Magnetocalorics Boosting the Dutch Energy Transition

Green heat pumps and waste heat to power in cities

Michael Maschek

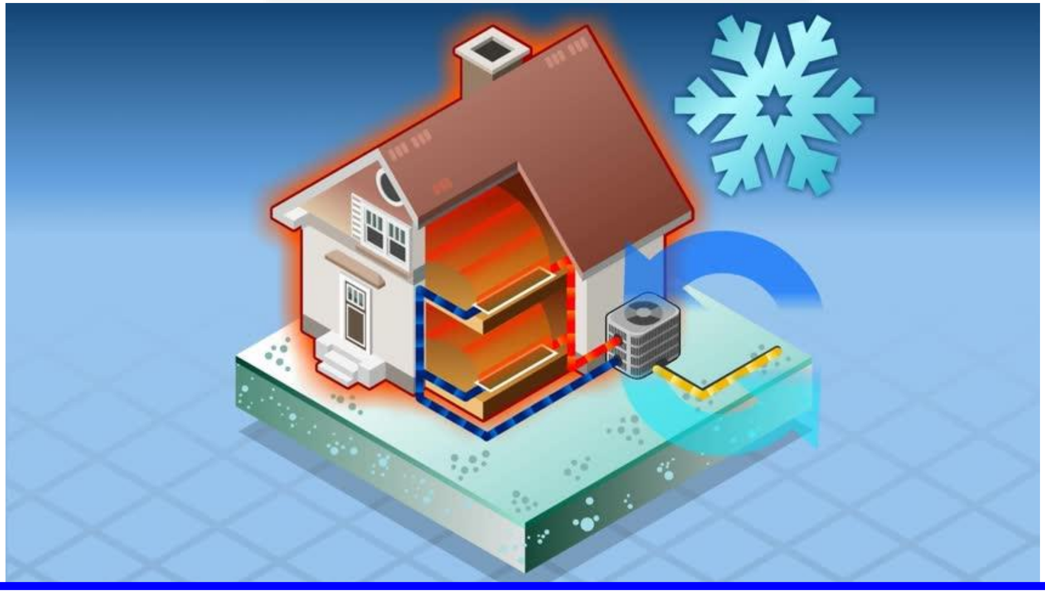
Website: magneto.systems

Climate-KIC is supported by the EIT, a body of the European Union

Challenges in the Netherlands… and everywhere

Magneto

Heating & Cooling



Waste heat: T < 100°C

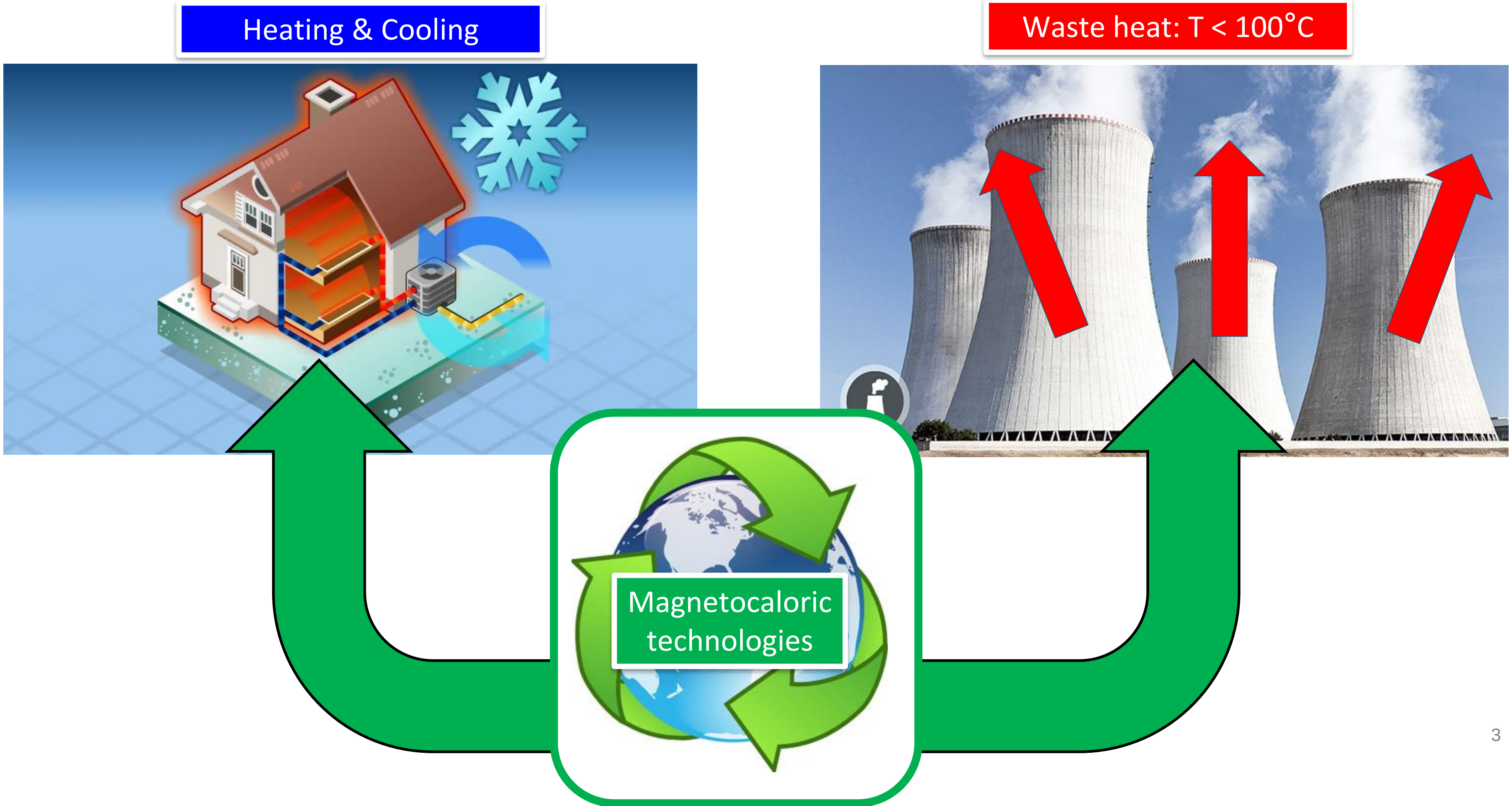
No heating with gas anymore in the Netherlands…

- District heating
- Gas compression heat pumps
  - Matured technology, high efficiency
  - Paris Agreement: Ban of refrigeration gasses (greenhouse gasses, toxic, flammable)
  - Switch to CO_2. High pressure systems up to 100 bar
  - Noisy

How to efficiently utilize waste heat…

- Abundantly available
- Heat is a low grade energy
- Difficult to store and transport
- Often extra effort to cool waste heat

Challenges in the Netherlands… and everywhere



Magnetic cooling: Giauque 1933

768 LETTERS TO THE EDITOR

Attainment of Temperatures Below 1° Absolute by Demagnetization of $Gd_2(SO_4)_3 \cdot 8H_2O$

We have recently carried out some preliminary experiments on the adiabatic demagnetization of $Gd_2(SO_4)_3 \cdot 8H_2O$ at the temperatures of liquid helium. As previously predicted by one of us, a large fractional lowering of the absolute temperature was obtained.

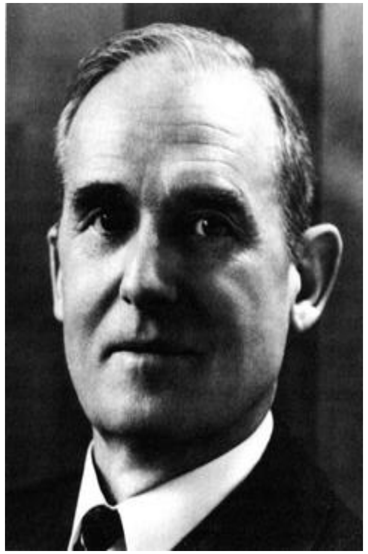
An iron-free solenoid producing a field of about 8000 gauss was used for all the measurements. The amount of $Gd_2(SO_4)_3 \cdot 8H_2O$ was 61 g. The observations were checked by many repetitions of the cooling. The temperatures were measured by means of the inductance of a coil surrounding the gadolinium sulfate. The coil was immersed in liquid helium and isolated from the gadolinium by means of an evacuated space. The thermometer was in excellent agreement with the temperature of liquid helium as indicated by its vapor pressure down to 1.5°K.

On March 19, starting at a temperature of about 3.4°K, the material cooled to 0.53°K. On April 8, starting at about 2°, a temperature of 0.34°K was reached. On April 9, starting at about 1.5°, a temperature of 0.25°K was attained.

It is apparent that it will be possible to obtain much lower temperatures, especially when successive demagnetizations are utilized.

W. F. Giauque
D. P. MacDougall

Department of Chemistry,
University of California,
Berkeley, California,
April 12, 1933.



Nobel prize 1949

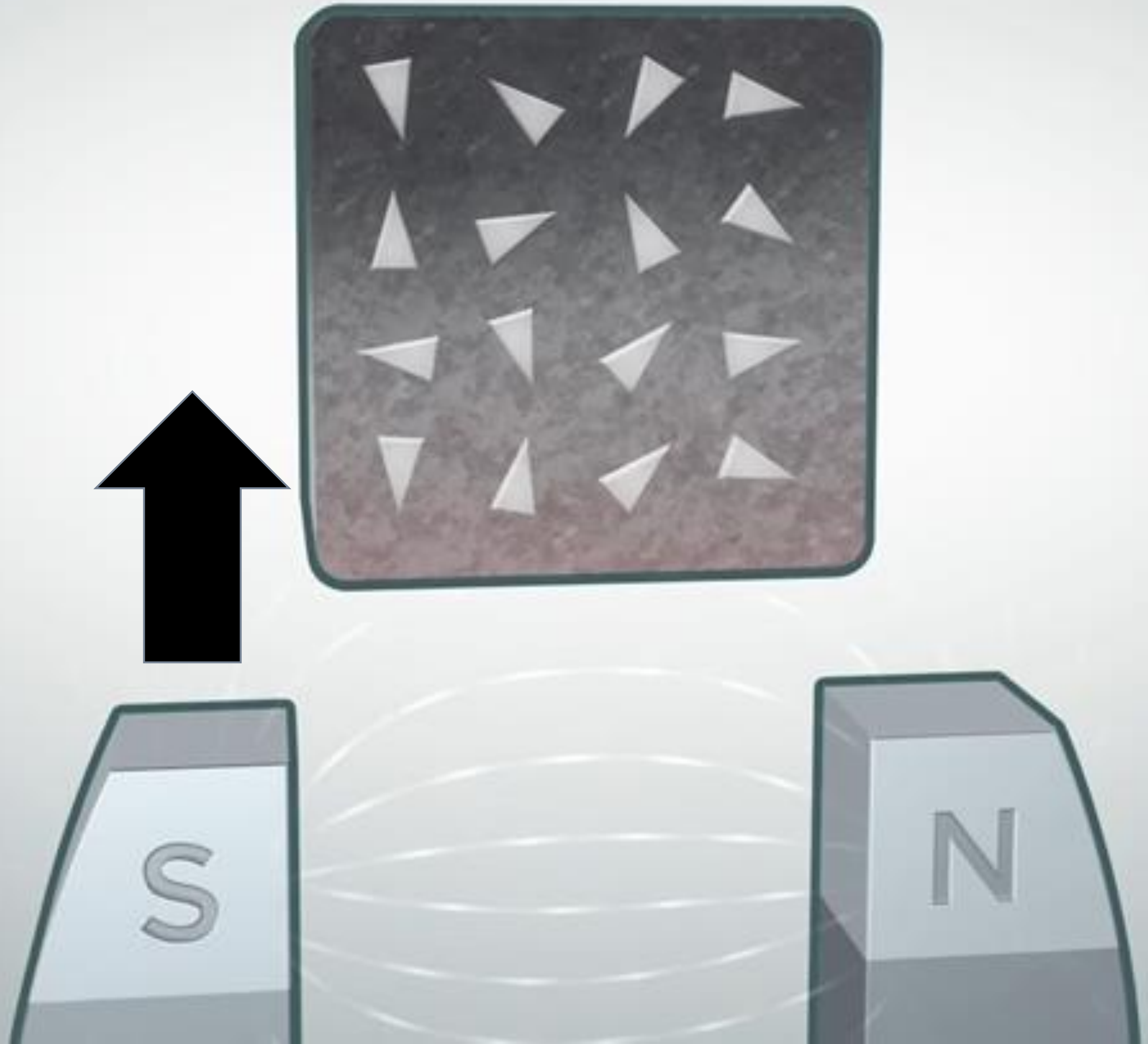
$61g\ Gd_2(SO_4)_3 \cdot 8H_2O$, $\Delta B = 0.8T$, $1.5K \rightarrow 0.25K$

Magneto

QUANTUM PHYSICS !

