



**“Research for a
better future”**

A Metal Hydride Thermal Sorption Hydrogen Compressor

Jan Petter Mæhlen, IFE

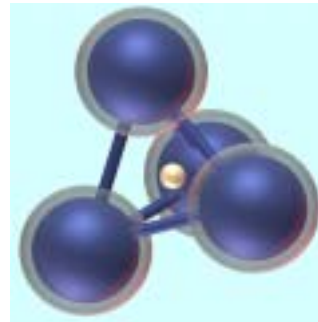
Contents

- About metal hydrides
- Compressing hydrogen using metal hydrides
- A compact-and-fast-response-semi-continuous-metal-hydride-thermal-sorption-hydrogen-compressor
- Test-results
- ...remarks

Motivation

- Hydrogen Society
- Hydrogen Storage
 - Solid
 - Re-liquefaction
 - High Pressure
- Auxillary
 - Sensors, valves,...
 - Heat management, Heat-pumps, ...
 - Hydrogen management

Metal hydrides



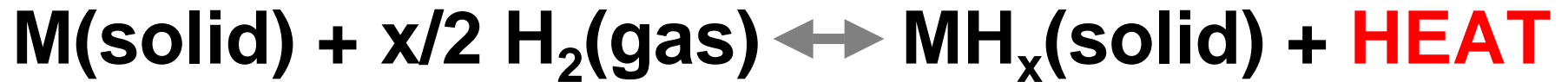


Background

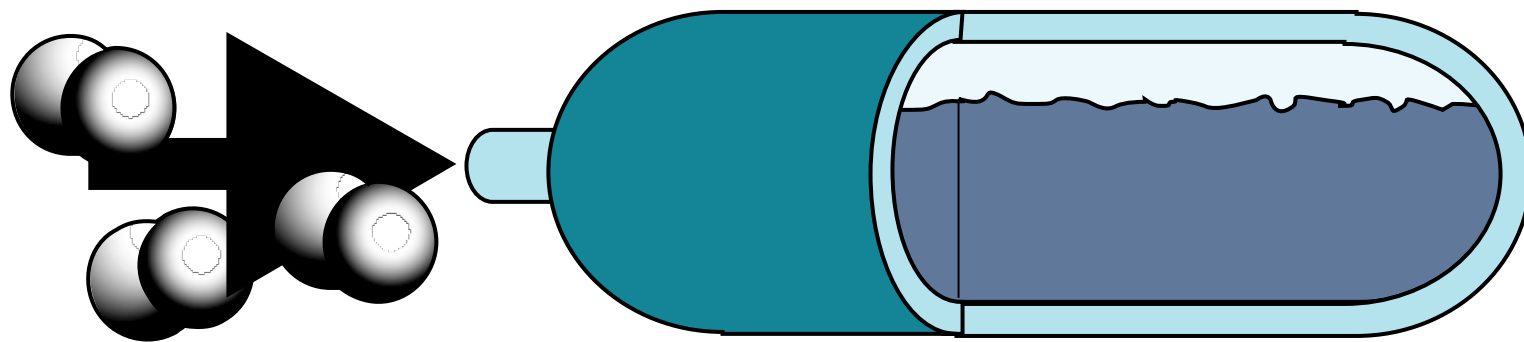
“Metal Hydride Compressor and Materials for its Efficient Performance”

1 year post doc. position (started 1.Jan.2004); part of the NORSTORE project **“Advanced H Storage Materials and their Integration into the Hydrogen Society”** 2003-2006 (Nordic Energy Research Program, 5 Nordic countries, Latvia and Russia, IFE coordinator: V.A.Yartys).

