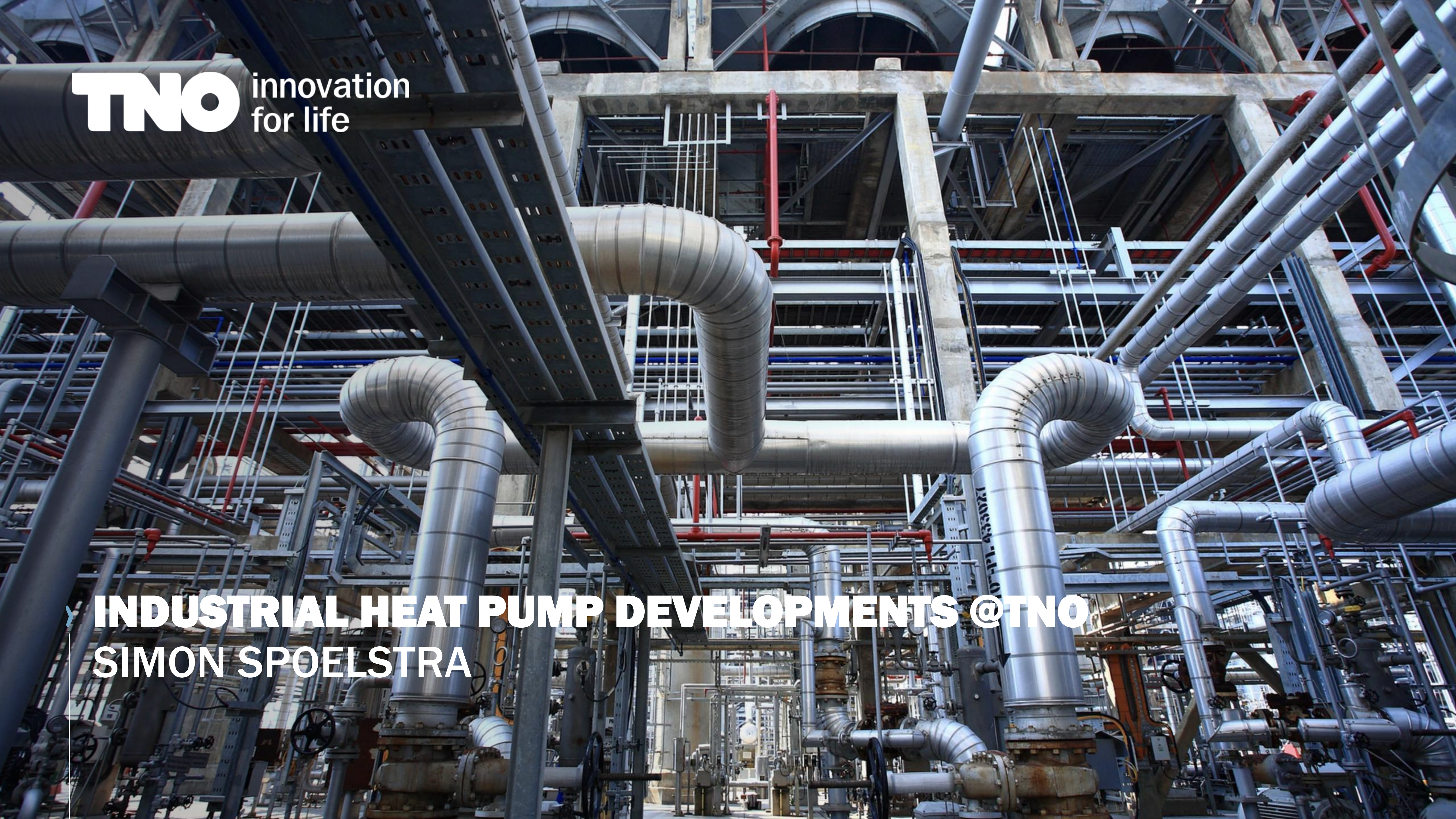

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# INDUSTRIAL HEAT PUMP DEVELOPMENTS @TNO

SIMON SPOELSTRA

# › ONDERZOEKSLOCATIE PETTEN (OLP)

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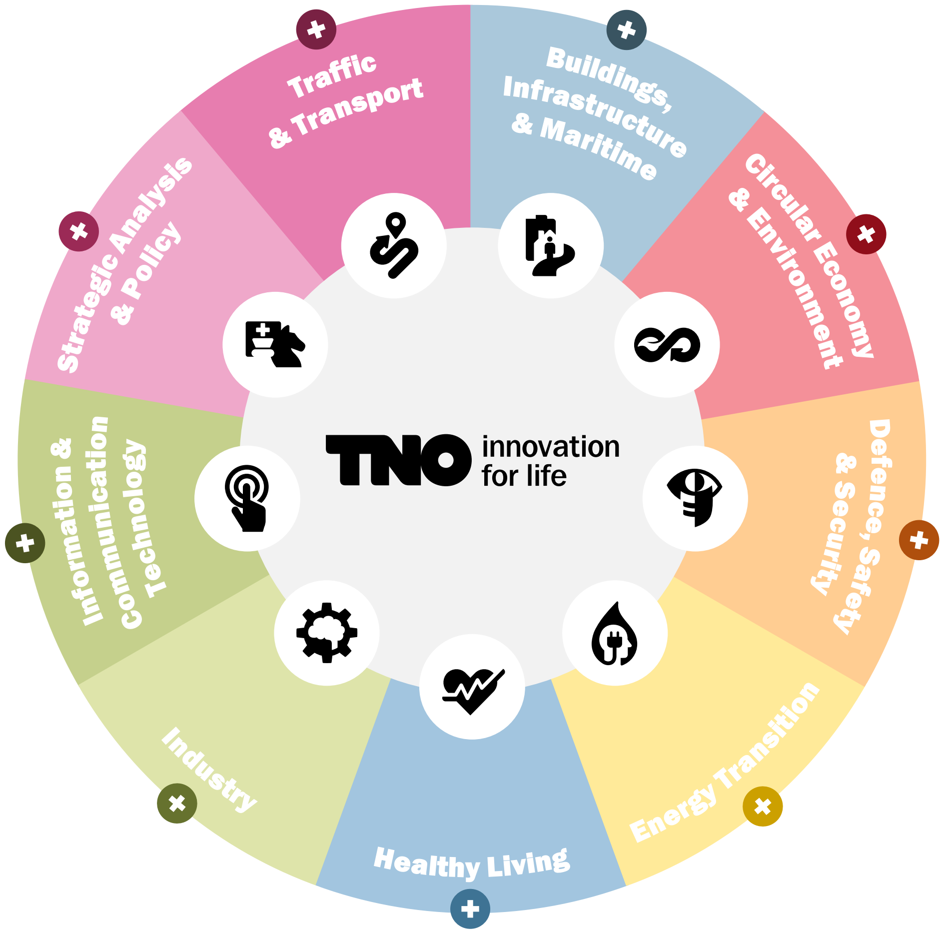
# DUTCH INSTITUTE FOR APPLIED RESEARCH
## THE NETHERLANDS