Magnetocaloric effect (MCE)

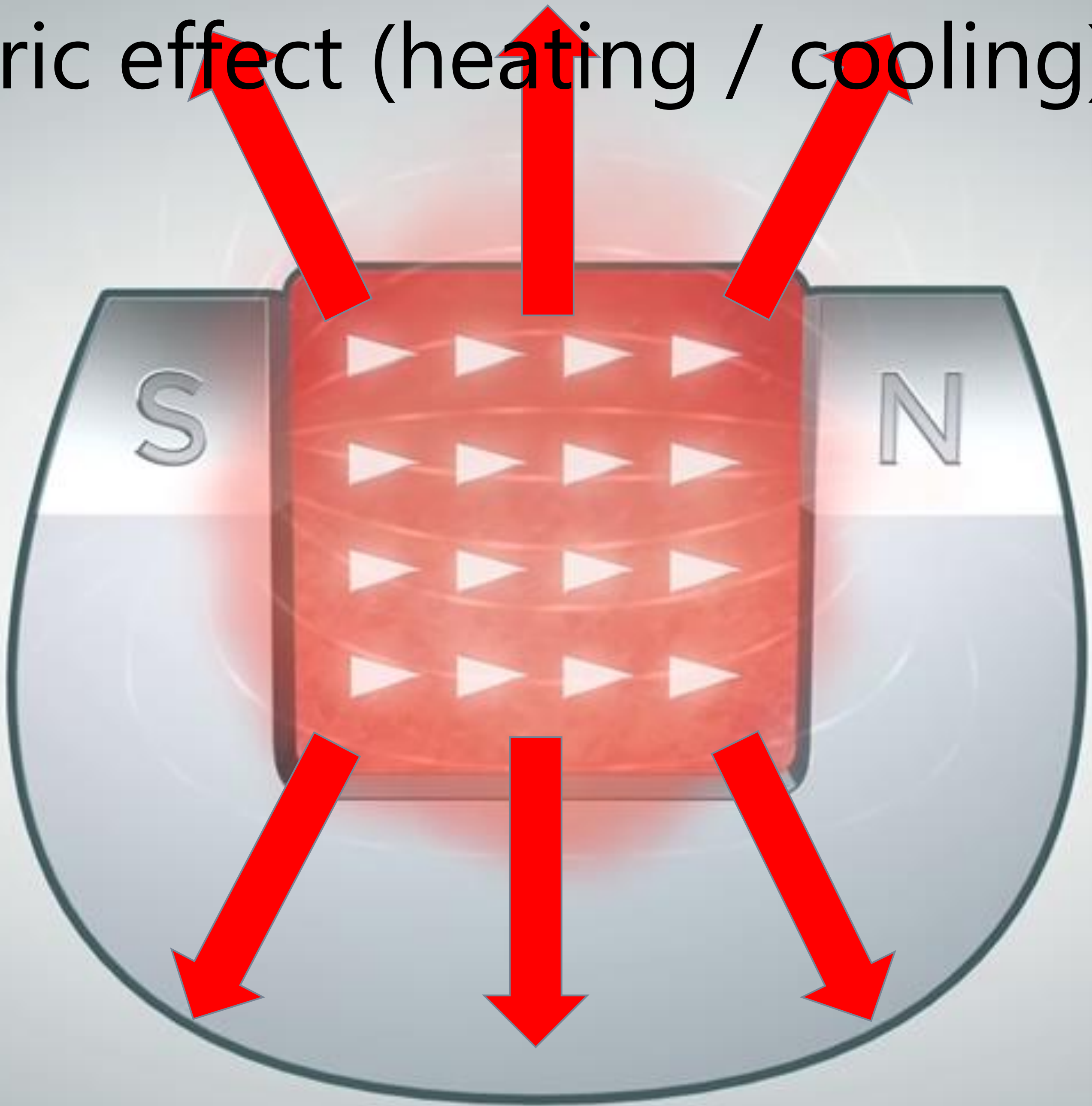
Magnetocaloric effect (heating / cooling)



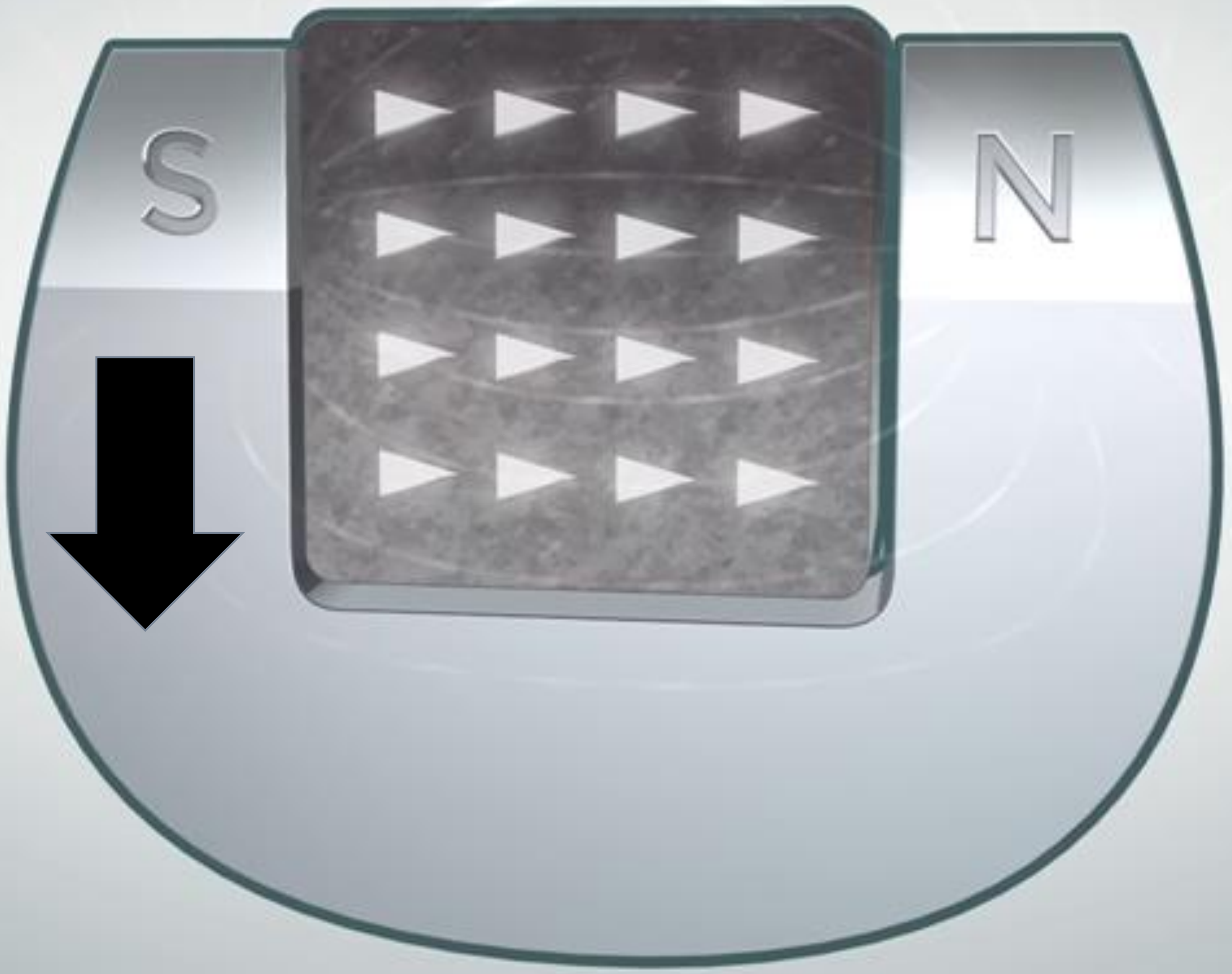
Magnetocaloric effect (heating / cooling)

apply
magnetic field

heating



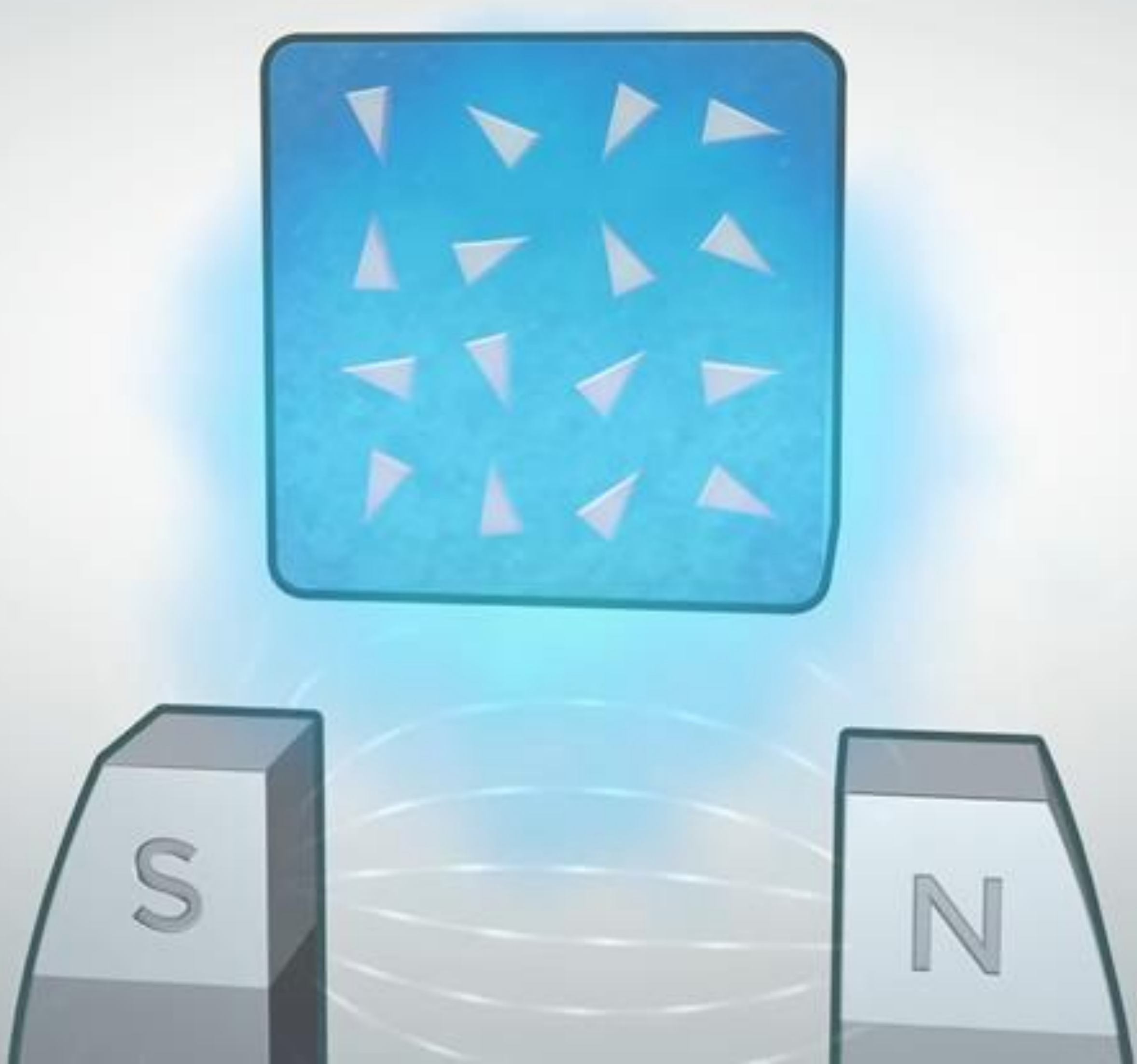
Magnetocaloric effect (heating / cooling)