Metal Hydrides



H₂

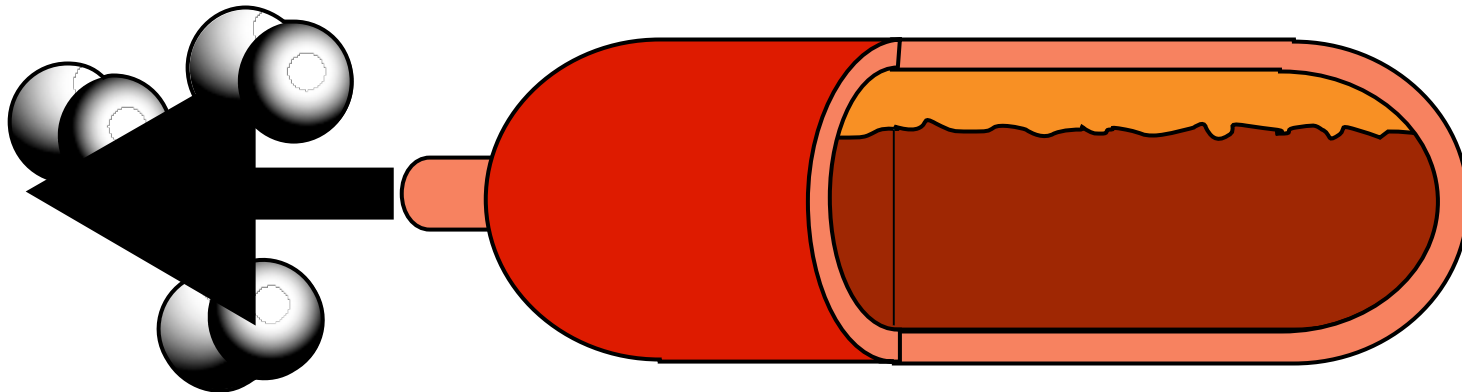


Forced loading by cooling

Metal Hydrides

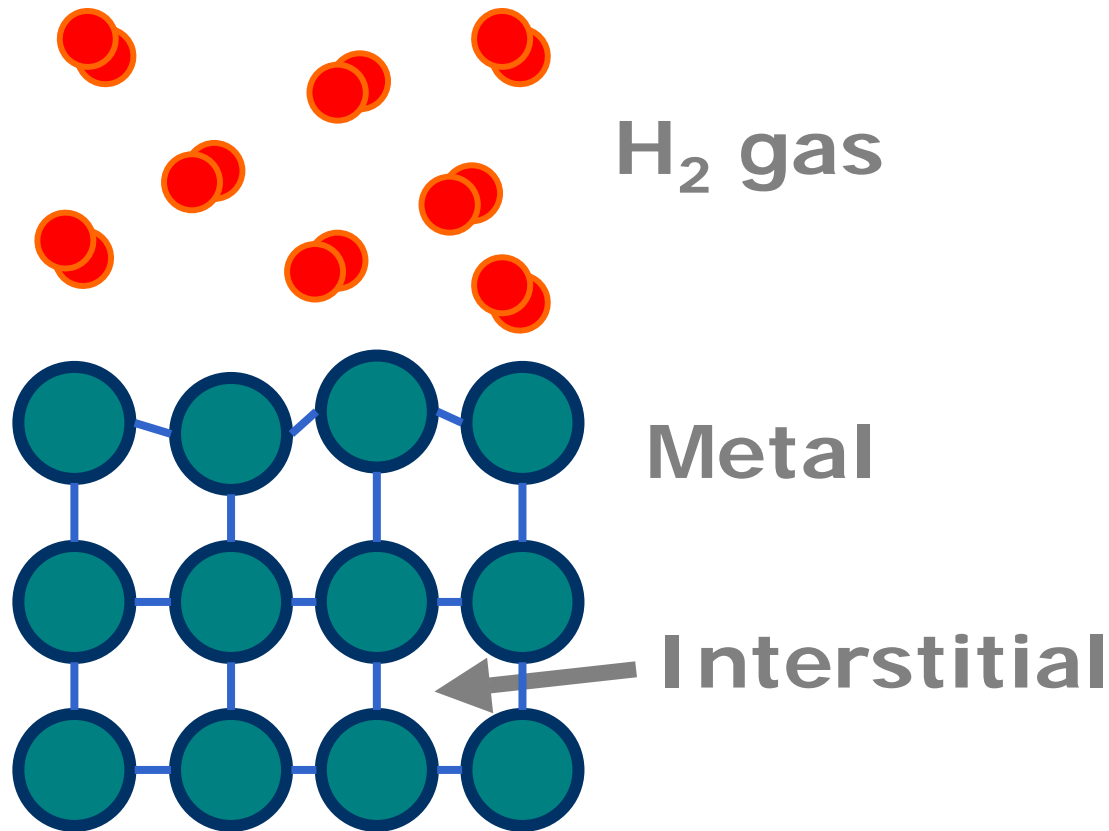