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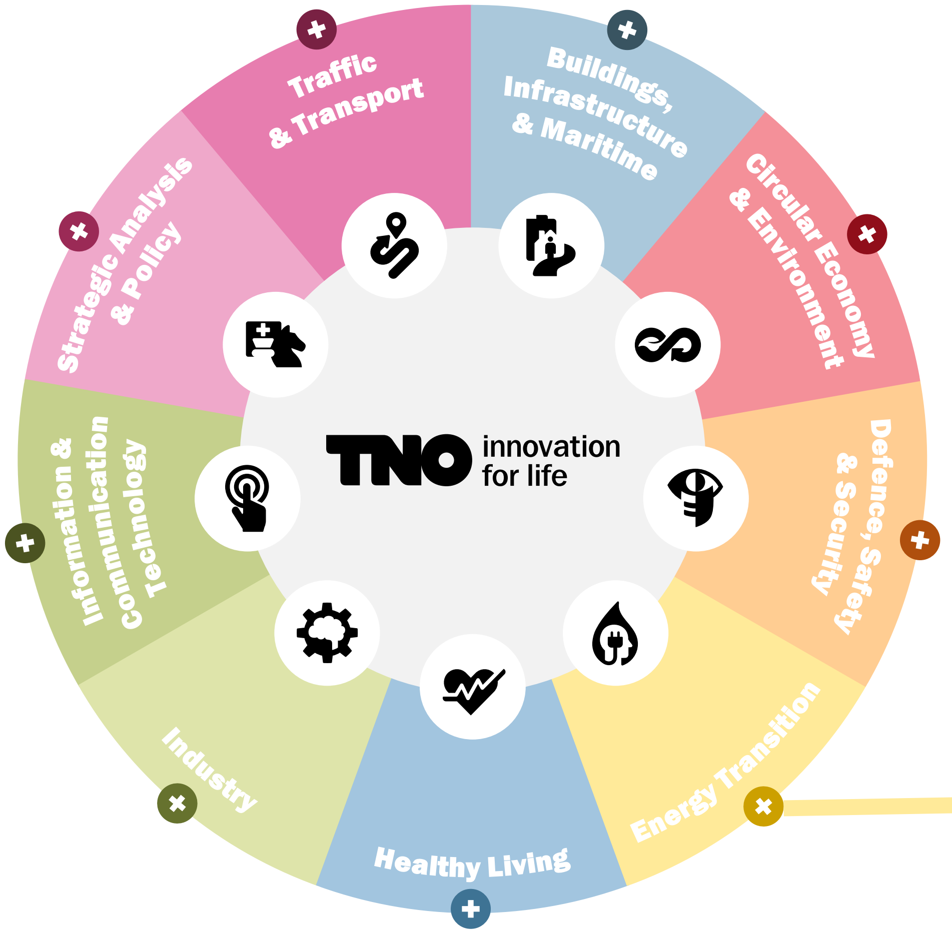
# FOUR ROADMAPS
## ENERGY TRANSITION




**Sustainable Subsurface**
*Home to the Geological Survey of the Netherlands. Levering knowledge of the subsurface for the energy transition.*

**Renewable Electricity**
*Developing and deploying expertise in wind and solar energy.*

**System Transition**
*Enabling a just and socially inclusive energy transition.*

**$CO_2$ Neutral Industry**
*Developing services and technologies for the a sustainable industrial sector.*

# ENERGY TRANSITION

## ROADMAP: TOWARDS $CO_2$ NEUTRAL INDUSTRY

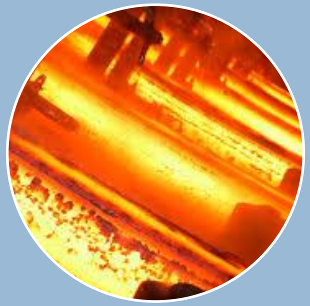

Radically New Industrial Processes

Synthetic Fuels & Chemicals

Biobased Fuels & Chemicals


Clean Hydrogen Production

Energy Infrastructure for Industry

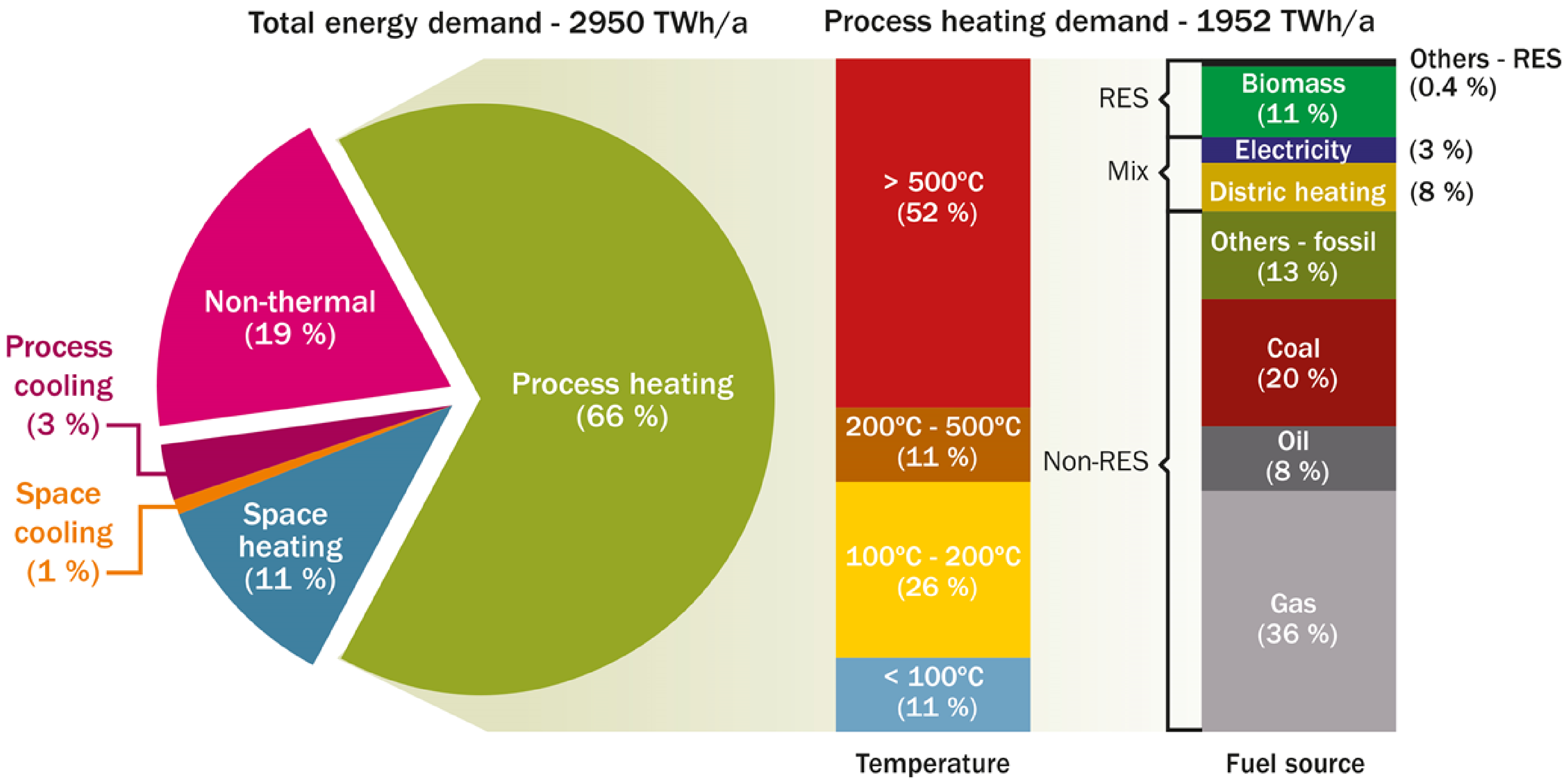


Sustainable Industrial Heat System


Industrial Carbon Capture

Industrial Transformation (multi-unit)

