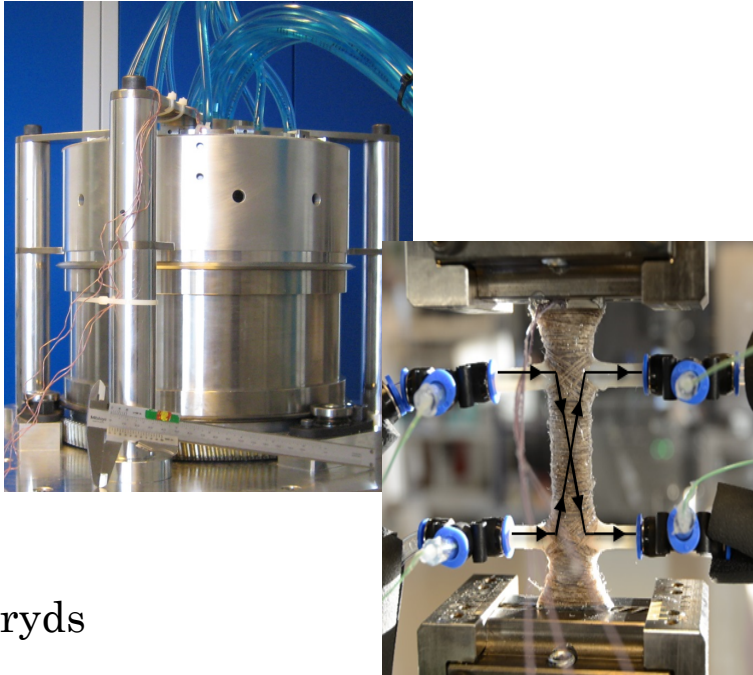# "MAGGIE" a highly efficient cooling device
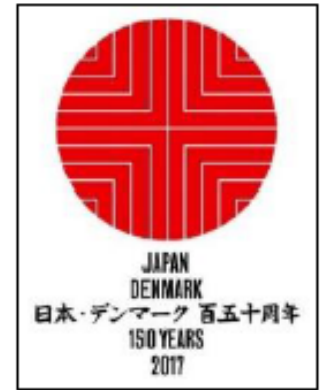
Nini Pryds

nipr@dtu.dk
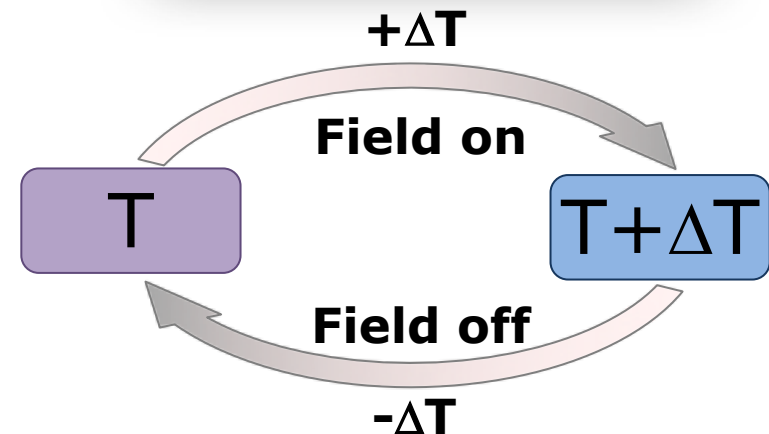
Technical University of Denmark
Department of Energy Conversion and Storag
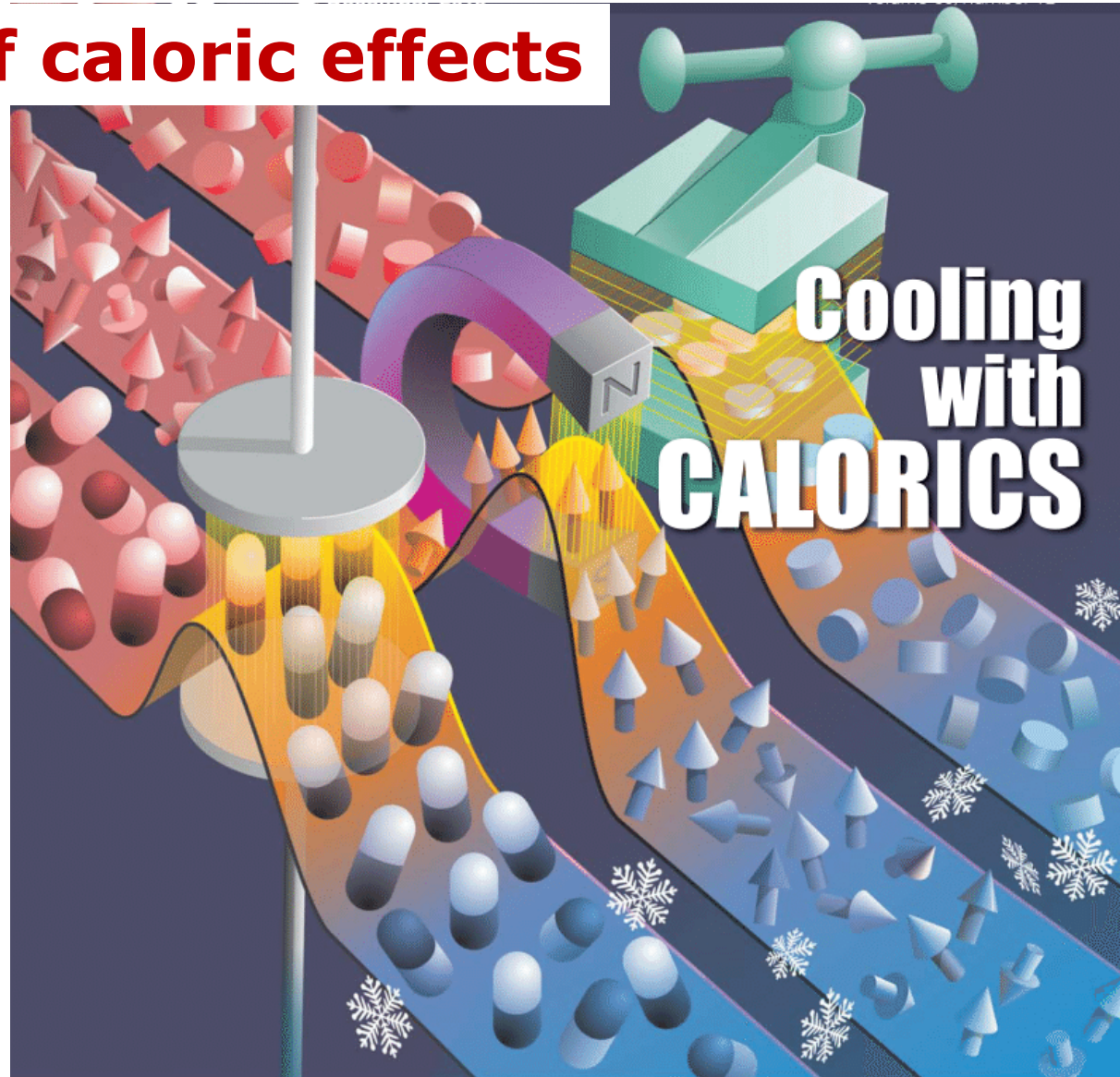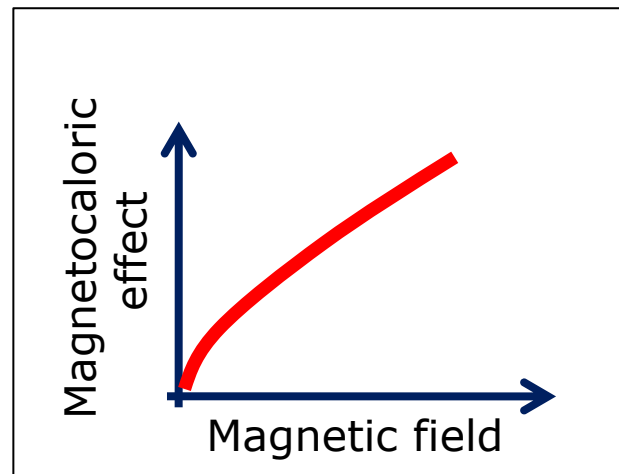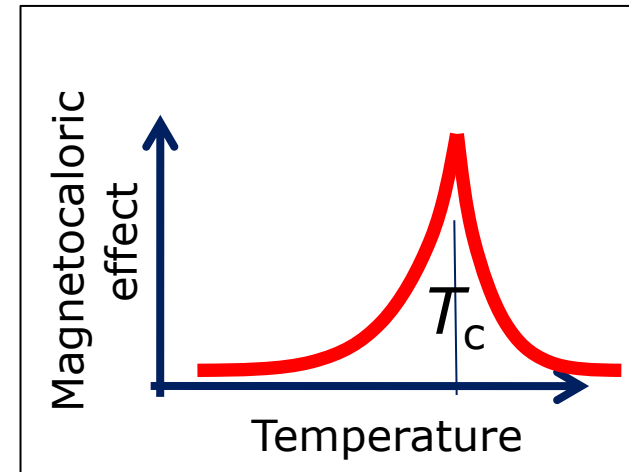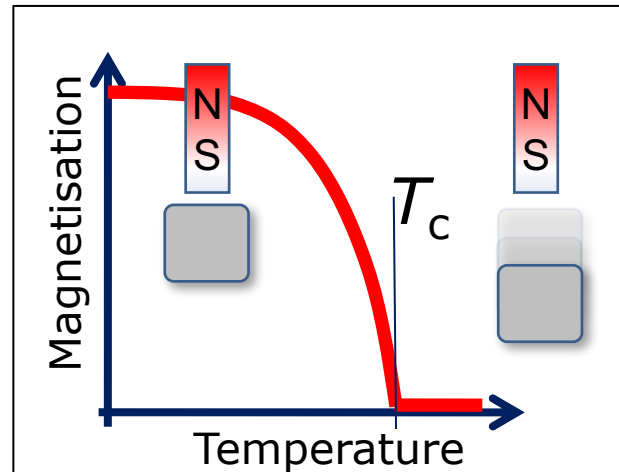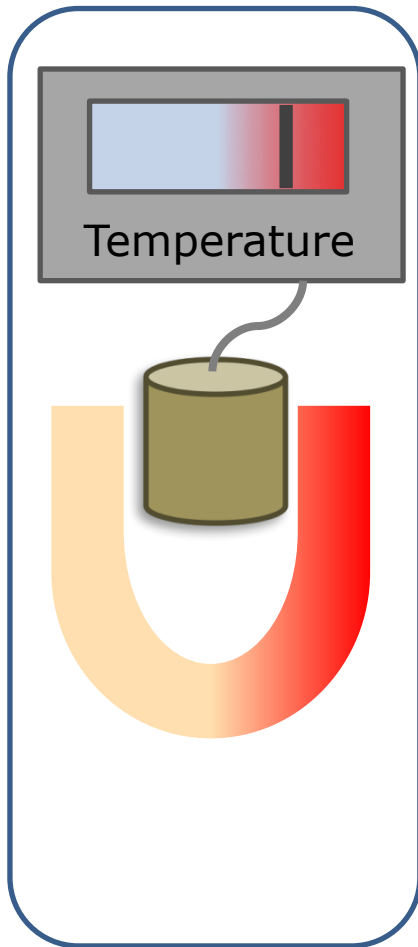
Why do we want a caloric cooling/heating?