H₂

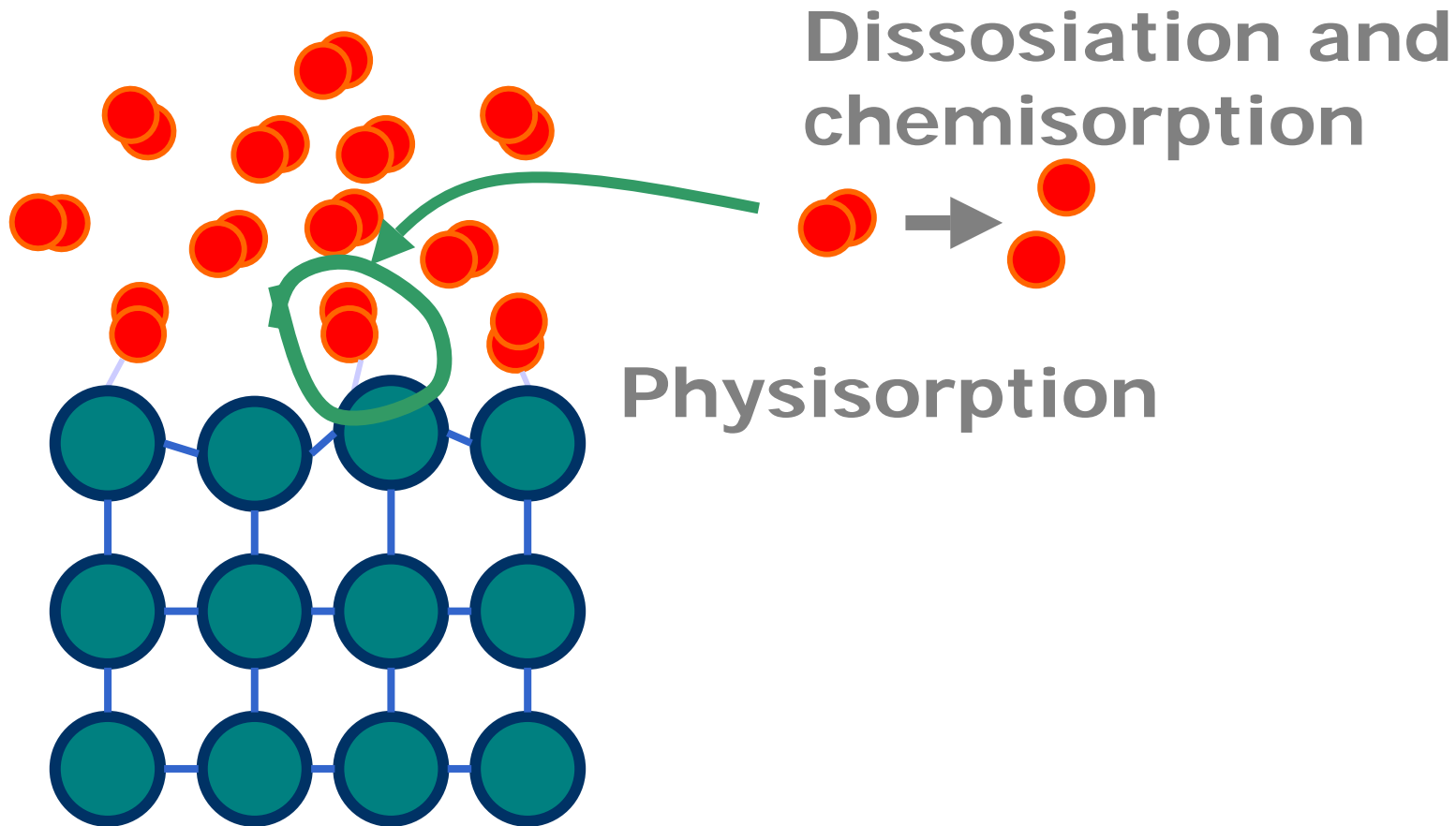


Forced discharging by heating

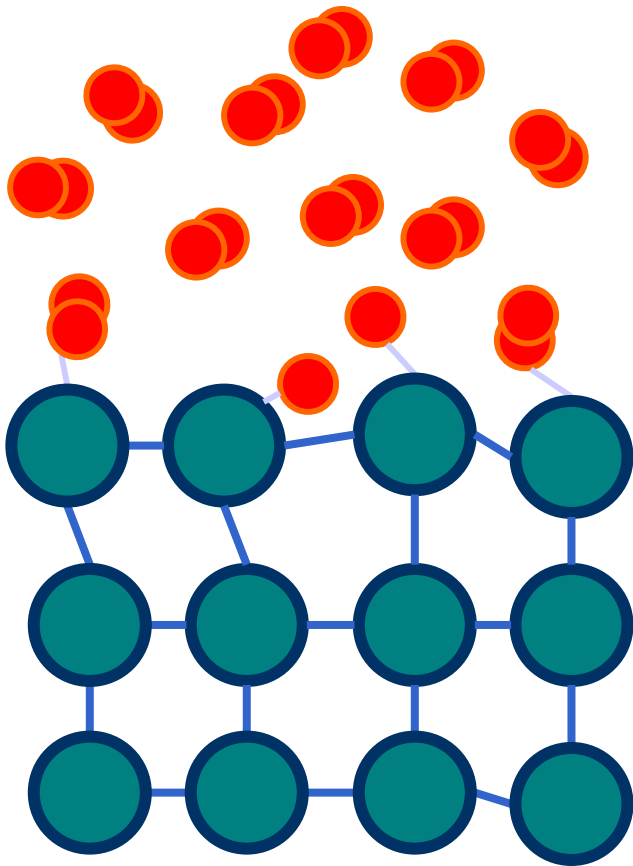
