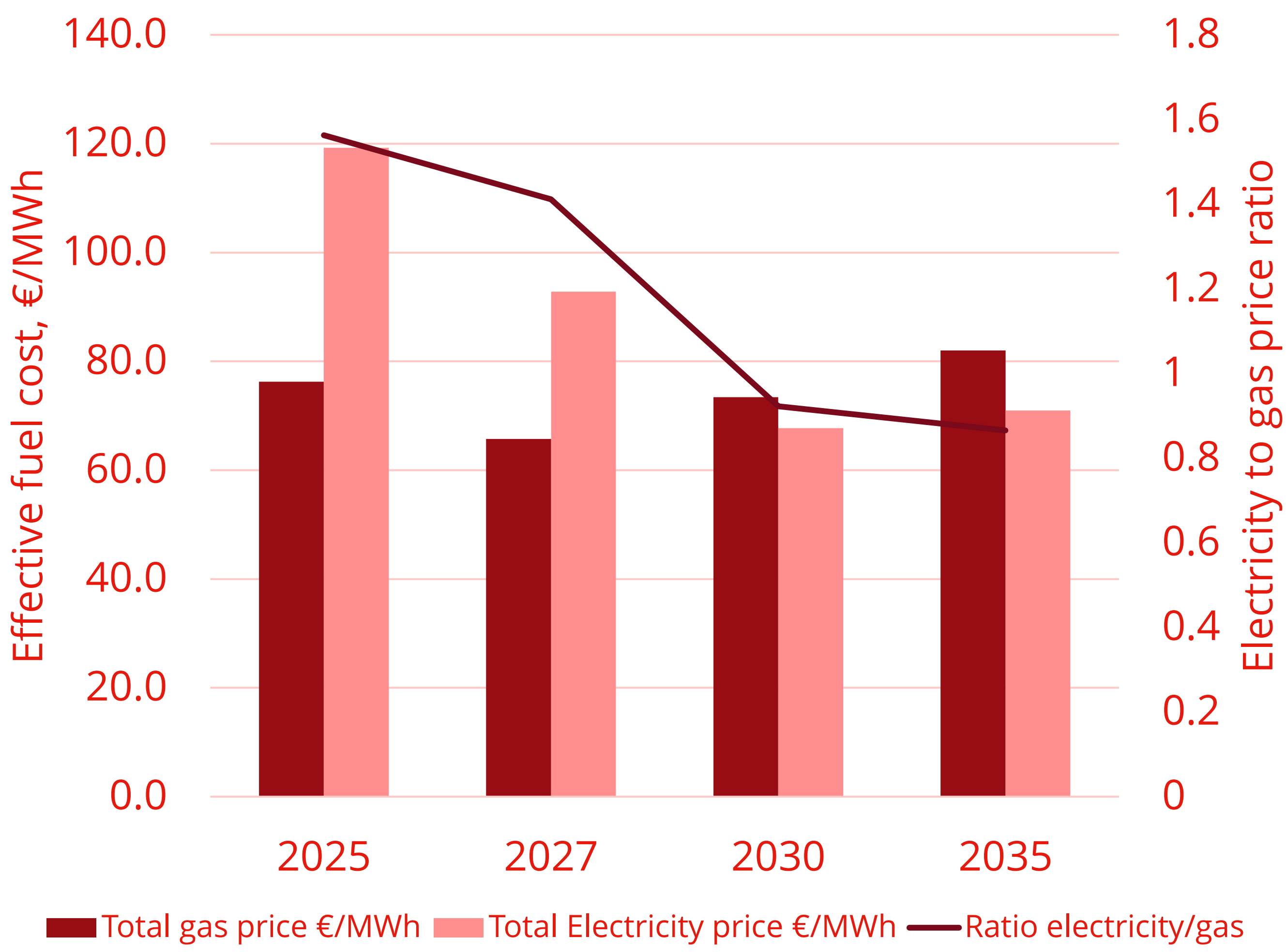
Development of **concept solutions**

Development of **decarbonization roadmap**

Implementation of decarbonization roadmap

What’s next?

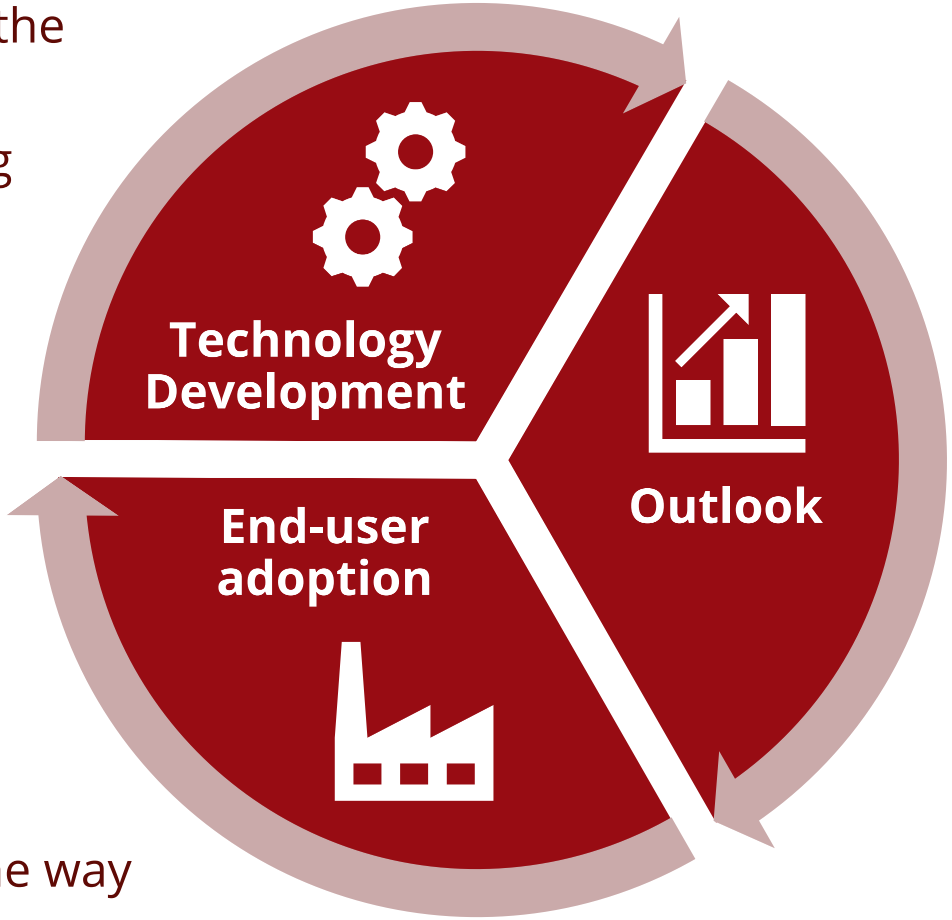
Development of fuel prices



- Data from the Danish Energy Agency - climate status and outlook 2023
- Transportation cost for electricity varies depending on contracts and area's – average assumed
- Taxes for electricity are limited to EU-minimum

Conclusions & Outlook

- Technologies are entering the market
- Technologies are becoming more competitive
- Increasing number of competitors



- Boundary conditions are becoming more favorable
- Scaling of supply-chain
- Learnings ahead from implementations
- Communication & education are key to success

- Decarbonization is gaining traction
- HP-based process heating requires shifted mindset
- Frontrunners are paving the way
- Wide-scale adoption supported by market developments

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