> No 'Greenhouse effect contributing' gasses

> Reversibility of the magnetocaloric effect promises high efficiency.

+ΔT

Field on

T   T+ΔT

Field off

-ΔT

Type of caloric effects

The magnetocaloric effect

$$\Delta S_M = \mu_0 \int_{H_1}^{H_2} \left(\frac{\partial M}{\partial T} \right)_H dH$$
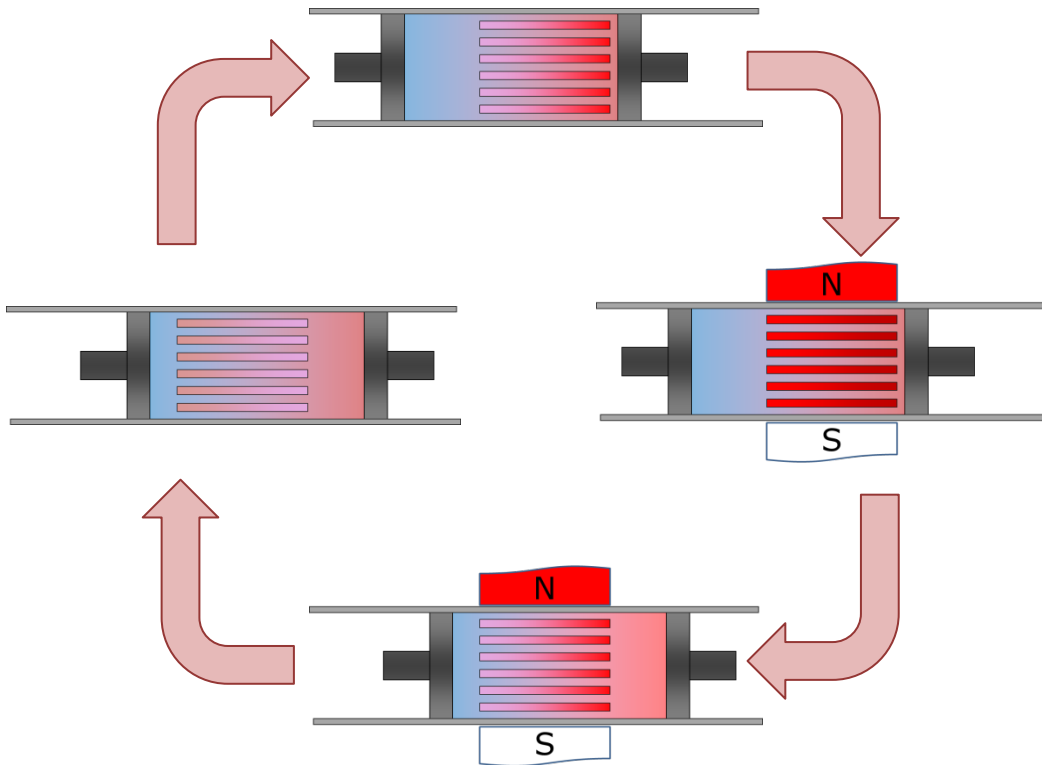
$$\Delta T_{ad} = -\mu_0 \int_{H_1}^{H_2} \frac{T}{C_H} \left(\frac{\partial M}{\partial T} \right)_H dH$$

"Who discovered the magnetocaloric effect?", Eur. Phys. J. H **38**, 507-517 (2013)
"Materials Challenges for High Performance Magnetocaloric Refrigeration Devices", Adv. En. Mat. 2, 11, (2012)

DTU Energy, Technical University of Denmark

Active Magnetic Regenerator (AMR) cycle

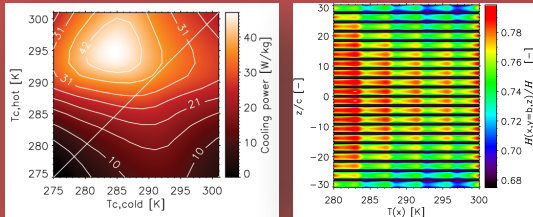## Active Magnetic Regeneration cycle

Porous regenerator structure

- What do we need?

  - Large surface area for heat transfer

  - Low pressure drop for low pumping power

  - Small geometry for fast heat transfer

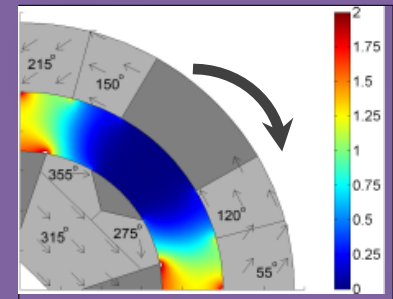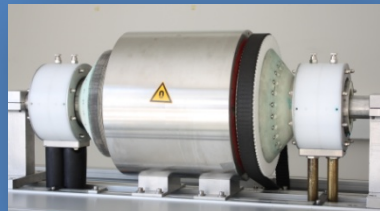# What is needed to build a succesful magnetic refrigeration device?

Characterisation
$\triangle T_{ad}$, $\triangle S$, c_p, k etc.

AMR, demagnetisation and heat transfer modelling

Modelling, design and optimisation
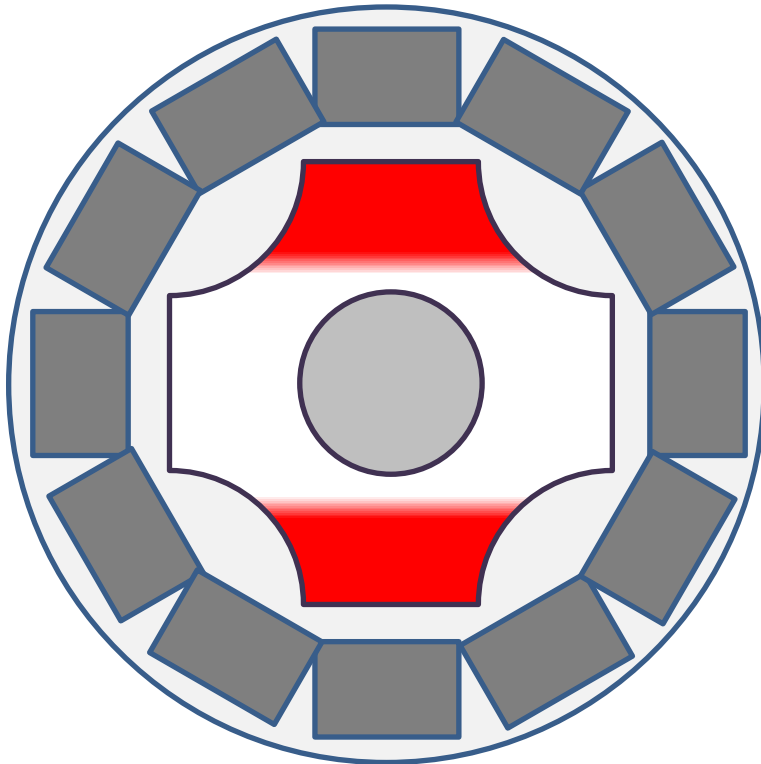

Design and construction

Why isn't magnetic refrigeration here yet? (What are the remaining challenges?)