# WHY FOCUS ON SUSTAINABLE INDUSTRIAL HEAT SYSTEM?

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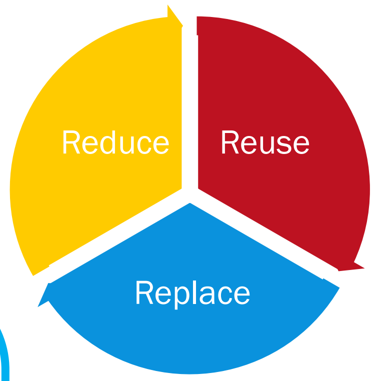
# R&D PROGRAM SIHS




| | Reduce (energy use) | Recovery & Reuse (energy) | Replace (energy source) |
|---|---|---|---|
| | Process Optimisation & Integration | | |
| Direct Use (T >200°C) | | • HT Heat Recovery from Solids<br>• HT Heat Recovery from Fluids<br>• Dispatchable HT Heat Storage | • Fuel diversification & Interchangeability<br>• Electric Heating<br>• Hybrid Solutions (electric and fuel use) |
| Indirect Use (T <200°C) | • Efficient Separation Technologies | • Heat Pumps<br>• LT Heat Storage | • New Technologies<br><br>Replacing driving force<br>Replacing the energy source |

# THERMAL SYSTEMS
## 14 FTE

- Knowledge
  - Industrial heat pump technology
  - Heat storage technology
  - Thermodynamics
  - Heat & mass transfer
- Modelling
  - EES, Modelica/TIL Suite
  - Matlab, Python
  - Excel
- Infrastructure
  - Carnot lab
  - Mollier lab

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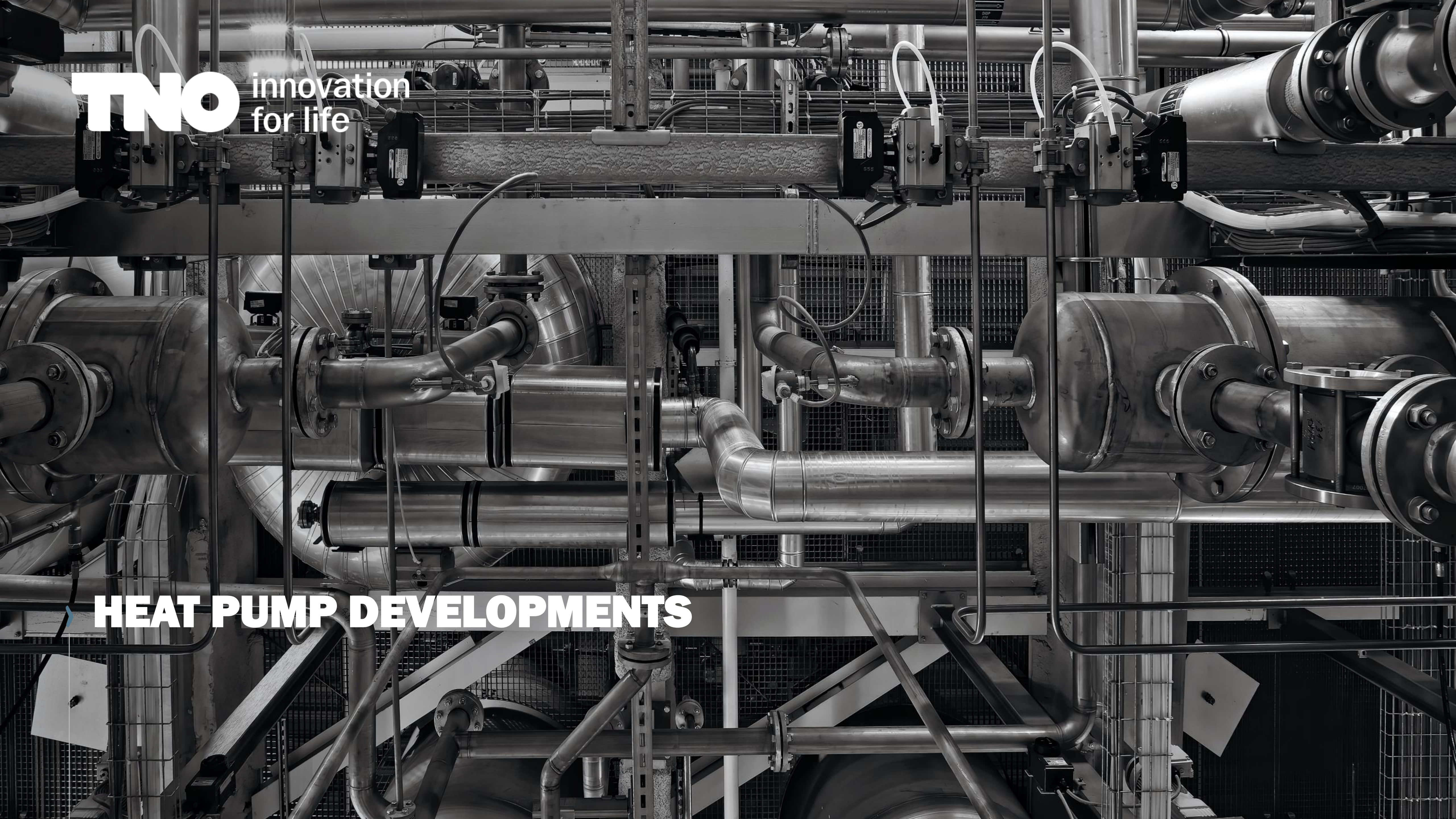
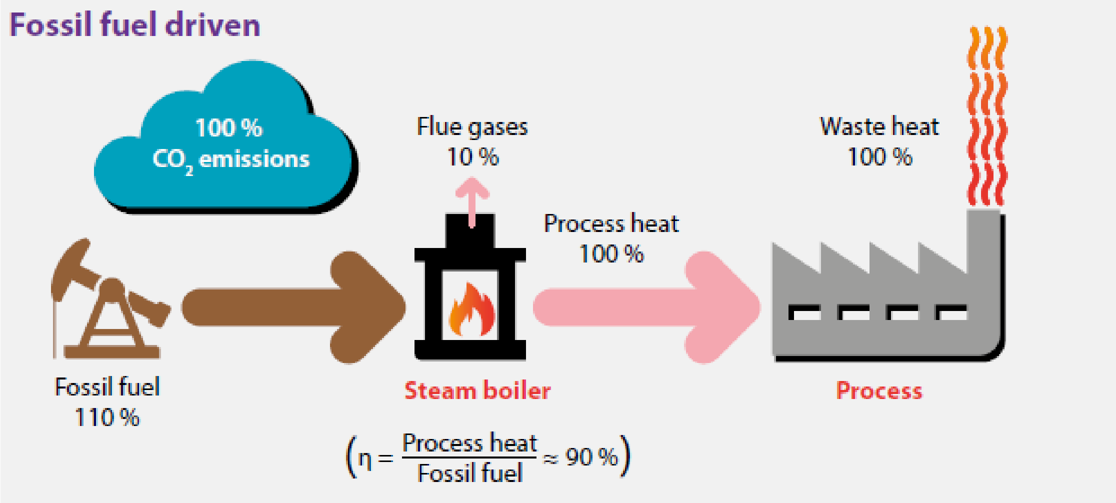