Magnetocaloric effect (heating / cooling)

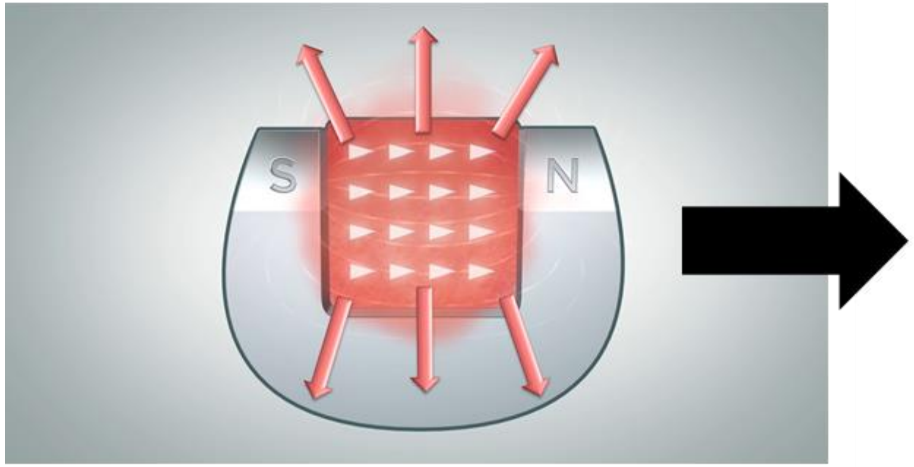
remove magnetic field

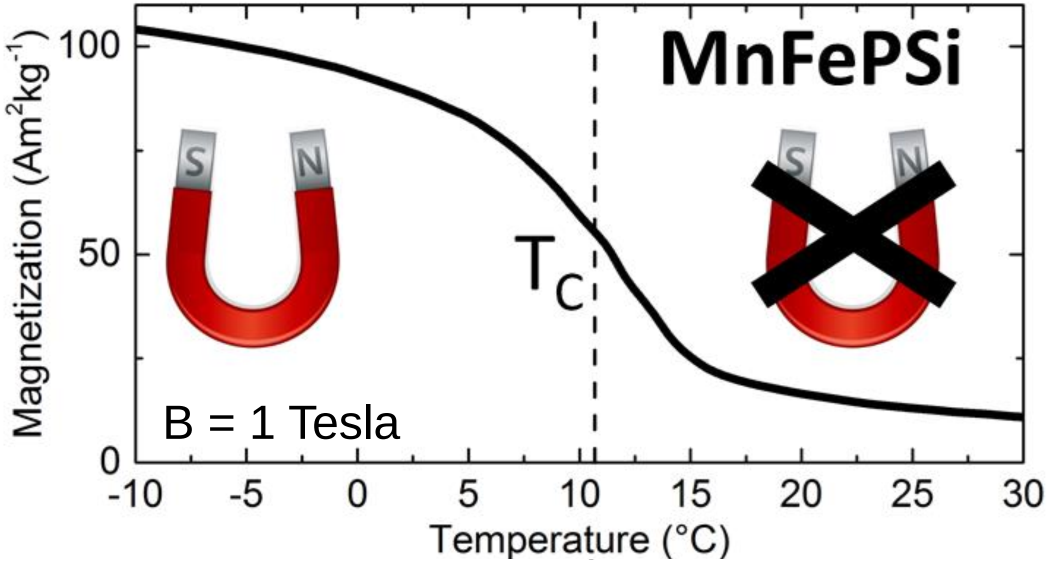
cooling

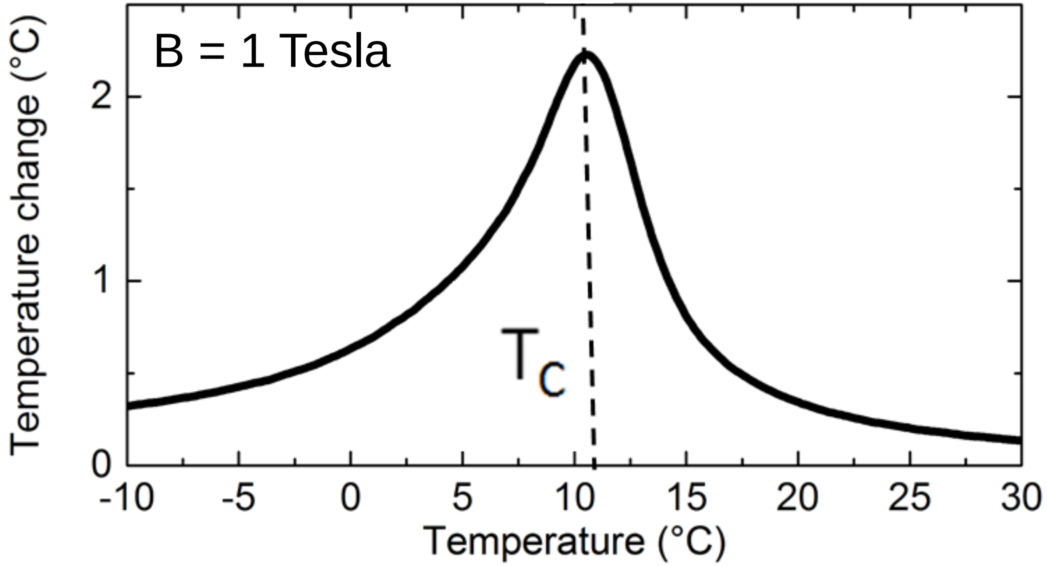


Magnetocaloric properties

Curie temperature: T_C
(Magnetic phase transition)







Magnetocaloric properties

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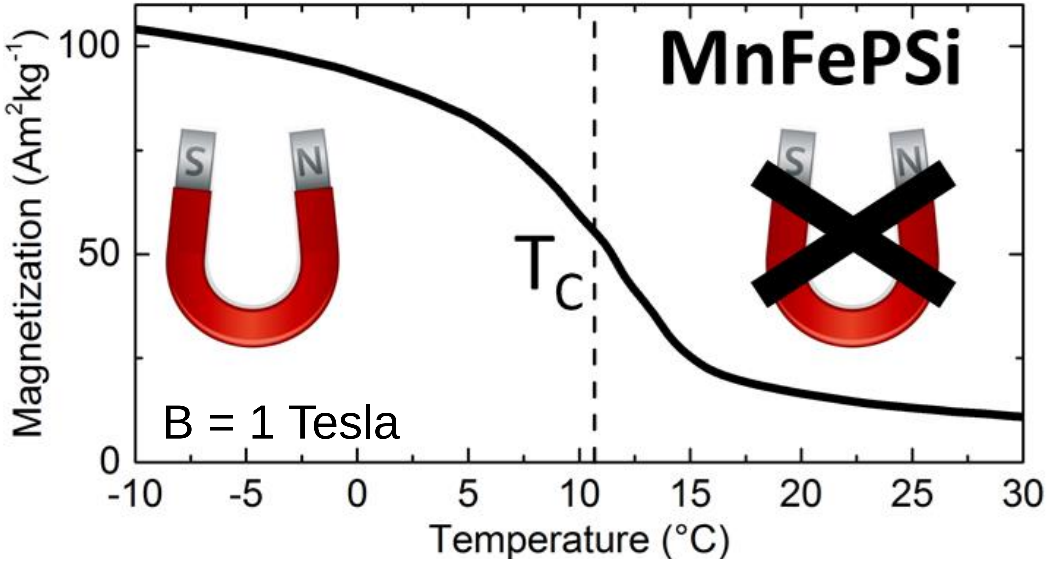
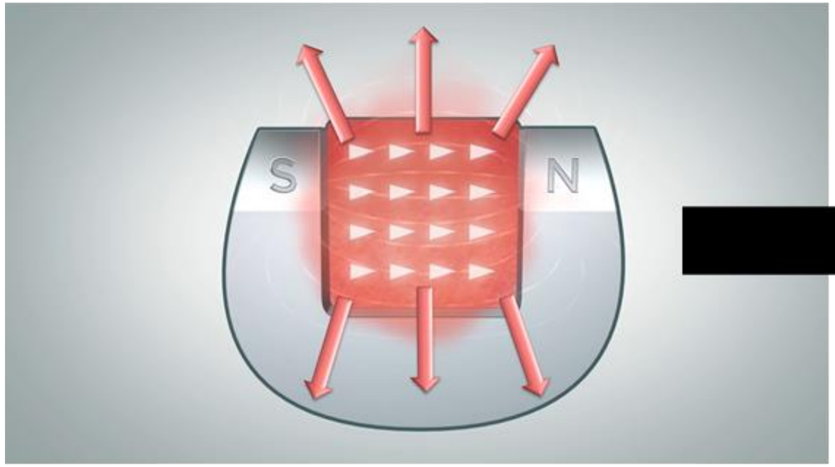
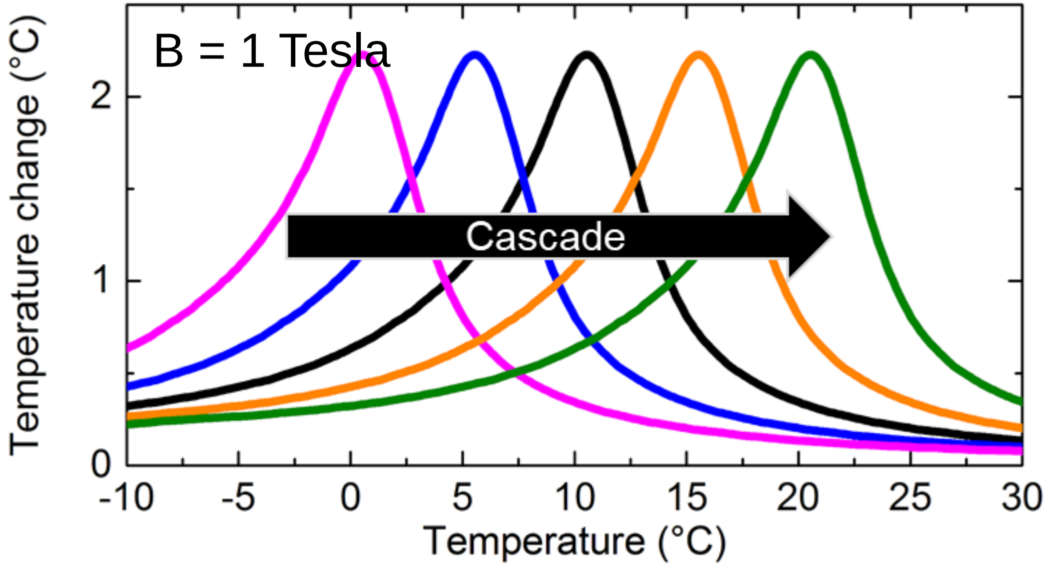