- The magnetocaloric effect is quite small!

- Practical and price limitations to the magnet.

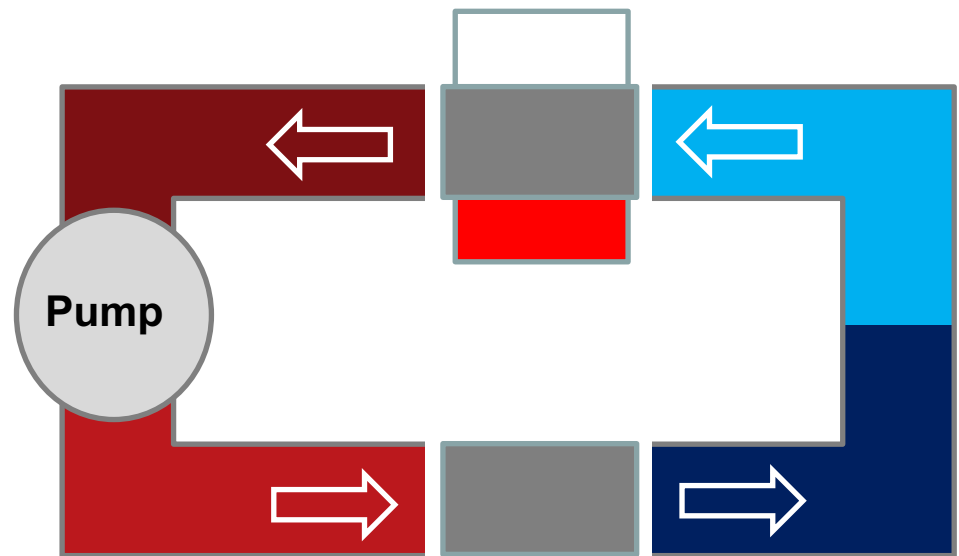- Complex engineering issues in need to be solved.

New!

MC

Design concepts

- Continuous use of the magnetised volume and magnetocaloric material

- Continuous flow of heat transfer fluid through any part of the regenerator

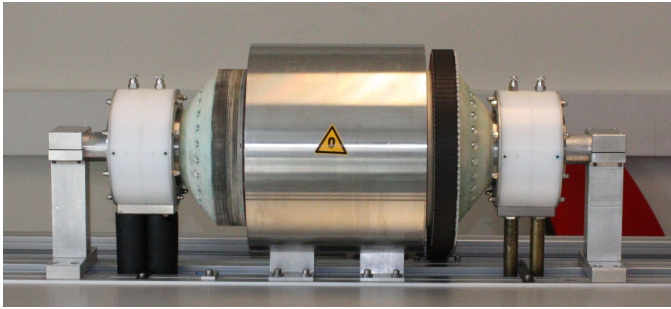Int. J. Refrigeration **37**, 78 (2013)

Devices built and tested

Many devices have been presented using different materials and geometries.

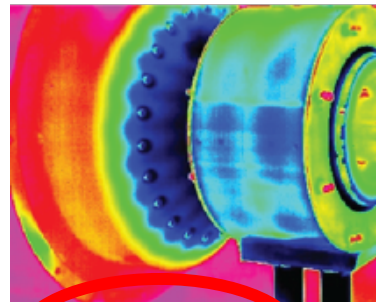**So, the concept has proven, but we still need higher efficient devices!**

A. Kitanovski *et al.* Magnetocaloric Energy Conversion: From Theory to Applications, Springer, 2015.
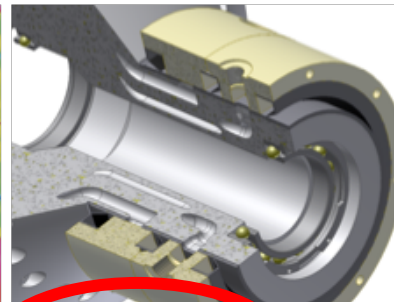
2012, *Int. J. Ref.*, 35(6): 1498-1505.

- Temperature span of **20.5 K at 100 W**
- Temperature span of **18.9 K at 200 W**
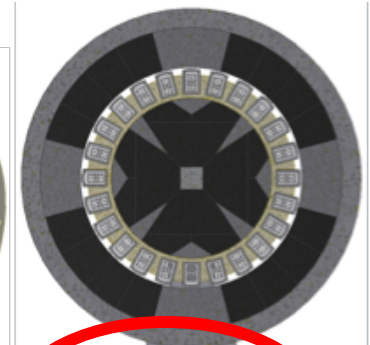- Temperature span of **13.8 K at 400 W**

Heat leakage
- Decreases cooling power

Valve and seal friction
- Increased motor work
- Heat dissipation subtracts from cooling power

Only 37% MCM in magnet gap (cross section)
- Expensive magnet wasted
- Uneven torque

Appl. Energy **111** (2013) 669-680.

MAGGIE : New Efficient Device
Design focus points

Magnet:
- 2D AMR model optimization combined with FE magnet optimization
- Mechanically simple and efficient rotation relative to regenerator
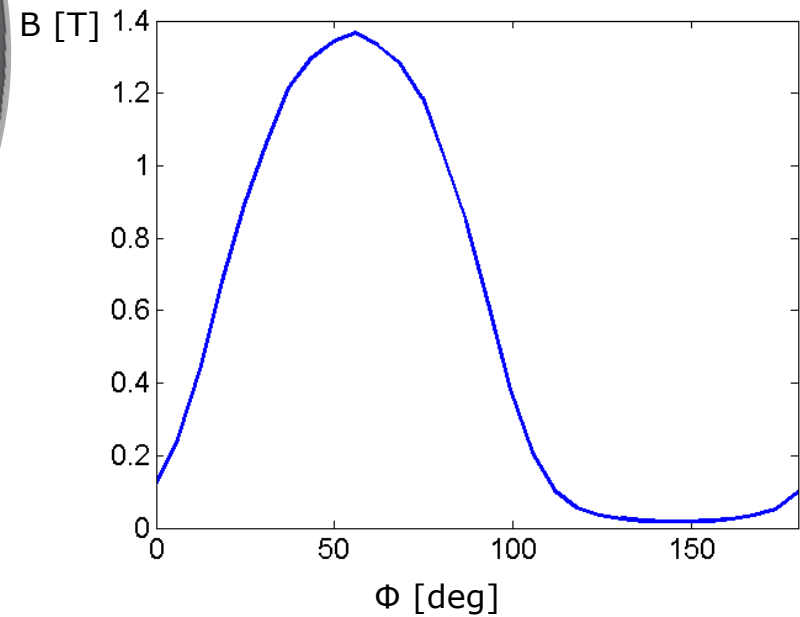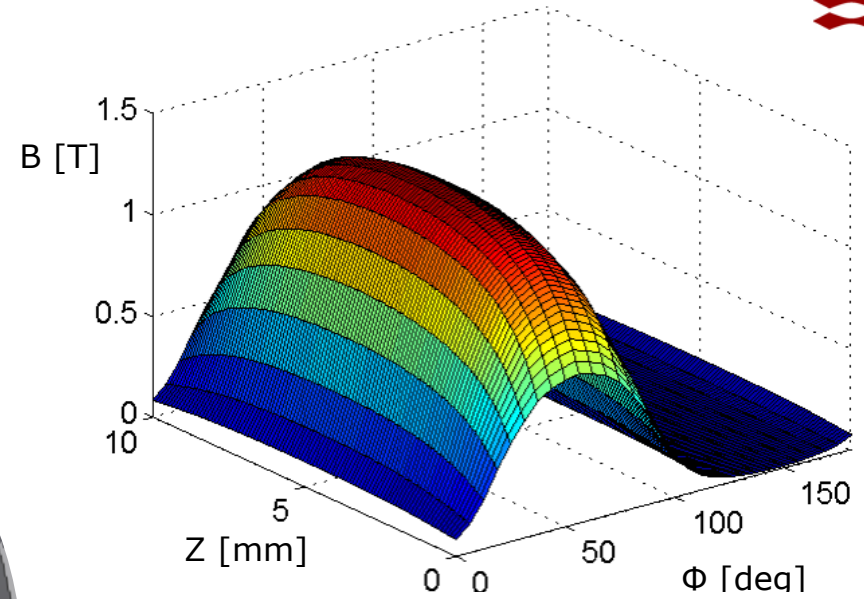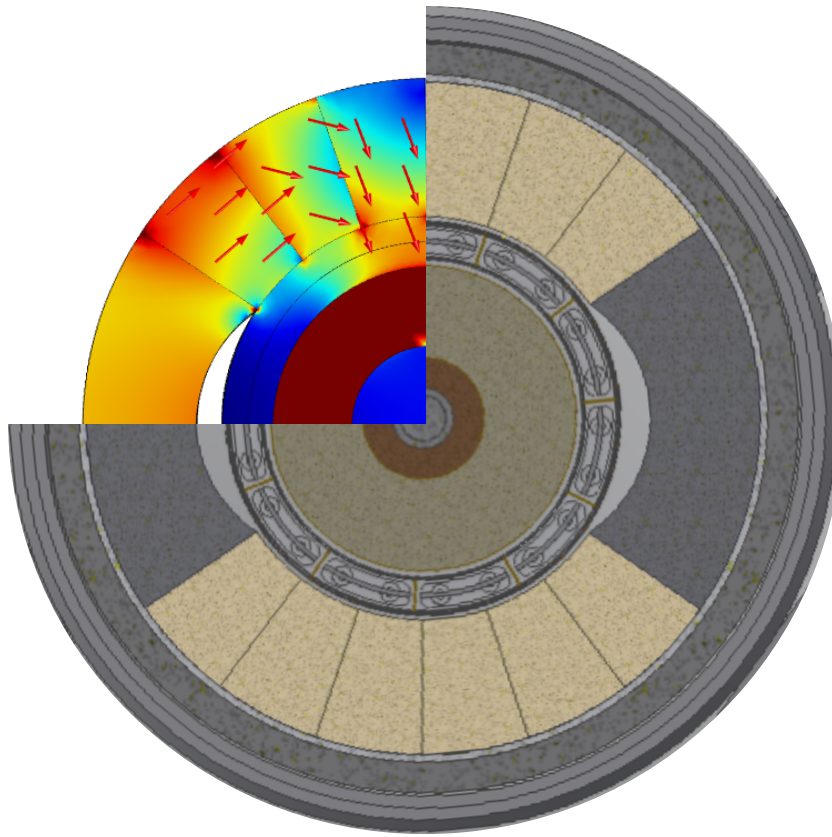
Regenerator:
- 2D AMR model optimization of bed dimensions for magnetic field
- Utilize magnetized volume: Minimize regenerator housing
- Minimize uneven torque: Minimize bed spacing
- Minimize regenerator heat leakage: insulating air gap