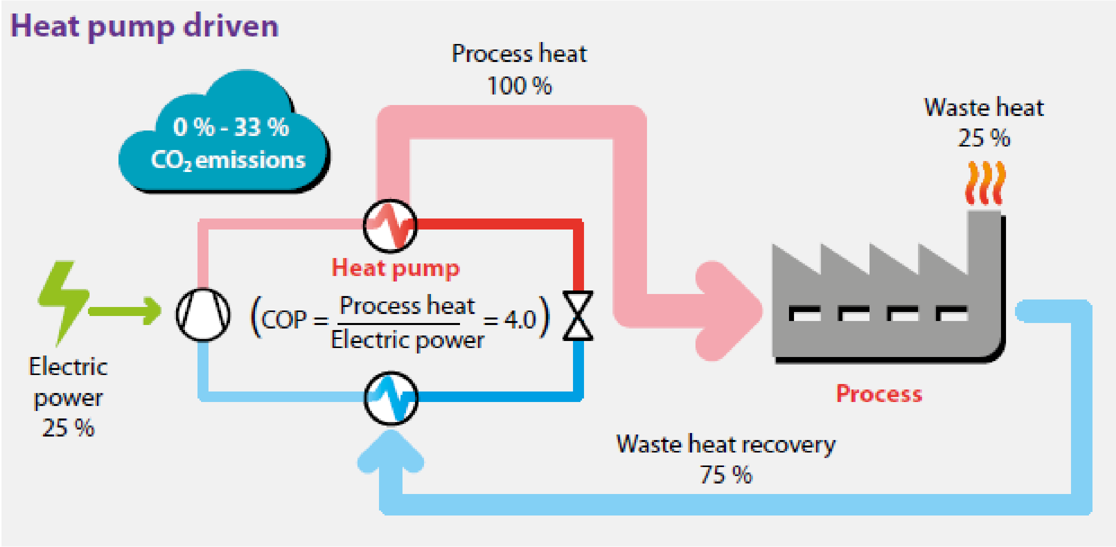
# HEAT PUMP DEVELOPMENTS

# INDUSTRIAL ENERGY USE

# TRANSITION TO CIRCULAR HEAT

- Structure of the existing energy system based around cheap and readily available fossil fuels
  - Heat is cascaded once through the process
  - Low temperature heat expended to environment
- Lacking knowledge on heat pump integration
  - Efficient, & flexible operation, contingency, etc.
- Technology availability is limited
  - Commercial availability to temperatures 90°C → 120°C
- Economic constraints (CAPEX and OPEX)
  - OPEX: Gas/Electricity price, $CO_2$ tax
  - CAPEX: Heat pump, integration costs (1-10x heat pump)
- Limited confidence in the technology



# INDUSTRIAL HEAT PUMP MARKET
## TOP-DOWN APPROACH - NL

- Top-down approach
  - Energy use for heating chemical, refining, food, paper industry
  - % of heat used < 100°C and between 100°C-200°C
  - Assume source of waste heat is always available and of sufficient temperature

- Theoretical heat pump market Netherlands
  - Current market 37 PJ or 1250 $MW_{th}$
  - Future market 155 PJ or 5400 $MW_{th}$

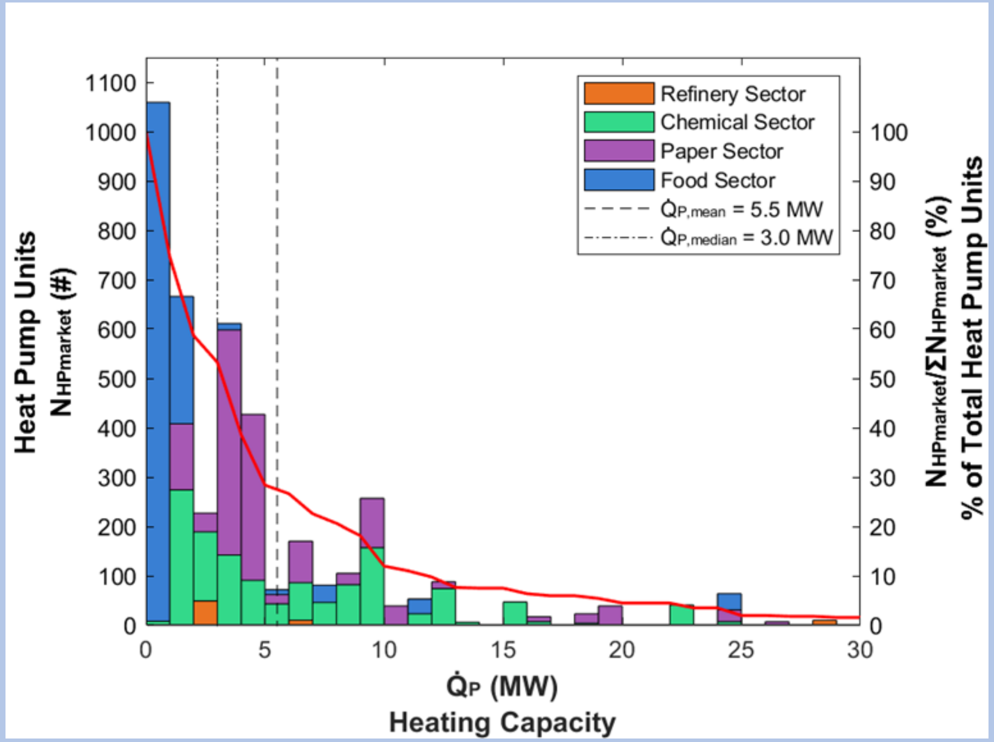
| | < 100°C (PJ/a) | 100°C - 200°C (PJ/a) |
|---|---|---|
| Refining | 0 | 20 |
| (Petro)chemical | 0 | 87 |
| Food | 36 | 29 |
| Paper | 1 | 19 |
| **Total** | **37** | **155** |

# INDUSTRIAL HEAT PUMP MARKET
# BOTTOM-UP APPROACH – EU-28

- Heating/cooling profiles per production process
- Distillation column database (chemicals + refining)
- Paper industry
- Food (brewery, milk, potato processing, sugar )
- Typical plant capacities used to calculate typical heat pump capacities
- Production statistics from Eurostat

- Savings, current electricity system – all renewables
  - Avoided fossil fuel use 371 – 724 PJ/a
  - $CO_2$-emission reduction 37 – 53 Mton/a

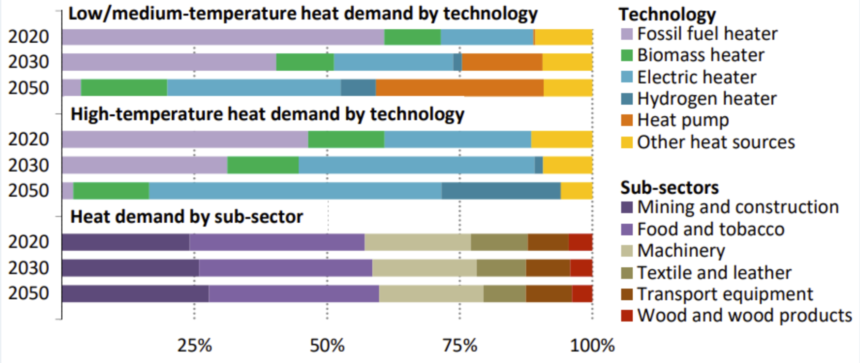
- Market paper can be found here




| | Thermal power (GW) | # units | Process heat (PJ/a) |
|---|---|---|---|
| Refining | 0.5 | 69 | 14 |
| (Petro)chemical | 9.1 | 1291 | 283 |
| Food | 5.5 | 1463 | 98 |
| Paper | 7.9 | 1351 | 245 |
| **Total** | **23.0** | **4174** | **641** |

# IEA NET ZERO 2050 REPORT

**Figure 3.20** ▹ **Share of heating technology by temperature level in light industries in the NZE**






*The share of electricty in satisfying heat demand for light industries rises from less than 20% today to around 40% in 2030 and about 65% in 2050*

Notes: Light industries excludes non-specified industrial energy consumption. Low/medium-temperature heat corresponds to 0-400 °C and high-temperature heat to >400 °C. Other heat sources includes solar thermal and geothermal heaters, as well as imported heat from the power and fuel transformation sector.