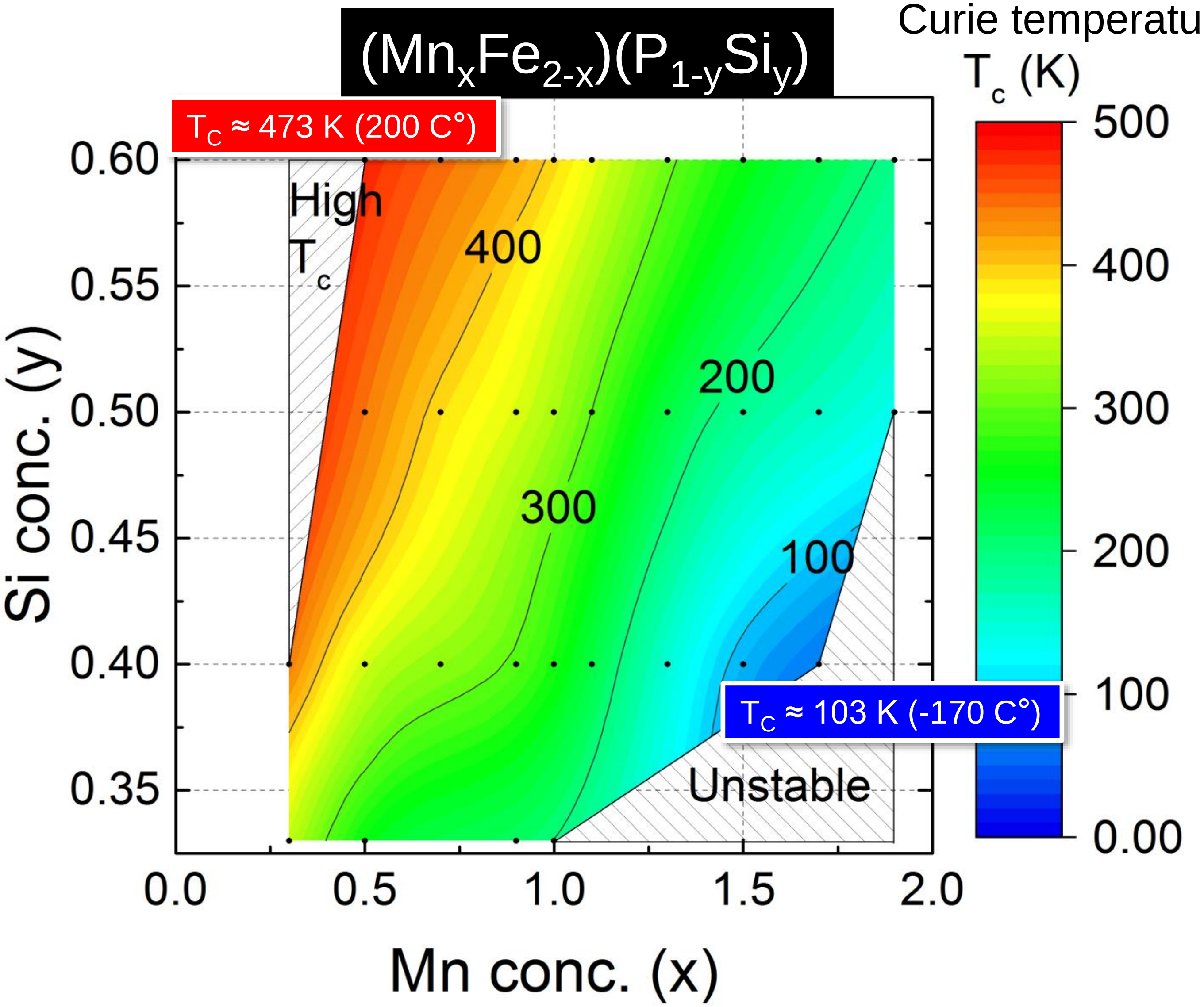




Magnetocaloric Material: Mn-Fe-P-Si

Mn-Fe-P-Si

- Developed by Prof. Ekkes Brück *et al.* (TUD, FAME)
- High performance for room temperature applications
- Abundant materials
- Non-toxic
- rare-earth free
- Large operation temperature range



X. You, TUD (FAME), PhD thesis 2020

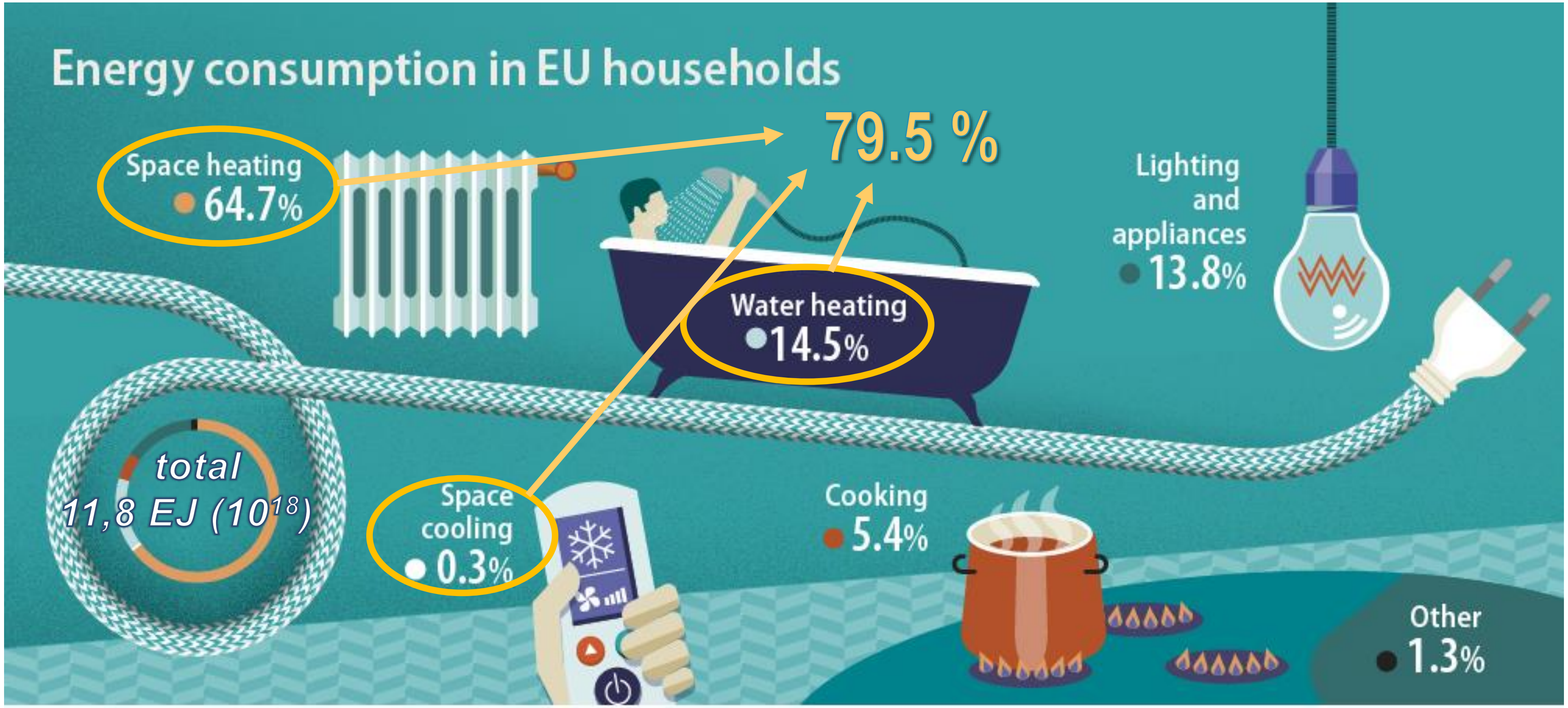
Magneto

Magnetocaloric heat pump

A real alternative to gas compression…

Introduction

- Energy consumption breakdown for residential sector



Data extracted in March 2018 ec.europa.eu/eurostat

Introduction

- What kind of space cooling and heating devices we have in a house?

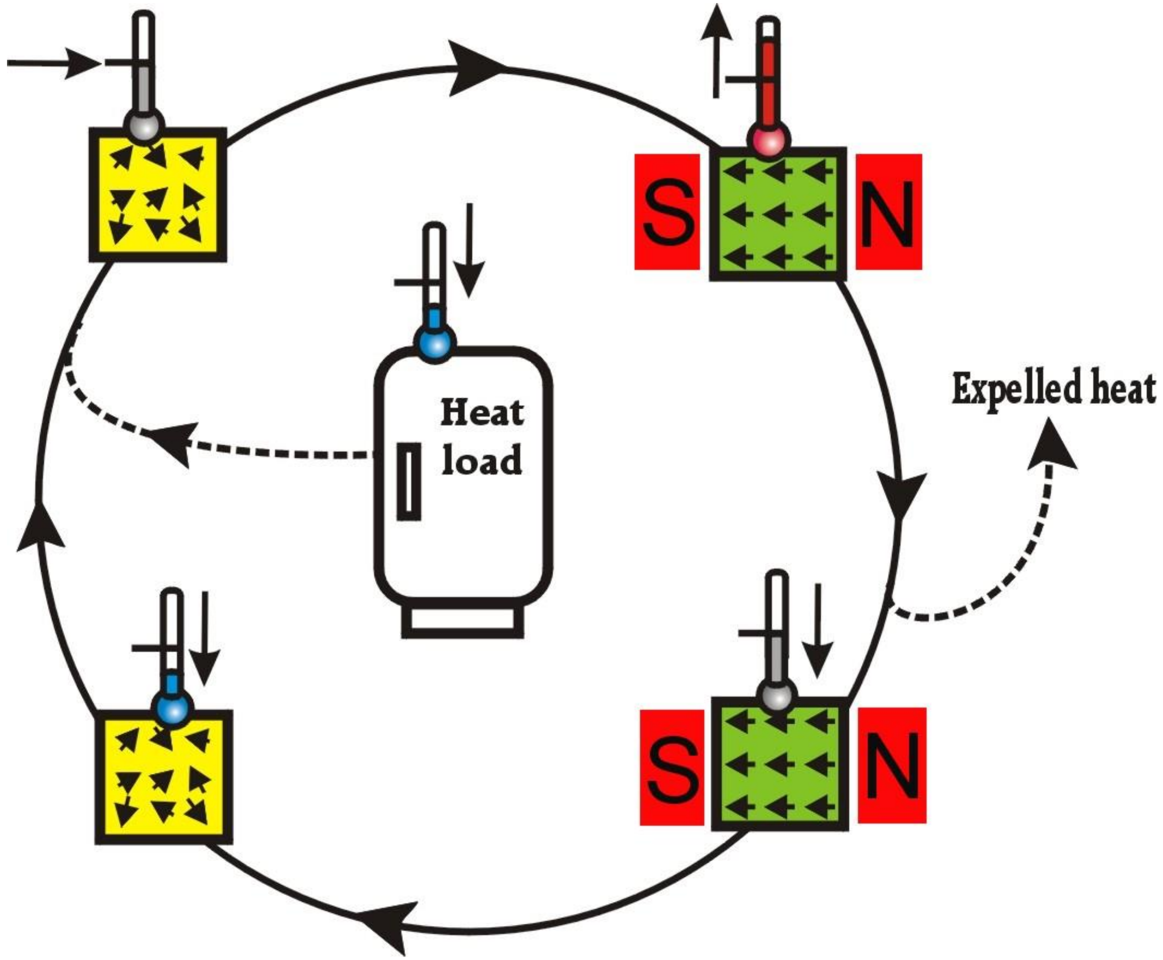
~35% of the global power consumption*

* GLOBAL STATUS REPORT 2016, UNEP

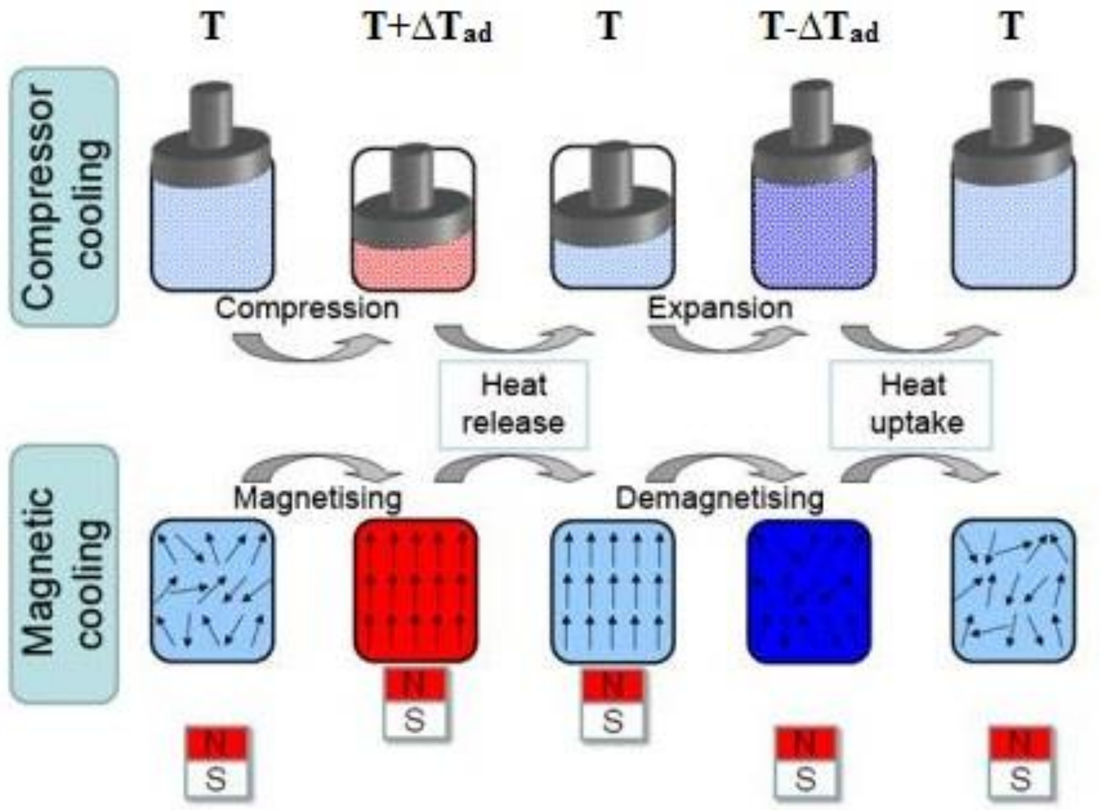
- Greenhouse & Ozone gasses: toxic, flammable
- Noisy