Flow system:
- Control flow profile in beds based on 2D AMR model optimizations
- Minimize friction
- Eliminate internal leak paths
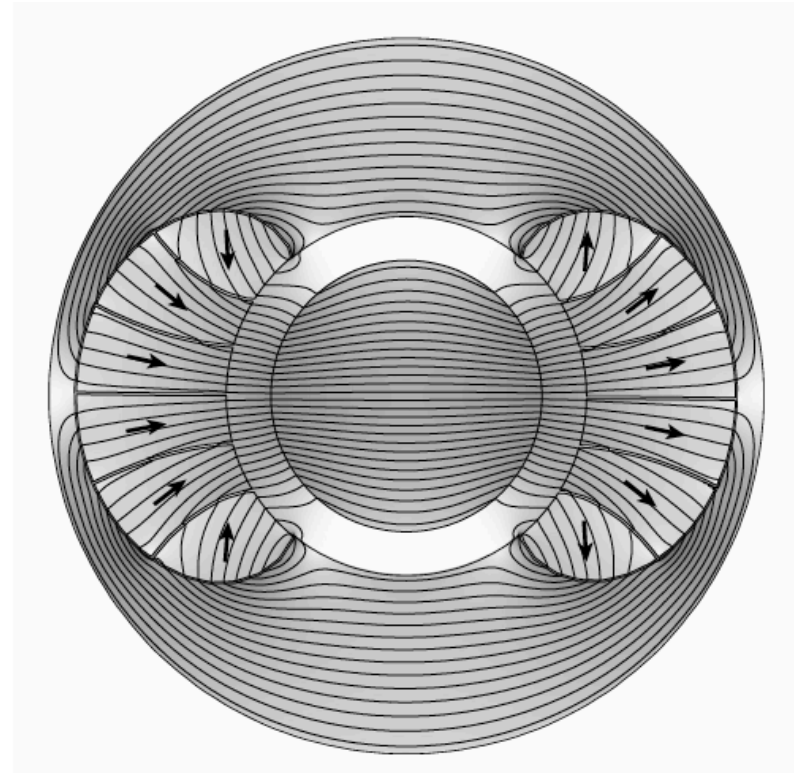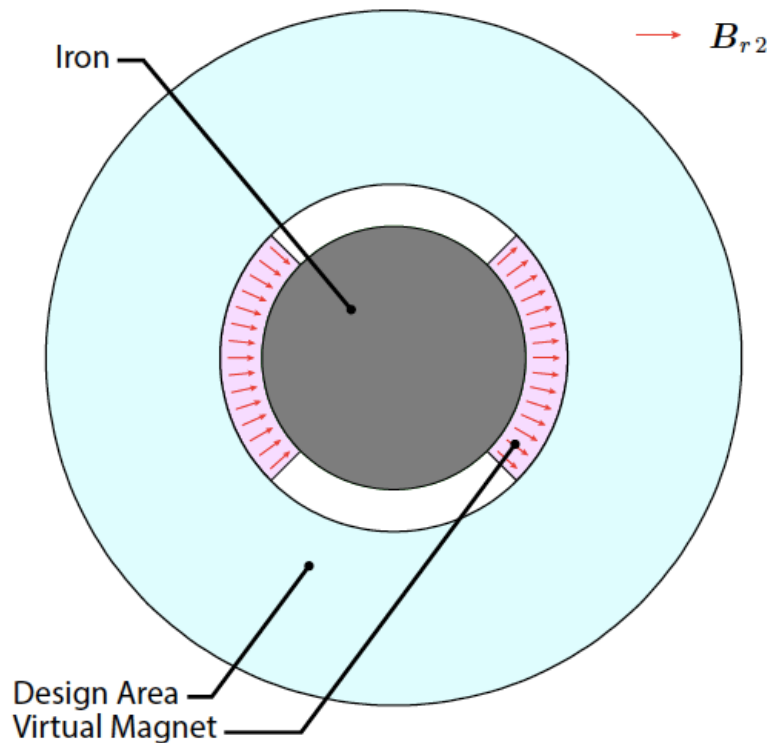
DTU Energy, Technical University of Denmark

Magnet design

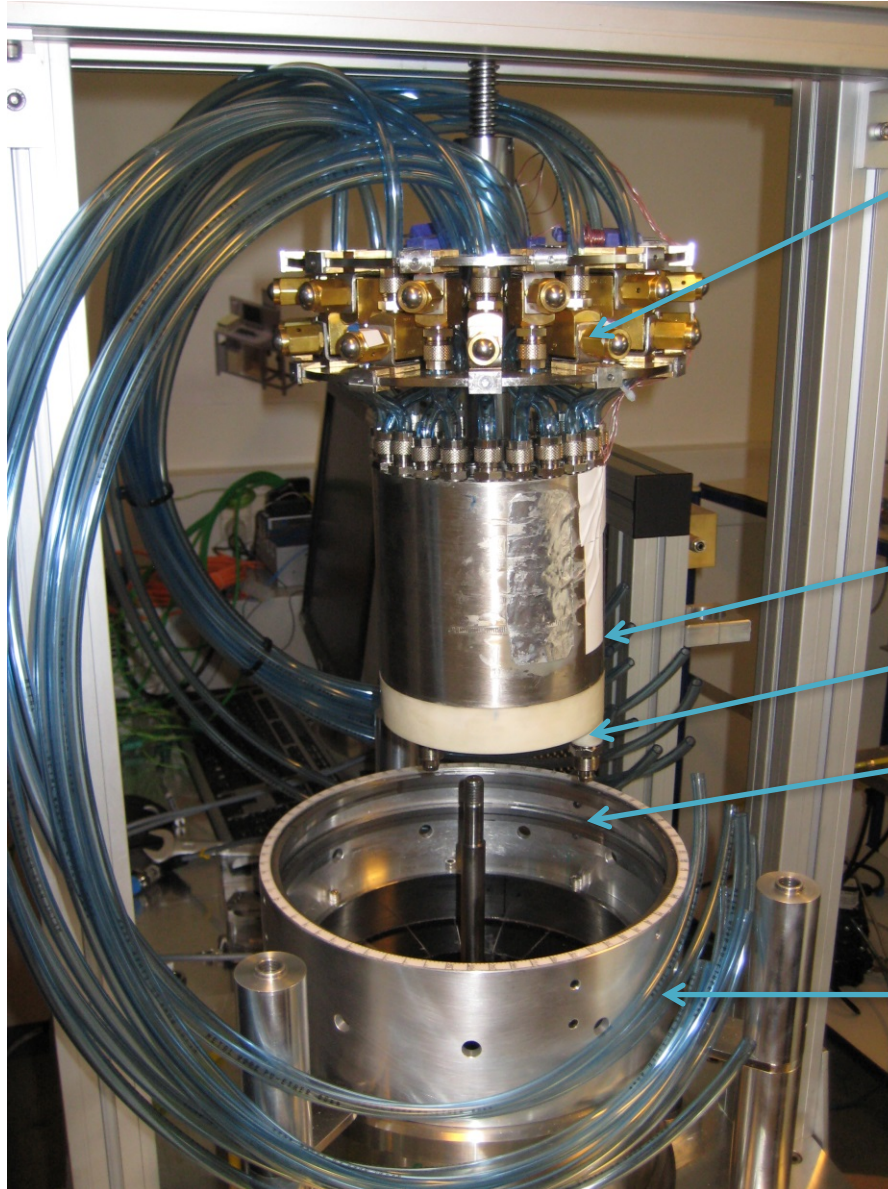# Optimally segmented magnetic structures

A numerical method where the magnetic structure is calculated based on the initial definition of the field required.