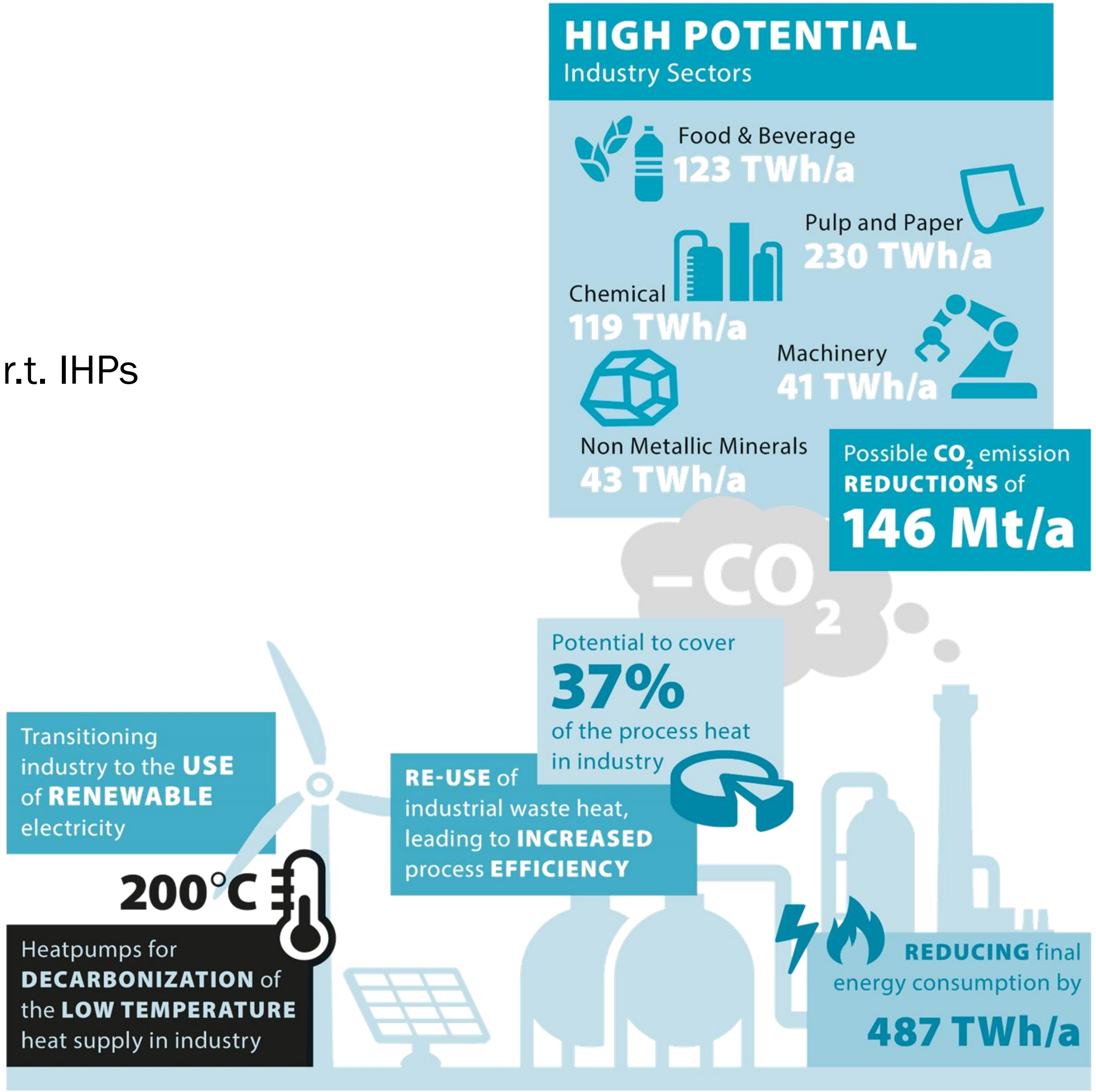
Electricity accounts for around 40% of heat demand by 2030 and about 65% by 2050. For low- (<100 °C) and some medium- (100-400 °C) temperature heat, electrification includes an important role for heat pumps (accounting for about 30% of total heat demand in 2050). In the NZE, around 500 MW of heat pumps need to be installed every month over the next 30 years. Along with electrification, there are smaller roles for hydrogen and bioenergy for high-temperature heat (>400 °C), accounting for around 20% and around 15% respectively of total energy demand in 2050 (Figure 3.20). The rate of electrolyser capacity deployment is much lower than heavy industries, but the unit sizes will also be

# END-USERS
# CHARACTERISTICS

- Well known end-user sub-sectors  for heat pump integration
  - Different products and processes → same drivers, challenges w.r.t. IHPs
- Food sector for first application of heat pumps in industry
  - Experience with technology

## DRIVERS FOR HEAT PUMP INTEGRATION

- Positive business case, driven by:
  - High energy prices (gas vs electricity)
  - Internalised and external price on $CO_2$
- Increased penetration of renewables in the electricity system
  - PEF 2.5→ 2.1→ 1.x
- License to operate
- Social elements
  - Consumer awareness, dependency on Russian gas, etc.

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# BUSINESS CASE

10 MW (16 ton/hr) steam (150 °C) required
waste heat of 80 °C available
8000 running hours

- Steam boiler
  - Efficiency 90%
  - 11 MW natural gas needed
  - Energy use 317 TJ/yr
  - Energy costs 12.7 M€/yr (@ 40 €/GJ)

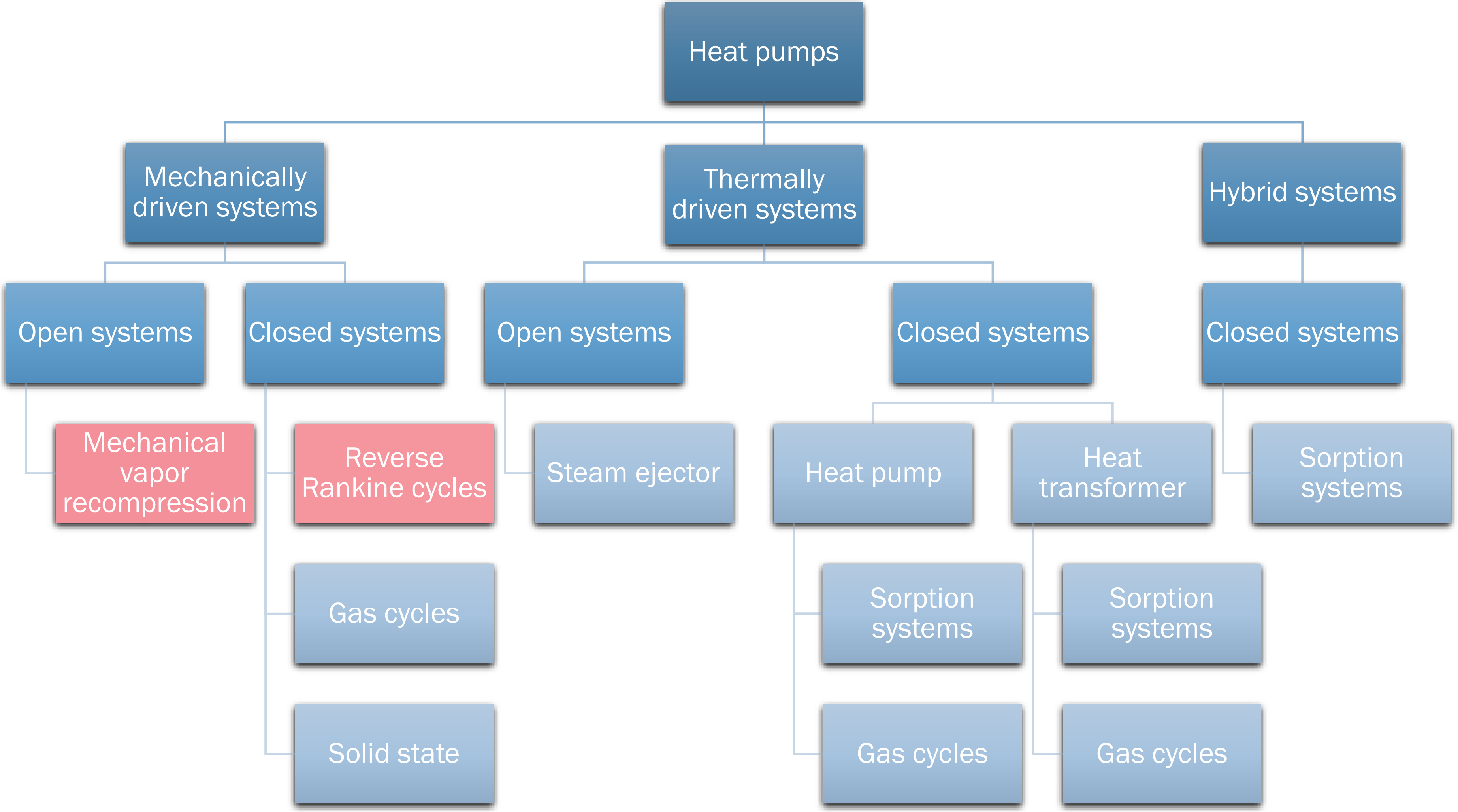
- Heat pump
  - COP = 3
  - 3.33 MW electricity needed
  - Energy use 26.7 GWh
  - Energy costs 5.3 M€/yr (@ 200 €/MWh)