- Fossil fuels
- Unsustainable resource

The Principle of Magnetocaloric Heat Pump

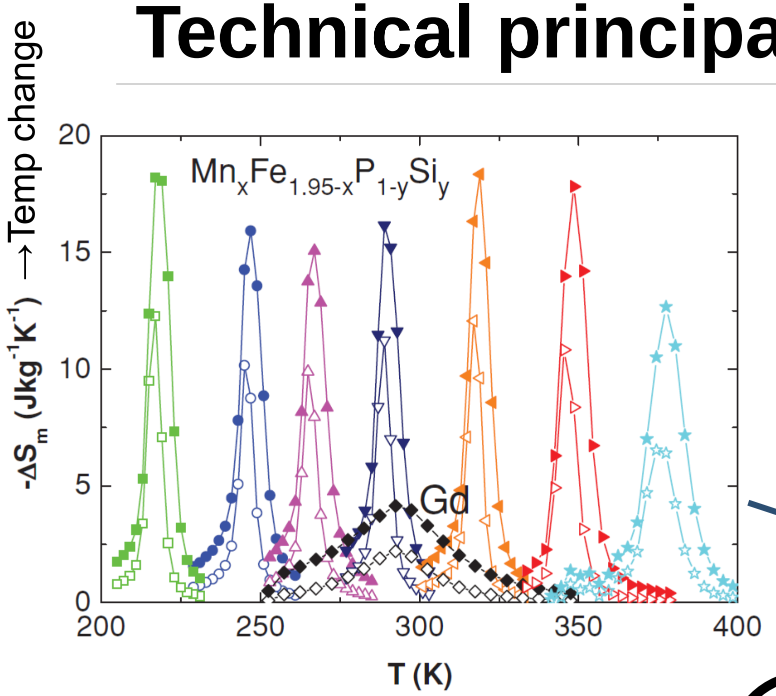


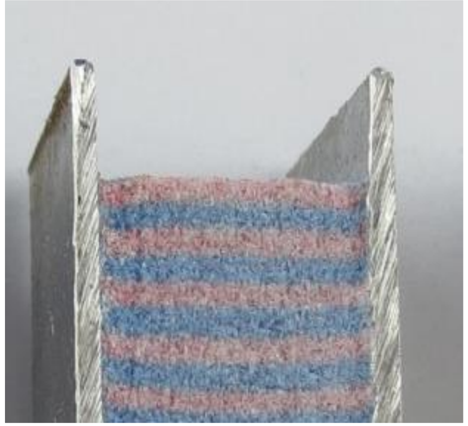
Gas compression cycle
40%~45% Carnot efficiency

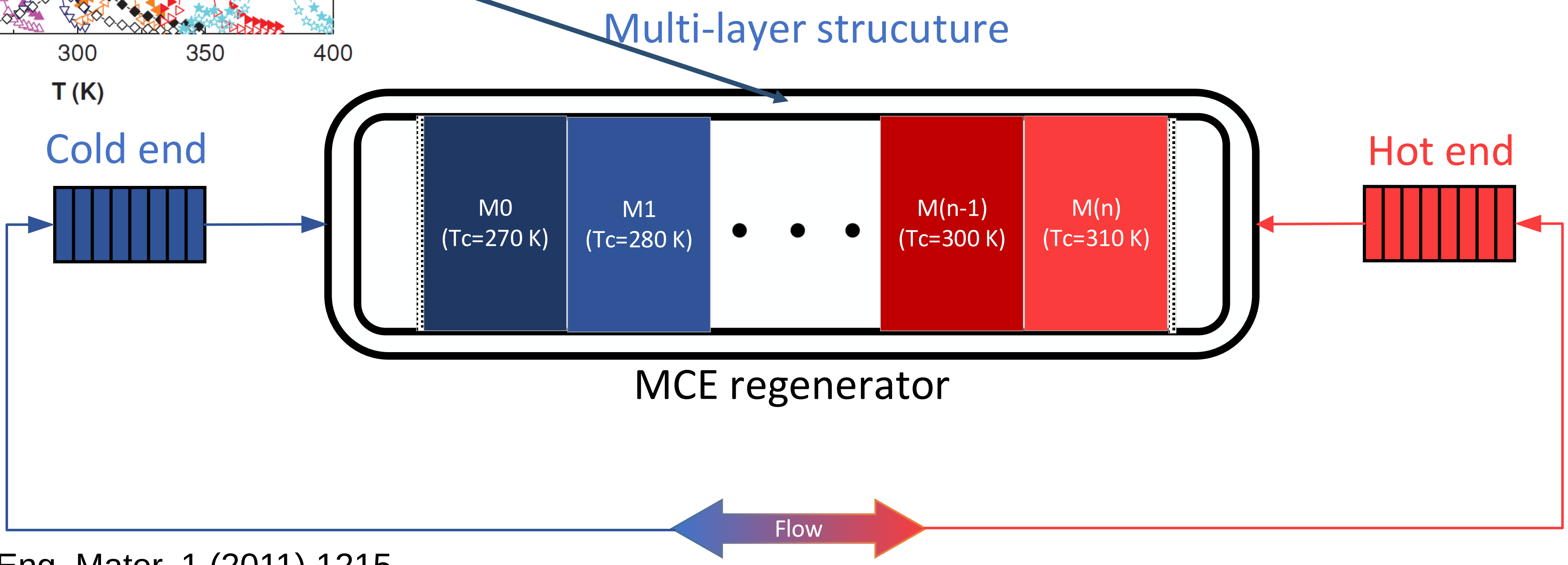


Magnetocaloric cycle:
60% Carnot efficiency

Technical principal – MCE Regenerator



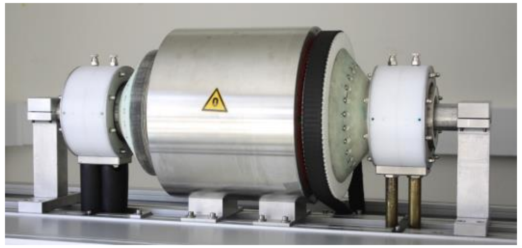




Dung *et al.*, Adv. Eng. Mater. 1 (2011) 1215.

State-of-the-Art – Magnetocaloric Heat Pump

- The prototypes

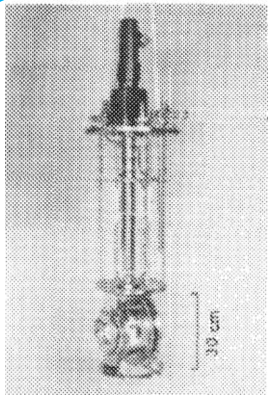


Lozano, J. A., et al. (2014). "Experimental and numerical results of a high frequency rotating active magnetic refrigerator." International Journal of Refrigeration

Johra, H., Filonenko, K., Heiselberg, P., Veje, C., Dall'Olio, S., Engelbrecht, K., Bahl, C., 2019. Integration of a magnetocaloric heat pump in an energy flexible residential building. Renewable Energy.

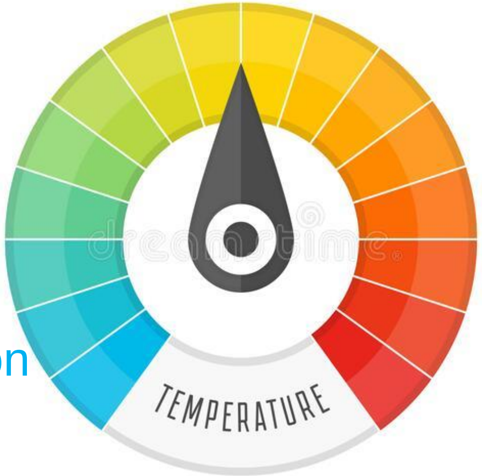
Lionte, S., et al. (2020). "A 15 kW magnetocaloric proof-of-concept unit: initial development and first experimental results." International Journal of Refrigeration

Room temperature application
-20 °C – 45 °C



Y. Hakuraku, H. Ogata
Journal of Applied Physics 1986

Jamie Holladay, pacific northwest national laboratory, june 2016

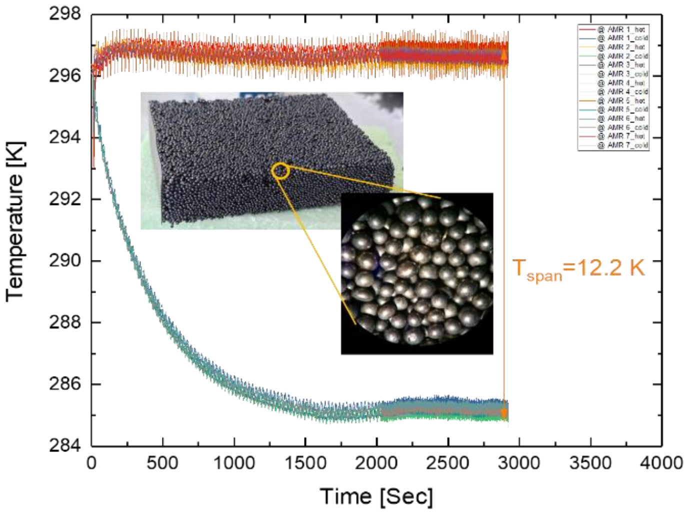


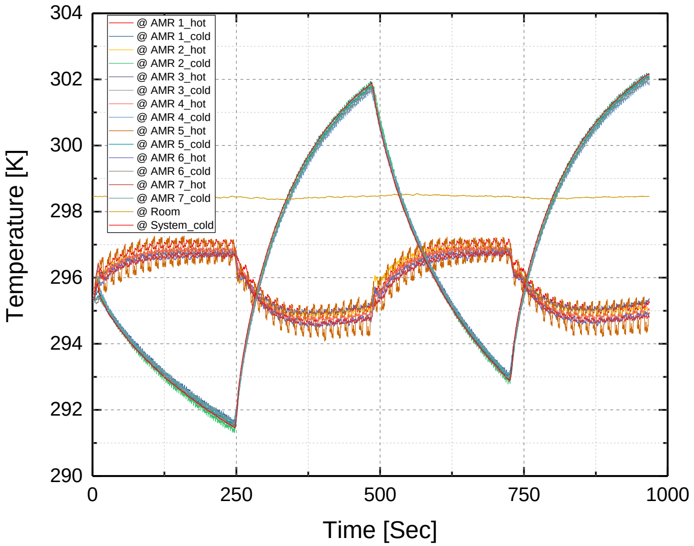
Low temperature application
-30 °C – -273 °C