Magnetic Refrigeration

Phys. Rev. Applied 5, 064014 (2016)
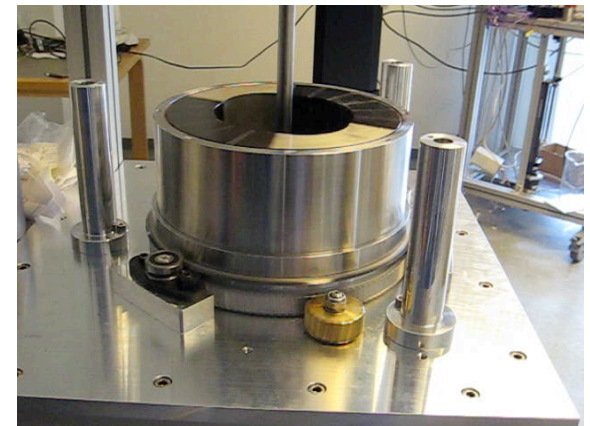
Regenerator with flow system assembly

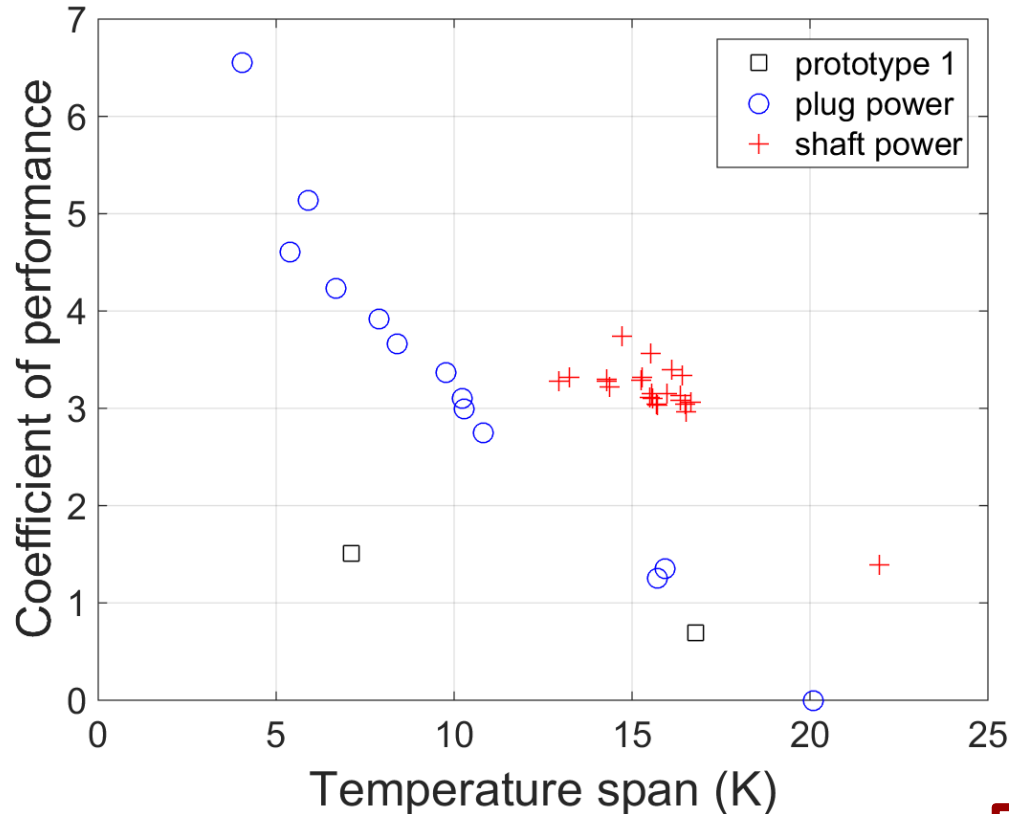Poppet valve system

Active magnetic regenerator

Cold side check valve system
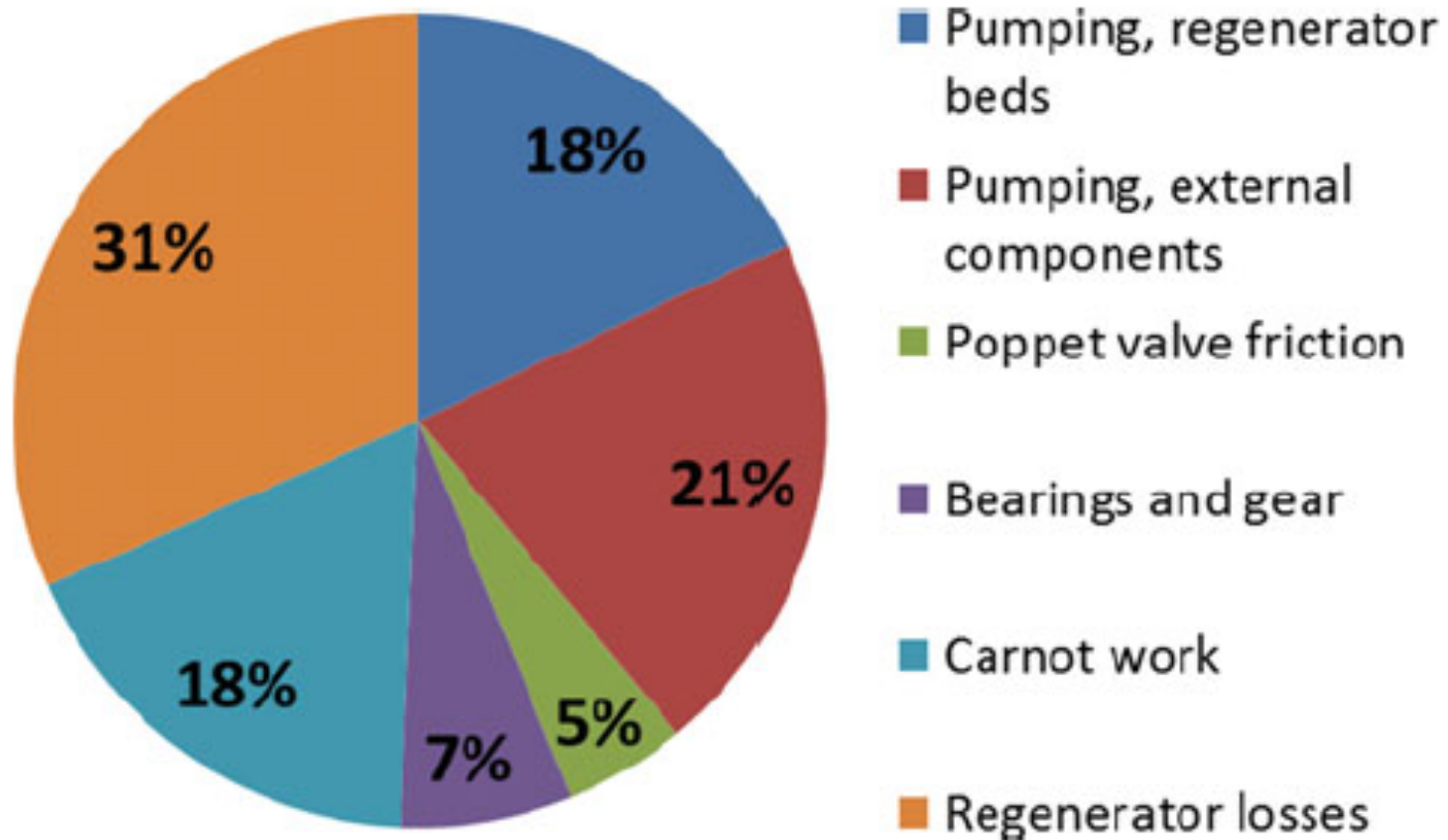
Cam rings

Rotating magnet

COP measurements for shaft work

$$COP = \frac{\dot{Q}_{Heater}}{\dot{W}_{motor} + \dot{V} \cdot \Delta P_{reg.}}$$
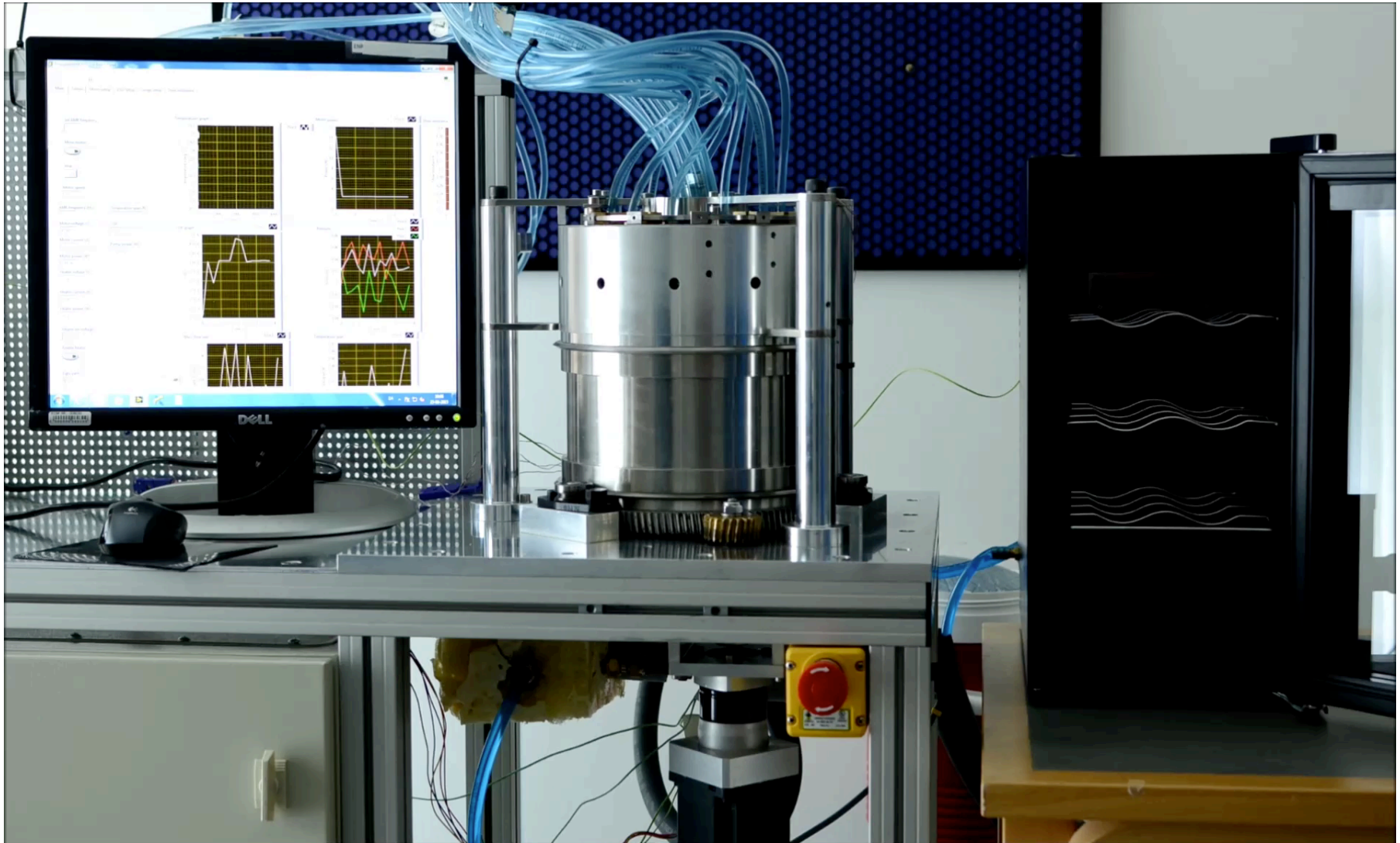
- Maximum temperature span 29.2 K @ 1.4 Hz and 3.4 L/min fluid flow

- COP of 3.32 (shaft power) with cooling power of 82 W and 15.3 K temperature span @ 1.0 Hz and 2.5 L/min fluid flow

- Maximum cooling power so far is 160 W at a temperature span of 5.5 K @ 0.47 Hz and 3.8 L/min fluid flow

- Full characterization has been delayed by flow system adjustment, minor component failures and component optimization

Relative Distribution of Power Input to the AMR