Yearly savings 7.4 M€/yr
Assume investment = 1000 €/$kW_{th}$, including integration => 10 M€
Simple pay back time = 1.4 years

# HEAT PUMP DEVELOPMENT GOALS

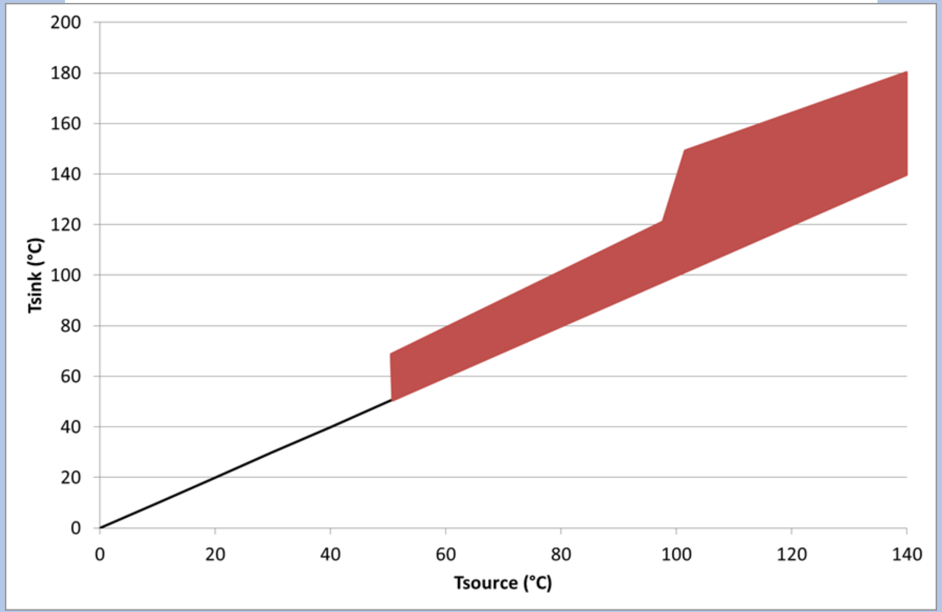
- Temperature window
  - Waste heat < 100°C
  - Process heat > 100°C , up to 200°C
- Performance targets
  - COP > 50% of maximum (Carnot) efficiency
- Unit size
  - Standard sizes of 1, 2 and 5 MW
- Cost targets
  - < 500 €/$kW_{th}$ (heat pump skid)

# HEAT PUMP CLASSIFICATION



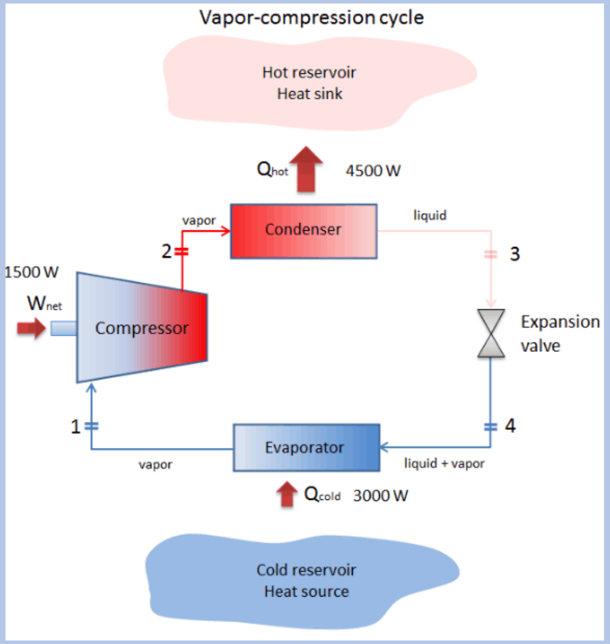
# MECHANICAL VAPOUR RECOMPRESSION

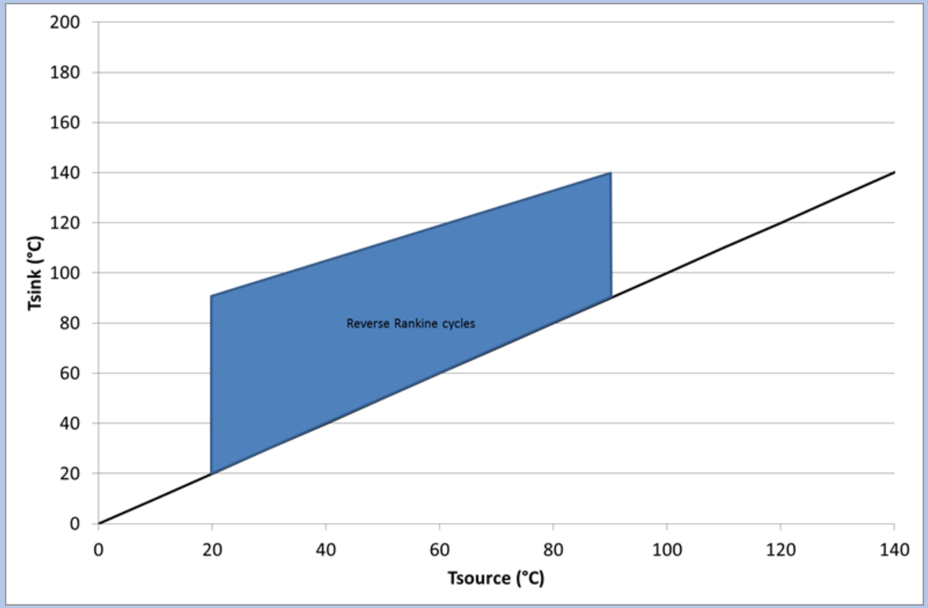
- Direct compression of process medium to higher pressure & temperature
- Applicability depending on process medium
- No intermediate heat exchangers => high efficiency
- Compressors
  - Centrifugal compressor, large capacity, low pressure ratio
  - Screw compressor, medium capacity,  high pressure ratio
  - Multistage
- Applied in food & chemical industry
- Best known example: steam compression