High temperature application
>50°C

State-of-the-Art – Magnetocaloric Heat Pump

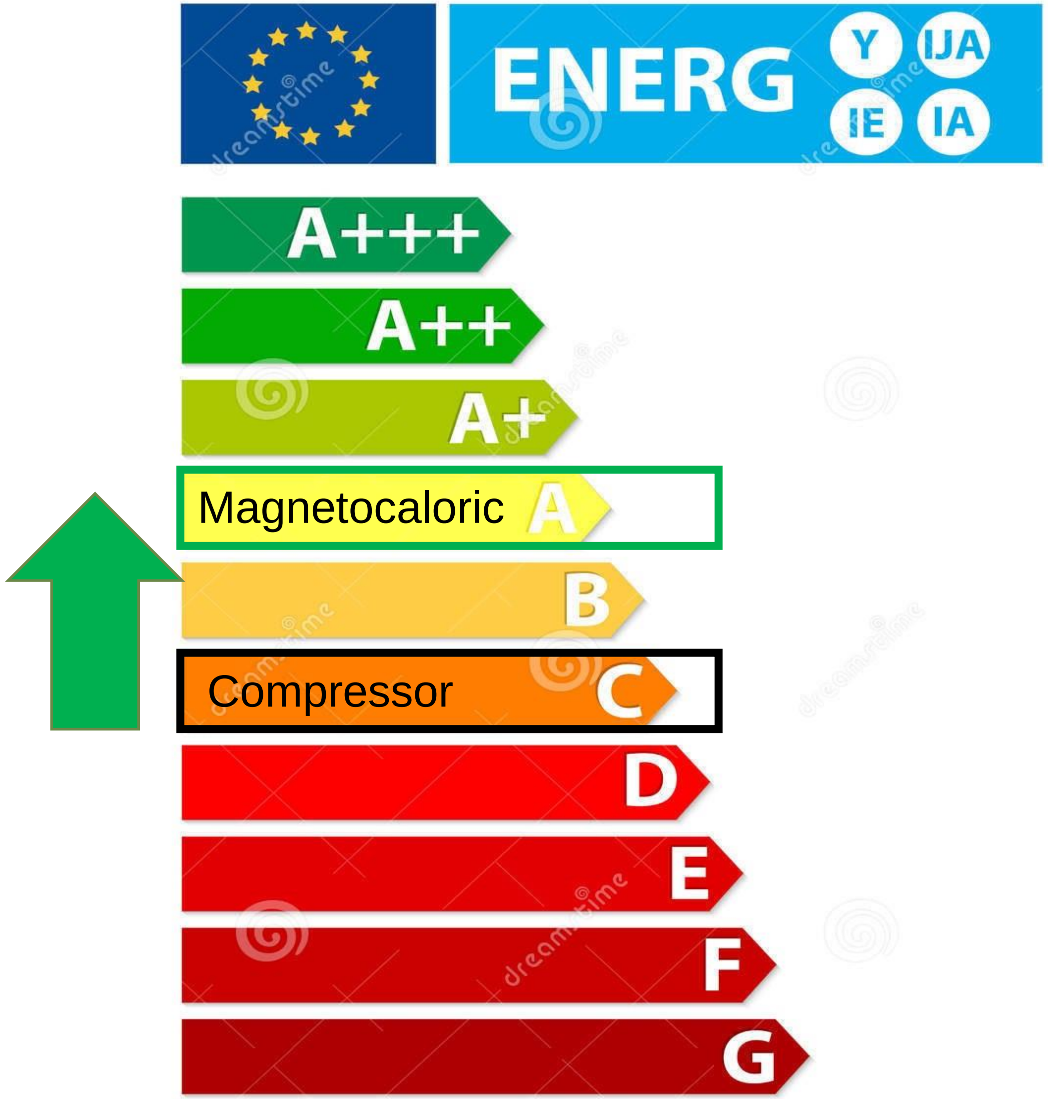
- Material Test Platform prototype in the lab of TU Delft / Magneto (Bowei Huang)





State-of-the-Art – Magnetocaloric Heat Pump

“Magnetocaloric Wine Cooler”



State-of-the-Art – Magnetocaloric Heat Pump

Magneto

“Magnetocaloric Wine Cooler”

Use
- Heating & cooling

Benefits:
- No toxic, flammable or greenhouse gasses
- Improved energy efficiency
- Compact design
- No compressor
- Safe and silent operation (less moving parts and low pressure < 3 bar)
- Fast activation (< 1 min)
- Simple maintenance (water, low pressure < 3 bar)

Challenge:
- Optimization of many different magnetocaloric materials
- Compressors still improving in performance and dropping in price

Magneto

Magnetocaloric Power Conversion

Waste-Heat below 100°C into Electricity

Business potential - Waste Heat < 100°C

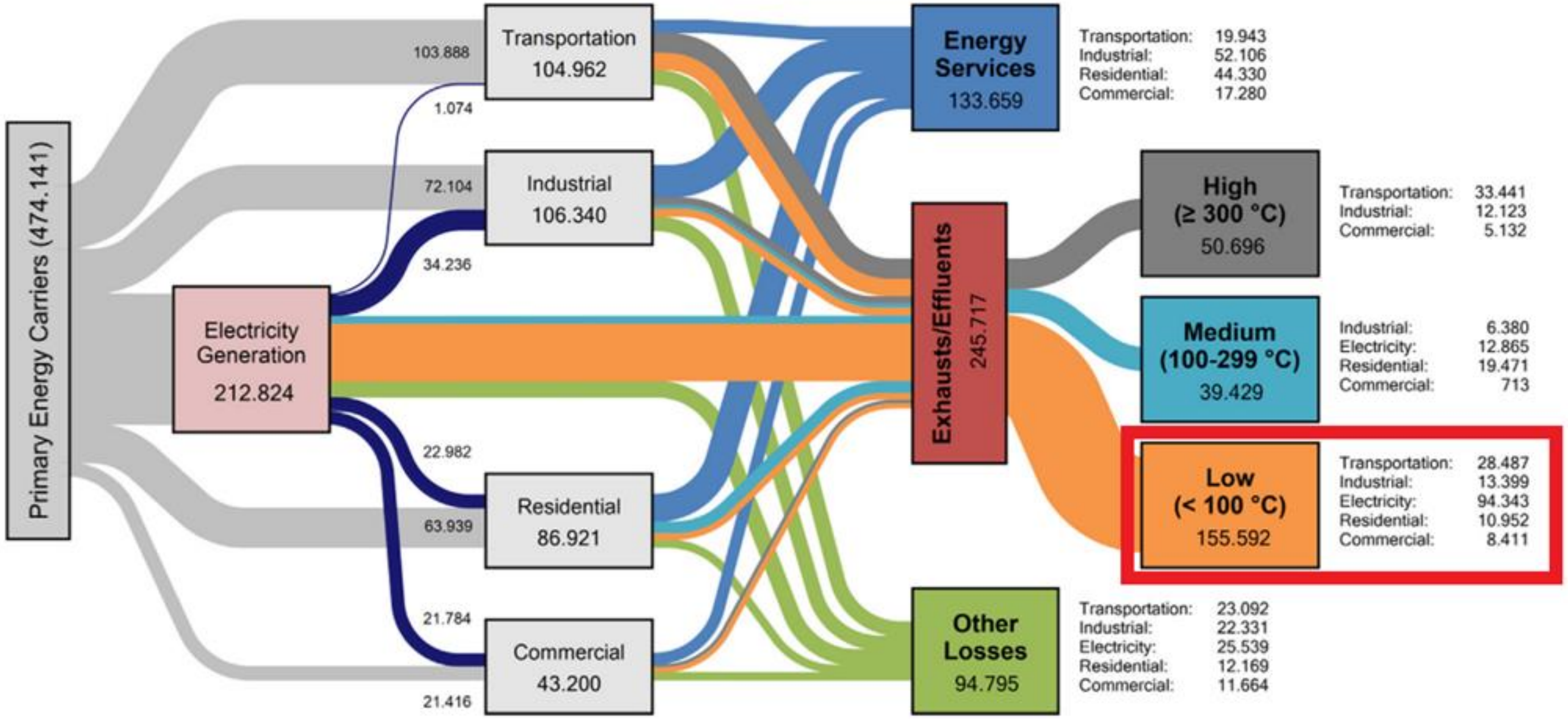
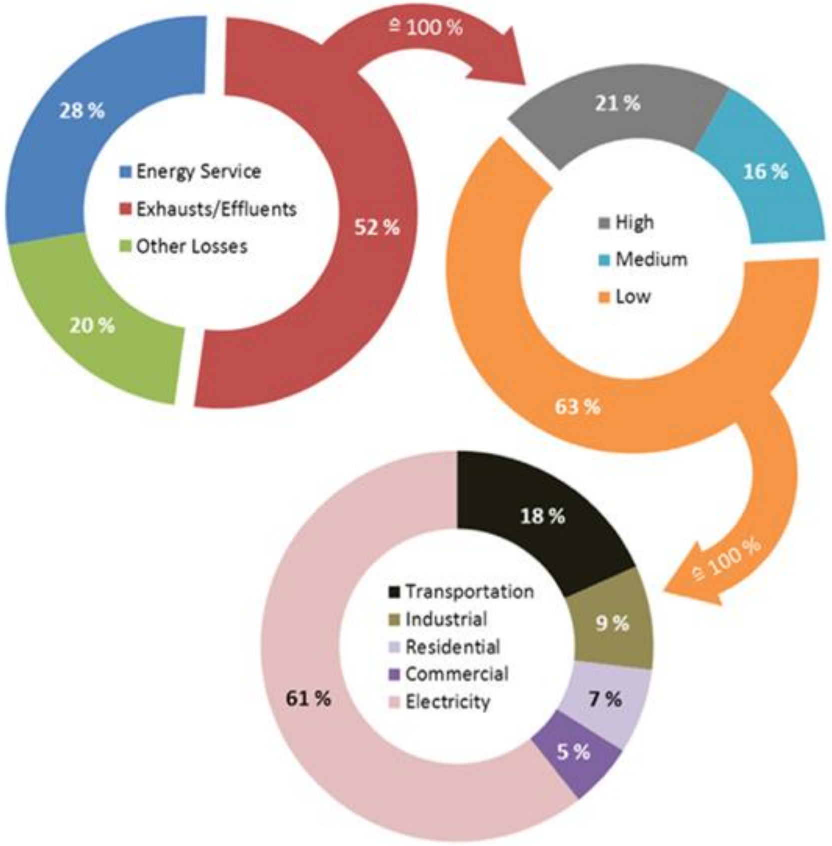
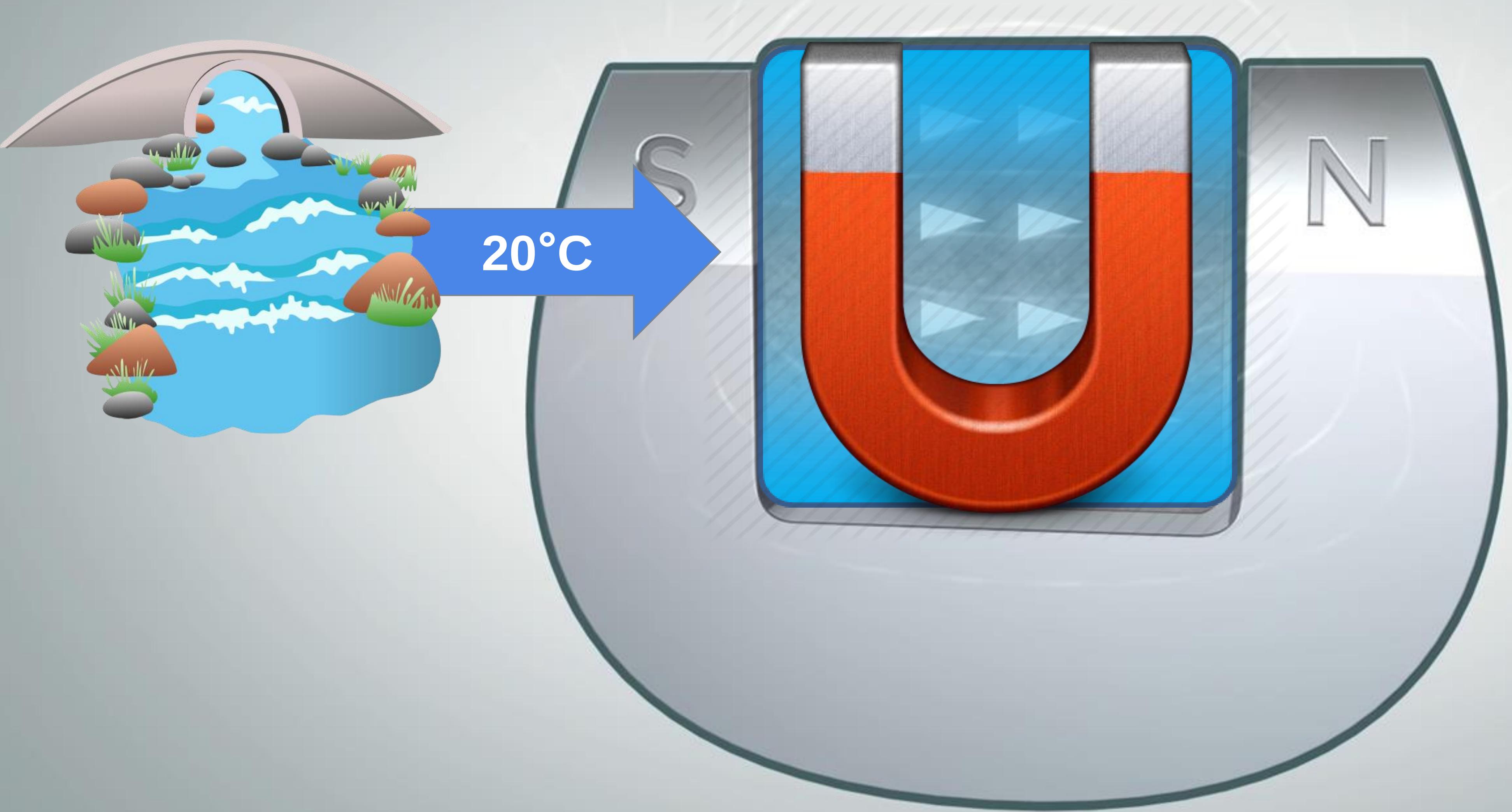


Fig. 5. Estimated global waste heat distribution of 2012 in PJ (according to theoretical approach).