- ■ Pumping, regenerator beds — 18%
- ■ Pumping, external components — 21%
- ■ Poppet valve friction — 5%
- ■ Bearings and gear — 7%
- ■ Carnot work — 18%
- ■ Regenerator losses — 31%

DTU Energy, Technical University of Denmark

Refrigeration:

Comparison of caloric materials

Magnetocaloric – moderate adiabatic ΔT_{ad} (~4 K) at a magnetic field of ~1 T. Typically low hysteresis
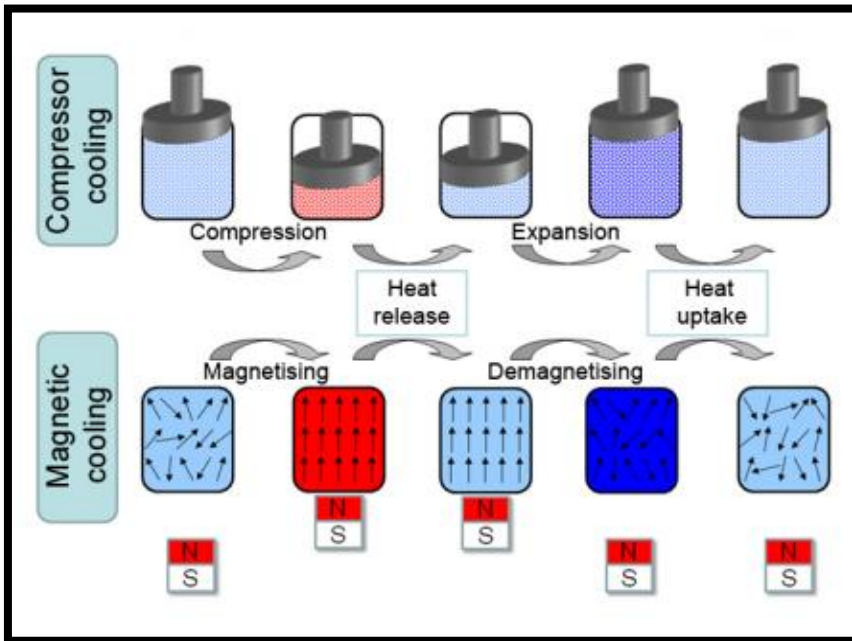 Drawback: rare earth cost
Elastocaloric – potentially high ΔT_{ad} (20 K or more) but at high stresses (over 100 MPa). Typically moderate hysteresis
  Drawback: fatigue in refrigerant, high forces
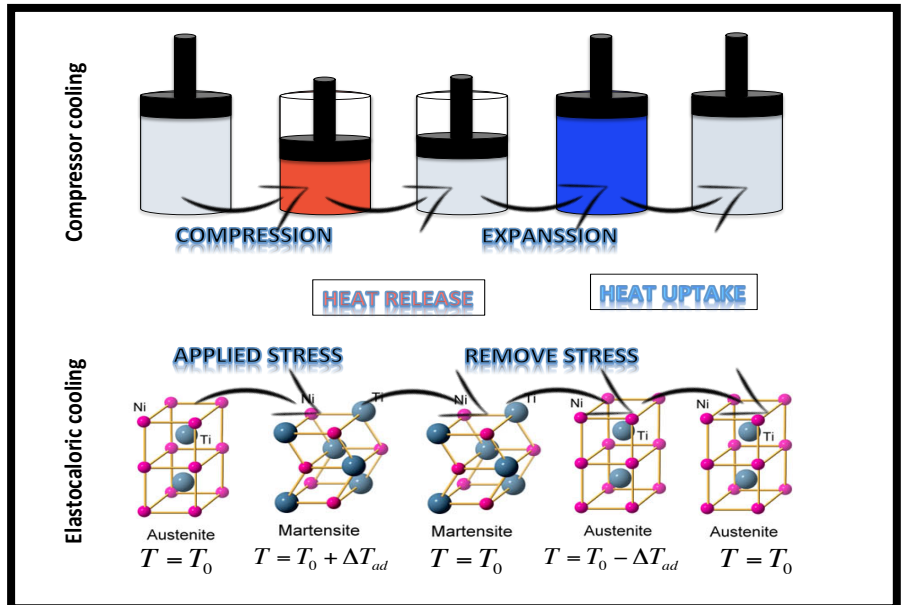
– Drawback: high voltage, material stability

- **Barocaloric** – moderate adiabatic temperature change (~4 K) at pressure change of ~2 kbar
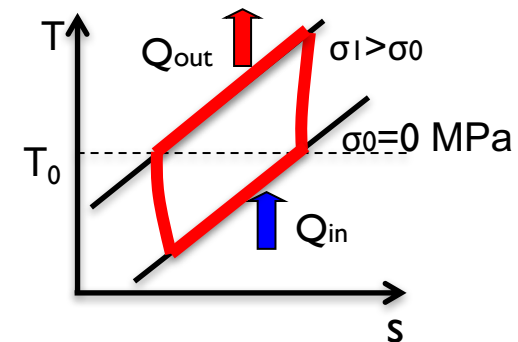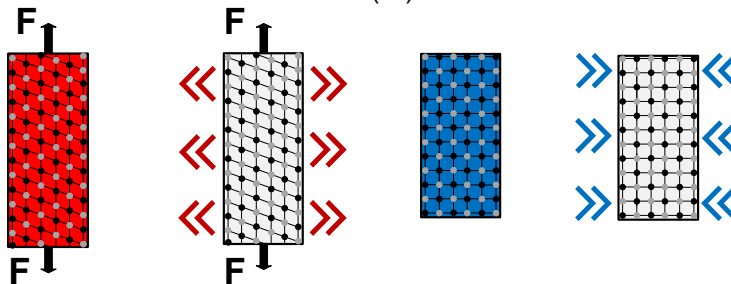 - Drawback: high pressure, implementation