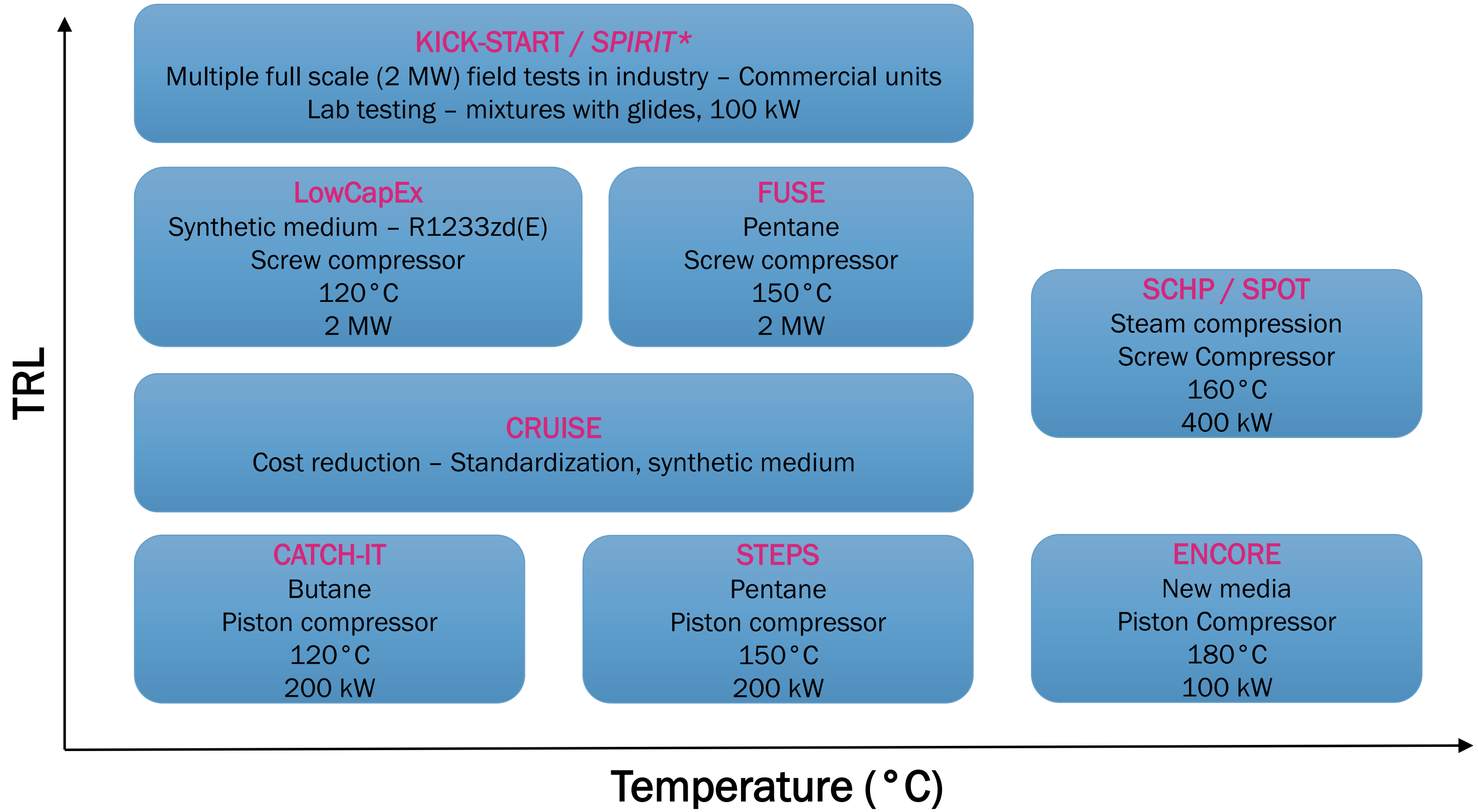
# REVERSE RANKINE CYCLES

- Technology originating from refrigeration
- Operating range determined by working medium
- Multistage compression for high temperature lifts
- Refrigerants subdivided into synthetic and natural ($CO_2$, $NH_3$, hydrocarbons)
- Commercially available for sink temperatures up to 120 - 140 °C
- Under development for sink temperatures > 140 °C, using either hydrocarbons or newly developed synthetic refrigerants



# TNO DEVELOPMENT ROADMAP



# INDUSTRIAL HEAT PUMP DEVELOPMENTS @ ECN / TNO

## A BRIEF HISTORY

CATCH-IT

Industrial pilot demonstration 120°C

STEPS

On-site pilot testing 150°C

CRUISE

Cost reduction for industrial heat pumps

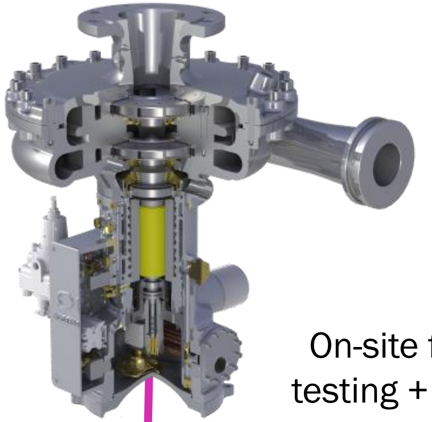
Low-CAPEX

ENCORE

Innovations in HP cycles and components

FUSE

On-site full-scale (1 MW) testing: Natural working fluid



SPOT/SCHP

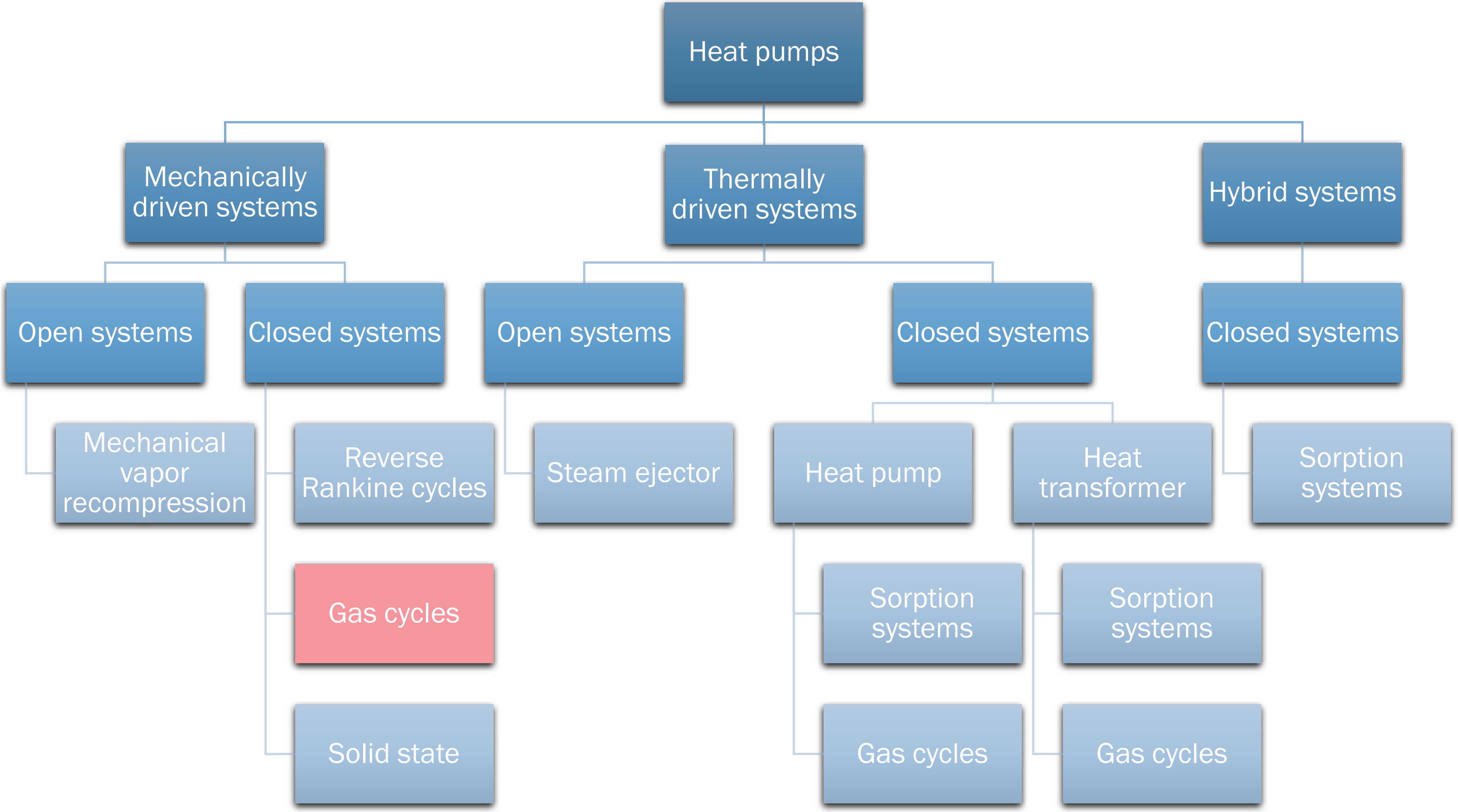
On-site pilot testing of direct steam compression