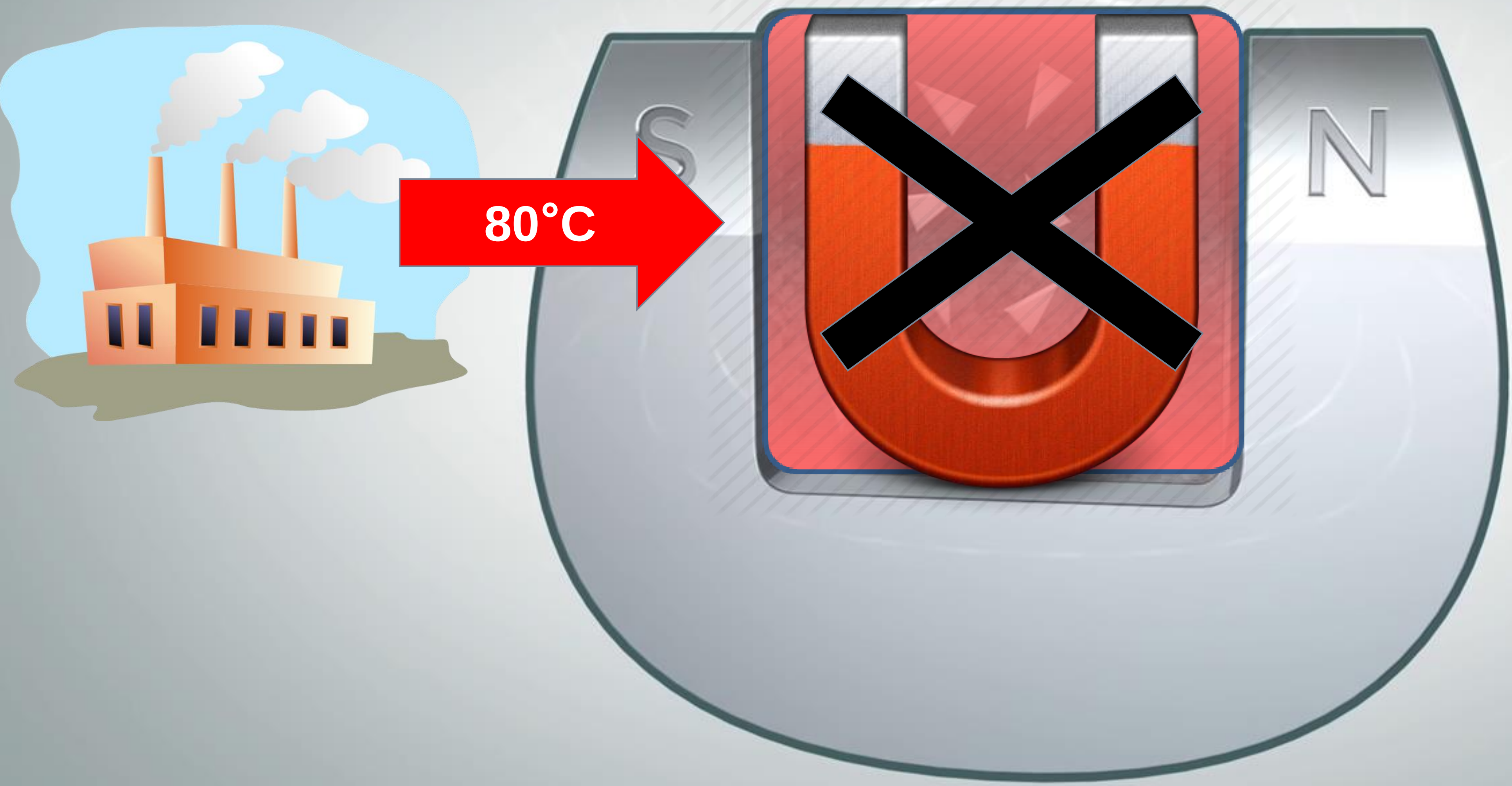
Magnetocaloric Power Conversion



Cooling ($T<T_C$)

magnetic

Magnetocaloric Power Conversion

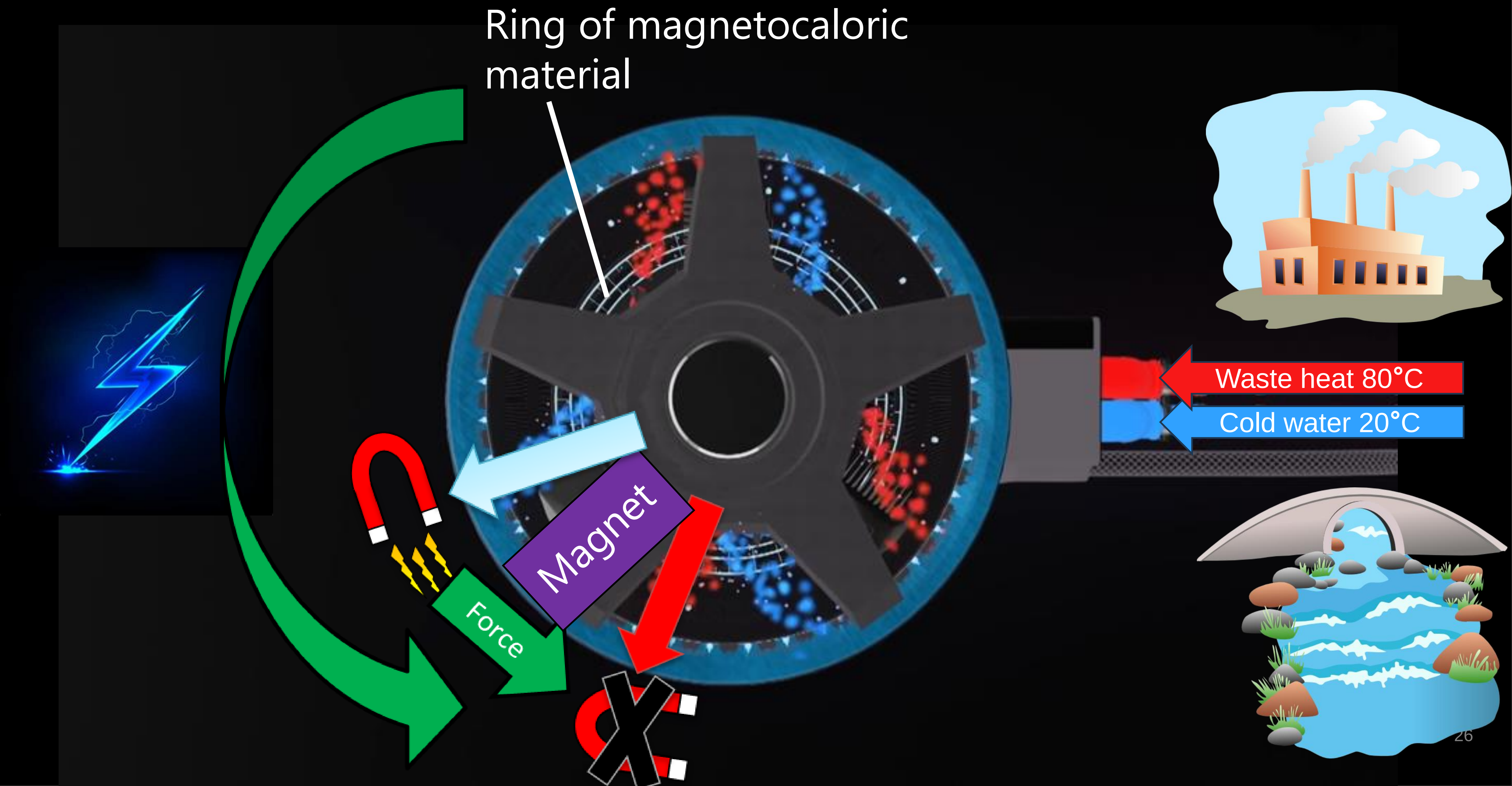


Heating ($T>T_C$)

non-magnetic

Magnetocaloric Power Conversion:

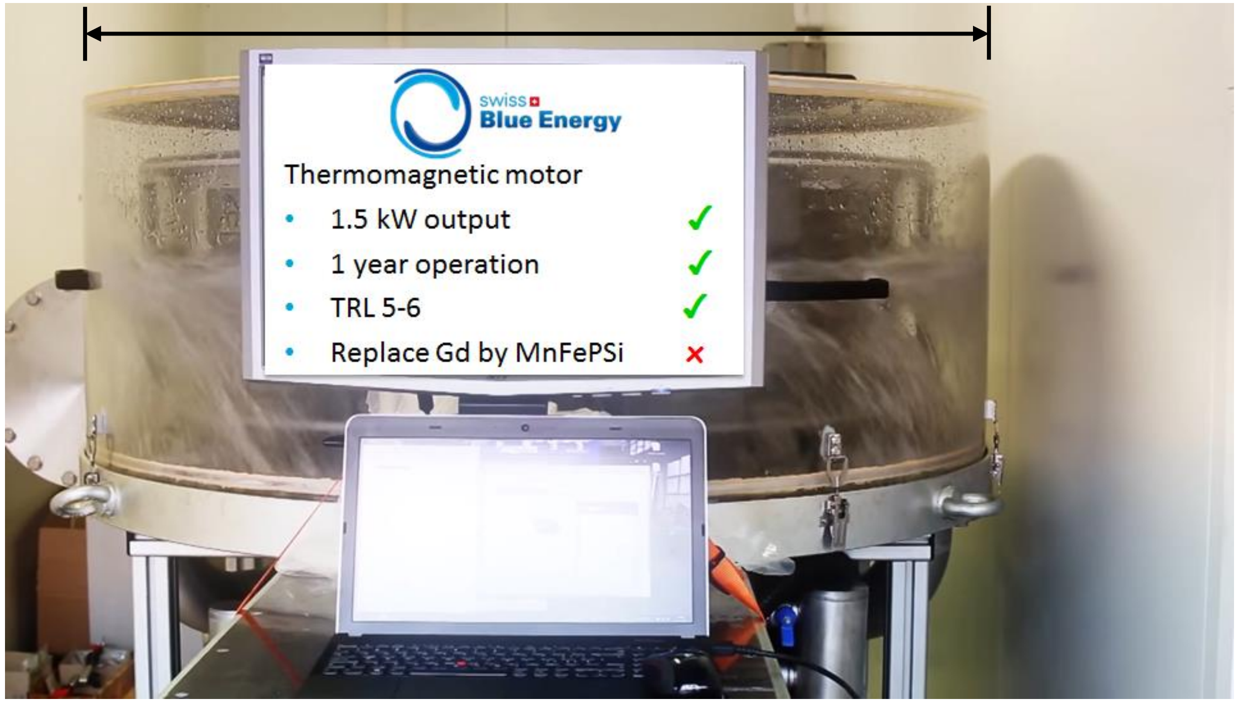
Thermomagnetic Motor



Magnetocaloric Power Conversion

“Thermomagnetic Motor” (demonstrator)