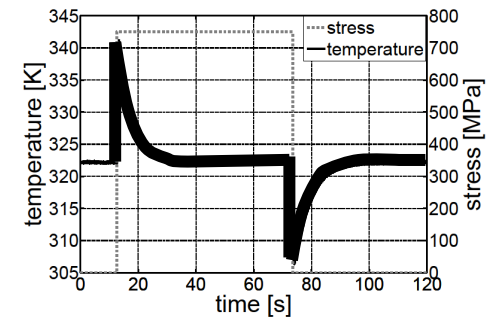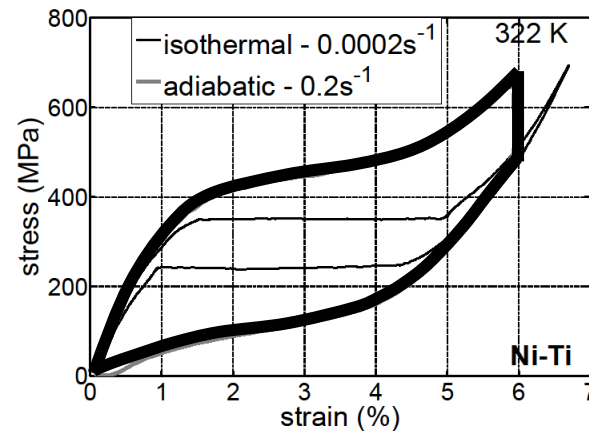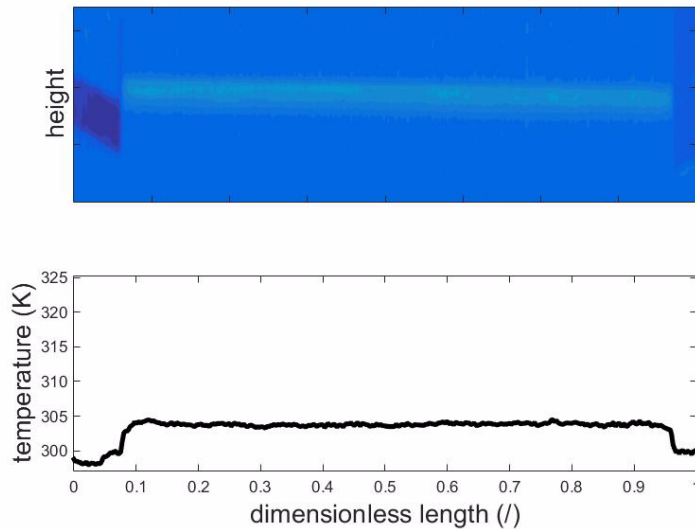**MagnetoCaloric effect**

ElastoCaloric effect

The basics of the elastocaloric effect (eCE)

The eCE is closely related with the superelasticity of the shape memory alloys and its latent heat of the transformation
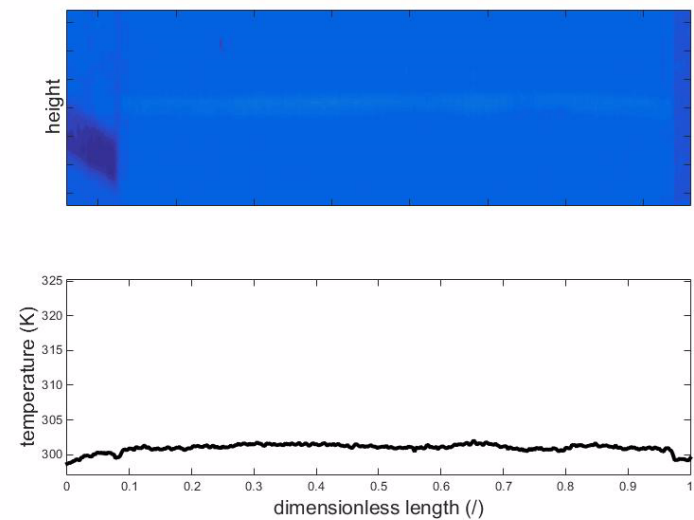
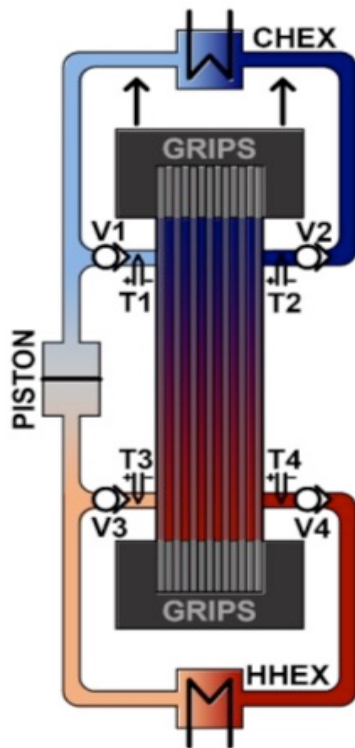# eCE of Ni-Ti wire – homogenity

virgin wire

fully stabilized wire

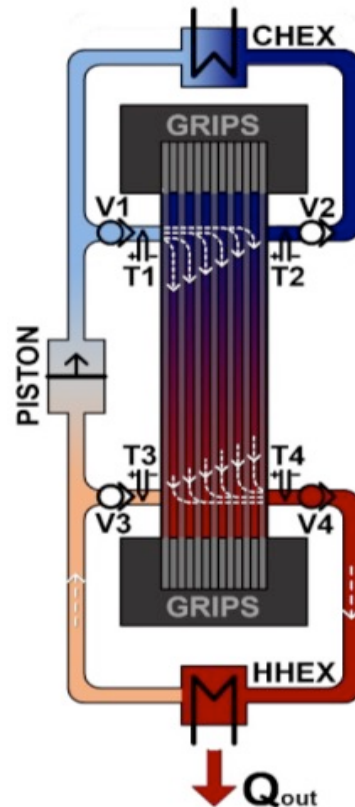*J. Appl. Phys., 117, 124901 (2015)*
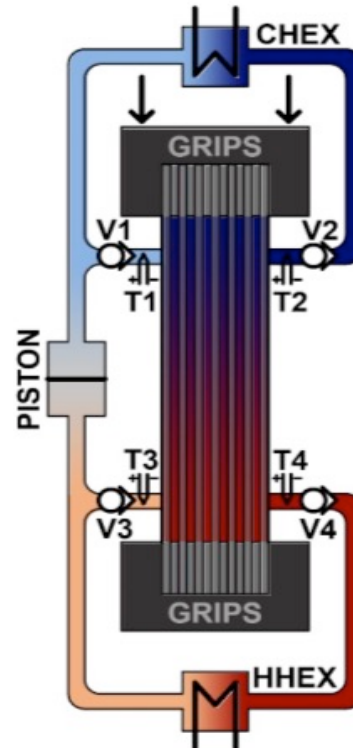
The active elastocaloric regenerator
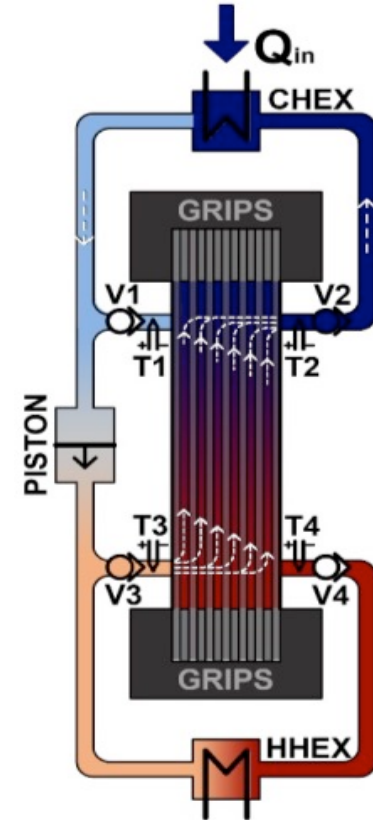