Kickstart

SPIRIT

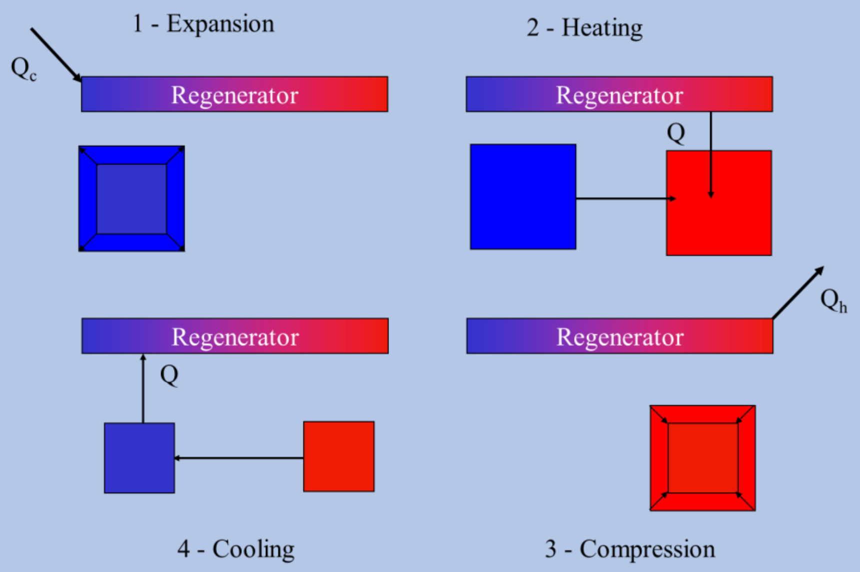
On-site full-scale testing + Industrial demonstrations

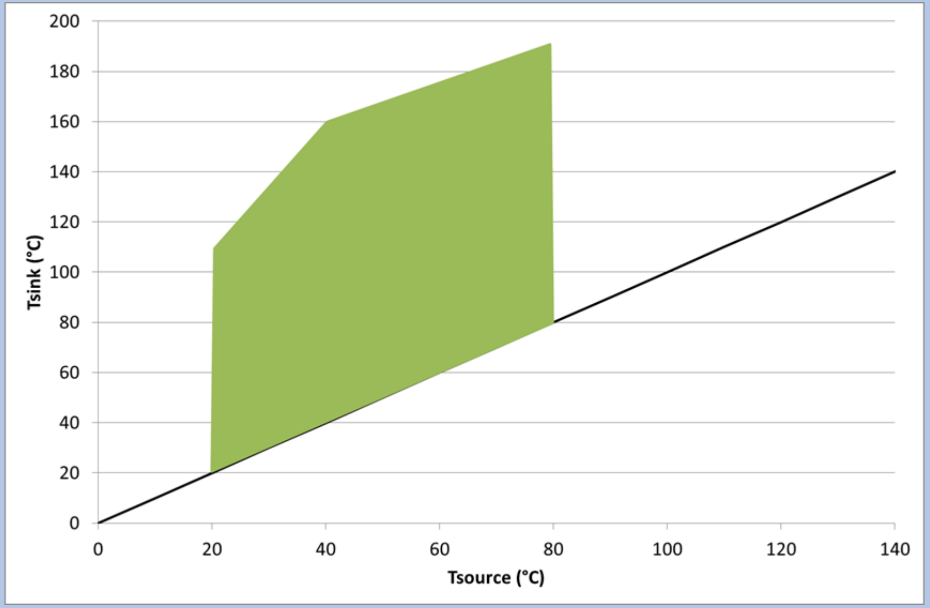
# HEAT PUMP CLASSIFICATION



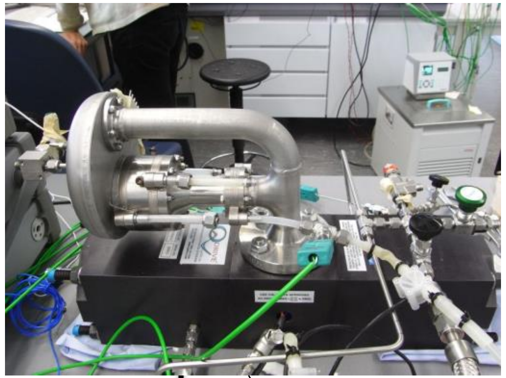
# GAS CYCLES

- Use gas as working medium therewith providing flexibility in operating range
- Working medium usually noble gas
- Stirling/thermoacoustic, Brayton cycles
  - Stirling heat pump commercially available
  - Brayton heat pump (ECOP) entering market, no installation in operation



# THERMOACOUSTIC HEAT PUMP
## DEVELOPMENT ROADMAP



TRL

**CRUISE**
Industrial piston
Compact
Cost savings study
10 kW

**COMTA**
Industrial piston
compact
Steam 110-180°C
10kW

**AP2013**
Piston compressor
Resonator
Oil 110°C
10 kW

**TASTE**
Piston compressor
Resonator
Steam 180°C
10 kW

**HPSEPS**
Linear motor
Resonator
Oil 110°C
0.25-10 kW

**Scale-up studies**

- Full scale design
- Cost reduction studies
- Modular design
- Standardisation
- Business case
- integration

Temperature (°C)

# FINAL REMARKS

- Large energy and $CO_2$-emission reduction potential for industrial heat pumps
- Multiple thermodynamic cycles available for heat pump applications.
- Wide range of operating temperatures already commercially available in the market, however
  - A temperature match does not necessarily indicate a match in capacity
  - Technically feasible does not mean economically feasible
  - Efficiencies are not included in the application area graphs and have large influence on economic feasibility
  - Individual companies may impose specific requirements with respect to working media on their sites
- Heat pumps fit in electrification trend and is a robust choice towards the future
- Developments are ongoing on increasing delivery temperature, performance, and cost reduction
- Large market in NL and EU (23 GW * 1000 €/kW = 23 G€)

- Read our (EU) white paper on relevance of industrial heat pumps for transition of industrial heat system
  https://publications.tno.nl/publication/34636827/LyEUaZ/TNO-2020-heatpump.pdf

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# THANK YOU FOR YOUR TIME AND ATTENTION

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