Ø = 1.5 m



Use

- Turning low grade waste heat (< 80°C) directly into electricity

Benefits:

- Vast/untapped energy source (< 80°C)
- Only 1 magnetocaloric material required for operation
- Emission-free
- Continuous power output
- Decentralized
- Modular design
- Low maintenance cost
- 1.5 kW output, ~0.2% thermal efficiency

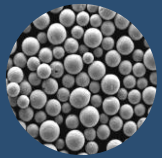
Challenge:

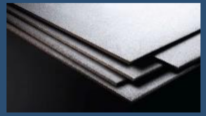
- Small (but emerging) market
- Improve thermal efficiency

Physics Meets Engineering

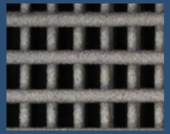
Magneto

Functional Material
Magnetocaloric material (MCM)

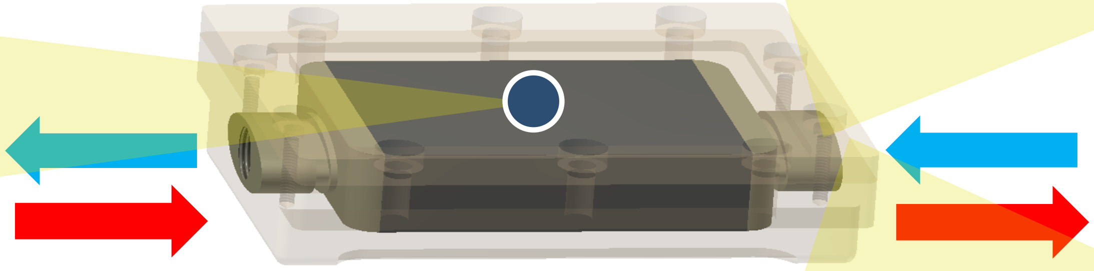

Spheres


Plates


Wires


3D mesh

Functional component
MCE regenerator
Heat exchanger



System
Magnetocaloric heat pump

Thermomagnetic motor

Magneto

Magneto B.V.

“Contributing to a greener and safer world by the commercialization of magnetocaloric materials”

Magneto B.V. - Team

Business Idea:

- Develop, produce and commercialize magnetocaloric materials (MCMs) and heat exchangers for industrial and domestic applications

Core

- Alexander Gunkel - Business
- Bowei Huang - Engineering
- Dr. Michael Maschek – Material Science
- Bennie Reesink - Technology
- Ted van Burk – Technician
- Ben Harrison - Technician

Support

- Prof. Ekkes Brück – Science (TUD, FAME)
- Duke Urbanik – Finance (Yes!Delft)

Magneto B.V. - Status

Magneto B.V.:

- TU Delft spin-off
- Prof. Brück: Fundamental Aspects of Materials and Energy (FAME)
- Located at Reactor Institute Delft (TUD)
- Deep Tech
- Currently financed by government funding / subsidies

Knowledge:

- 16 years at TU Delft (FAME, Prof. Brück)
- 10 years collaboration with BASF
- 90 papers, 12 PhD theses, 5500 citations

Patents:

- More than 30 patent families in collaboration with TUD and BASF
- 3 patents obtained

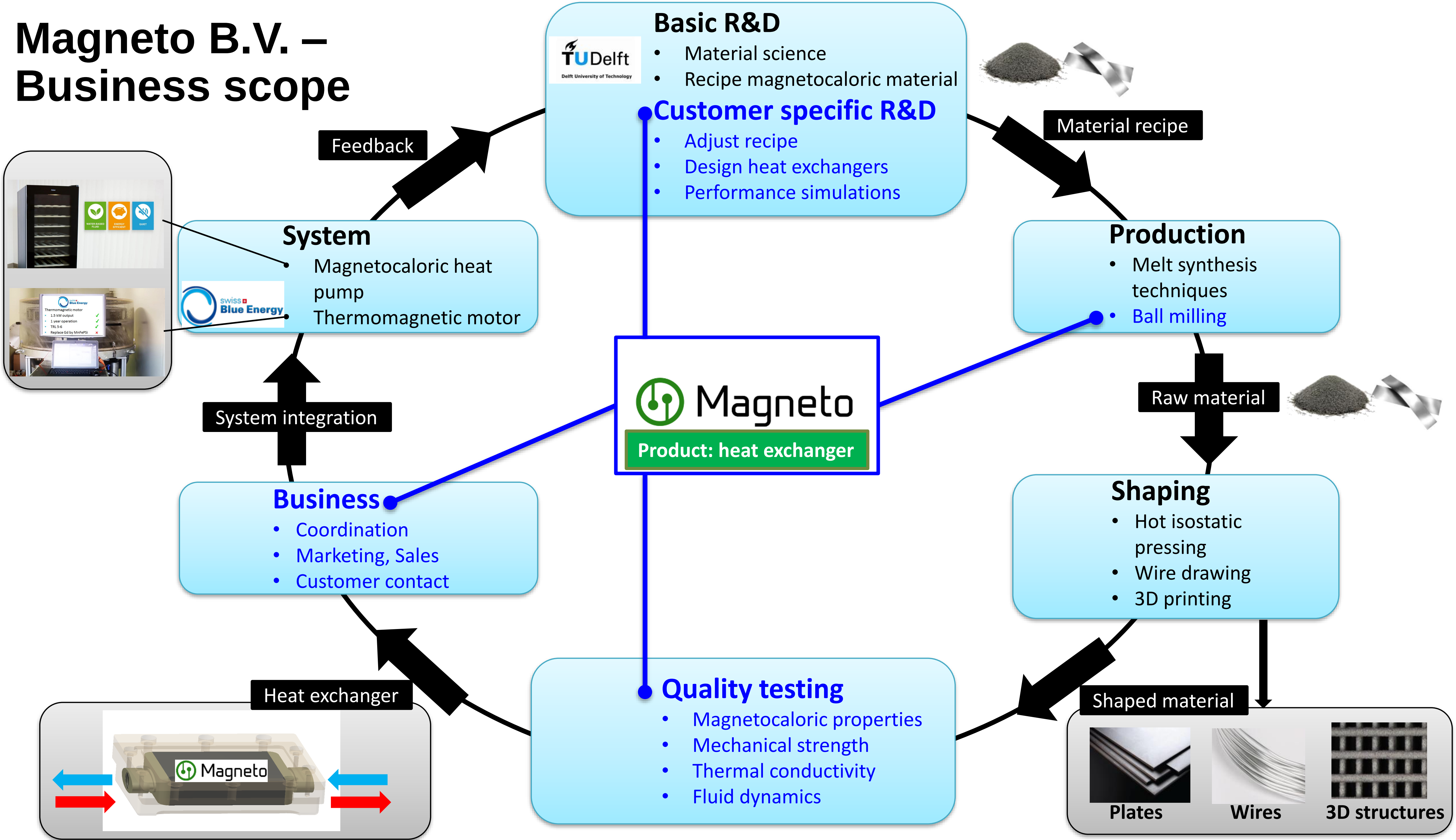
Agreements with BASF:

- Business development support
- Machinery and materials

Future:

- Material and process patents
- Highly specialised expertise

Magneto B.V. – Business scope



Magneto B.V.

Magneto

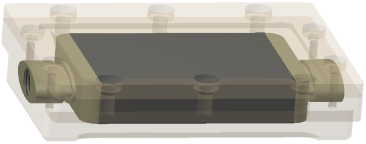
2021 2022 2023 2024 2025 2026

MCM (powder)

kg-scale MCM

kg-t-scale MCM

Heat exchanger

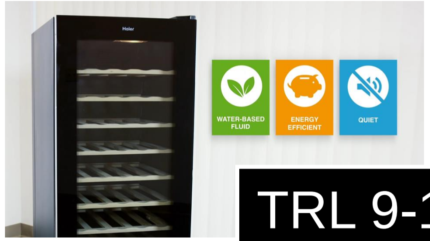


TRL 5-6

TRL 7-8

Magnetocaloric Heat Pump

Magneto or Partners?



TRL 9-10 (5-10 years)

Thermomagnetic motor

Waste-heat to Power in Amsterdam

Waste-Heat-to-Power in Amsterdam

Climate-KIC is supported by the EIT, a body of the European Union

EIT CLIMATE KIC: “Local, magnetocaloric power conversion opportunities for Cities”

- FAME (Fundamental Aspects of Materials and Energy)
- TPM (Technology, Policy and Management)

Amsterdam Institute for Advanced Metropolitan Solutions

Feasibility Study

- Amsterdam
- Waste Heat Sources
  - Temperature
  - Volume
  - Accessibility
- Identify use cases

Magnetocaloric Heat Exchanger

- Design & production
- Optimization for city conditions

Thermomagnetic Motor Prototype

- Design & construction
- Test platform for heat exchangers

Testing

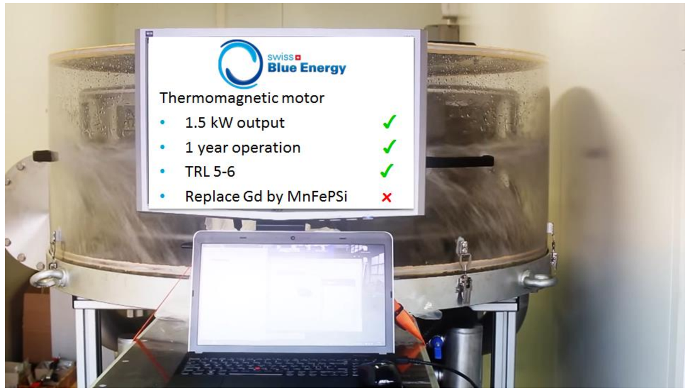
- Using data from feasibility study to simulate use case conditions

Waste-Heat-to-Power in Amsterdam

Magneto

Climate-KIC

Climate-KIC is supported by the EIT, a body of the European Union



Stakeholders in Amsterdam:
- Vattenfall
- Heat network (Vattenfall + WPW)
- Afval Energie Bedrijf
- RWZI Zaandam-Oost (HHNK)
- Orgaworld (Renewi)
- Cargill Multiseed
- OQ Chemicals
- Datacenters/DDA

Feasibility study: **Magnetocaloric power conversion in Amsterdam with Thermomagnetic Motor**
[Longjian Piao (TPM), Jaco Quist (TPM), Paul Voskuilen (AMS)]

Opportunities
- Waste heat (< 80°C) abundantly available:
  - most of the stakeholders can provide waste heat of 5 to 20 MW
- Cold source (< 20°C) also available due to existing infrastructure
  - Cooling towers
  - River, canals
- High stability of heat stream, low temperature fluctuations

Challenges
- Most waste heat already been recycled
  - Reuse internal processes
  - Office heating
  - Selling to heat network
- Stakeholders expect matured technology (TRL > 8)
- Cheap electricity

Conclusion
- Most critical: Improve efficiency (~5%) and reduce cost
- Deep tech! 5-10 years R&D

Challenges in the Netherlands… and everywhere

Magneto

Heating & Cooling

Waste heat below 100°C

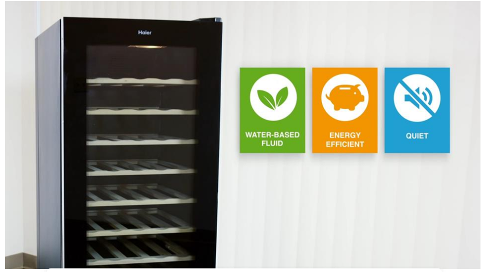
Magnetocaloric technologies

Sustainability in the Netherlands… and everywhere

Magneto

Heating & Cooling

Waste heat below 100°C



Magnetocaloric Heat Pump

Thermomagnetic Motor

Magnetocaloric Applications

Heating & Cooling
MAGNETOCALORIC HEAT PUMP

Waste heat: T < 100°C
THERMOMAGNETIC MOTOR

Thank you for listening

Magneto
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Website: magneto.systems