Step 1: loading

Step 2: fluid flow to HHEX – heat rejection

Step 3: unloading

Step 4: fluid flow to CHEX – heat absorption

○▷ check valve (V)   ⇌ thermocouple (T)   ---▷ fluid-flow direction

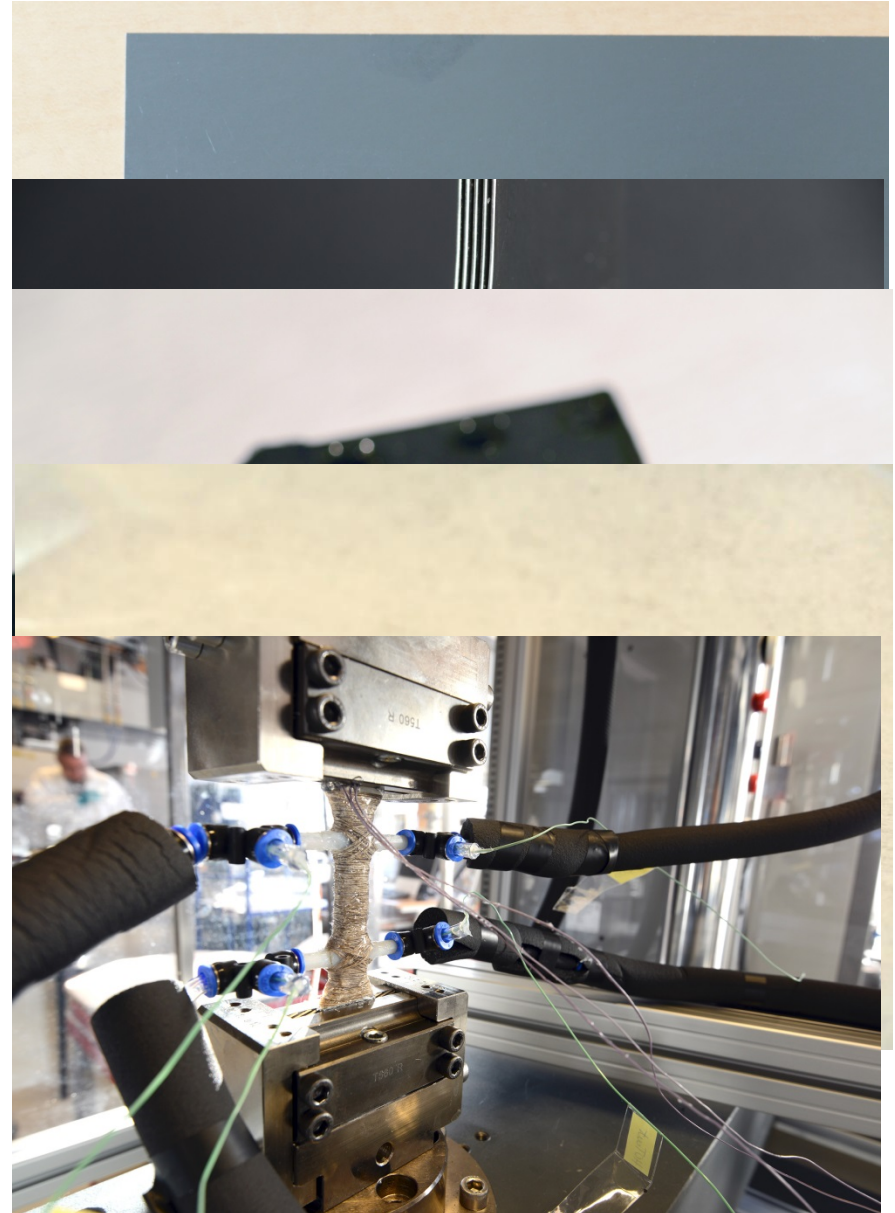# Construction of the elastocaloric regenerator

Start with NiTi sheets with correct austenitic finish temperature

Cut to dog bones and polish

Stack sheets and weld

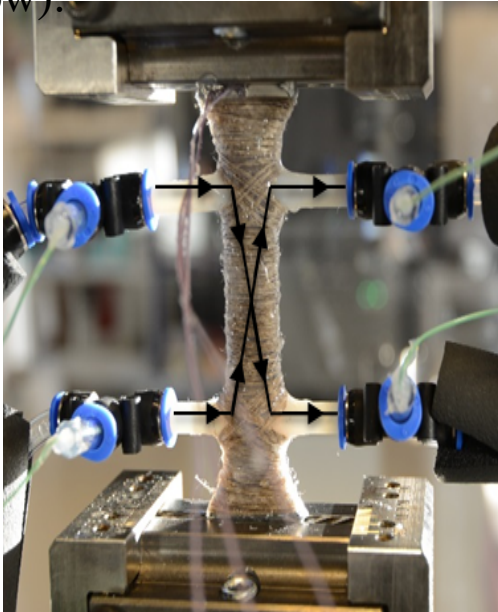Attach flow ports and install housing

Grip in mechanical tester, connect tubing

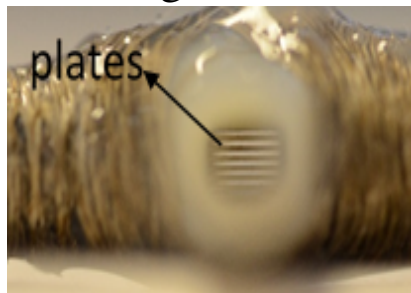**DTU Energy, Technical University of Denmark**

The elastocaloric regenerator in operation

A photo of the elastocaloric regenerator (the arrows shows the direction of the fluid flow):
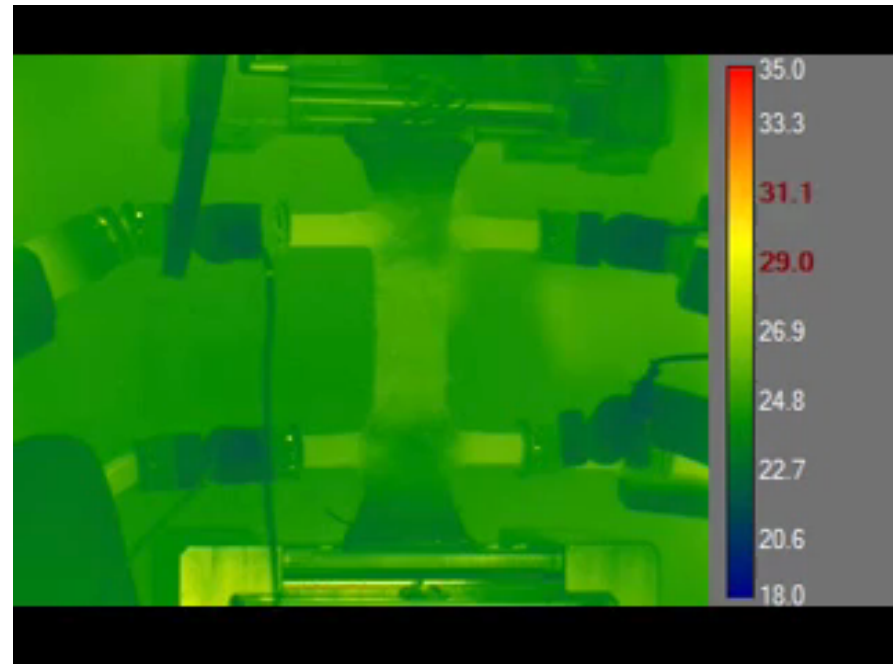
A view of the elastocaloric plates in the regenerator through the fluid flow insert:

plates

DTU Energy, Technical University of Denmark

The IR **video** of the operation of the elastocaloric cooling device during the first couple of cycles:

35.0
33.3
31.1
29.0
26.9
24.8
22.7
20.6
18.0

Temperature span 15K @ cooling power of 800 W/kg max. COP 6

The stone age did not end because we run out of stones - we just transitioned to a better solution.

The same opportunity lies before us with energy efficiency and clean energy devices.

Caloric devices are promising - and there is still a lot of potential to be explored!
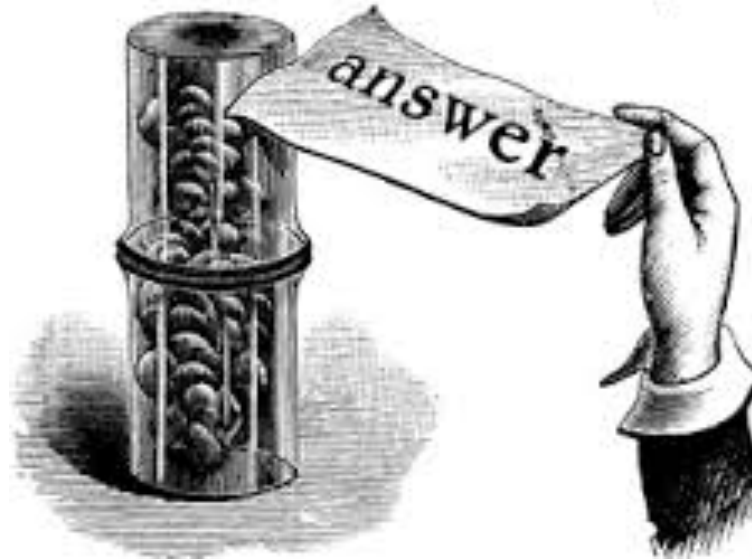
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Kristina Navickaite

Innovation Fund Denmark
RESEARCH, TECHNOLOGY & GROWTH

OTTO MØNSTEDS FOND

DET FRIE FORSKNINGSRÅD
DANISH COUNCIL FOR INDEPENDENT RESEARCH

European Commission
HORIZON 2020

H.C. Ørsted COFUND

And many companies......among other some Japanese companies

Mechanical **A**lternatives **G**iving **G**reatly **I**mproved **E**fficiency (MAGGIE)

THANK YOU FOR YOUR ATTENTION!!

I hear,
I know.
I see,
I remember.
I do,
I understand.