Metal-Hydrogen Reaction



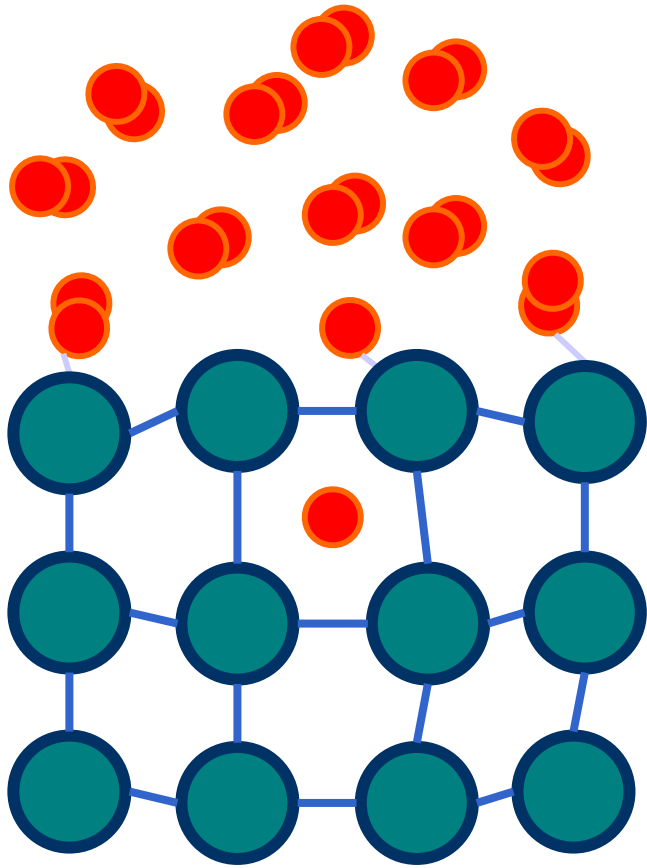
Metal-Hydrogen Reaction



Metal-Hydrogen Reaction

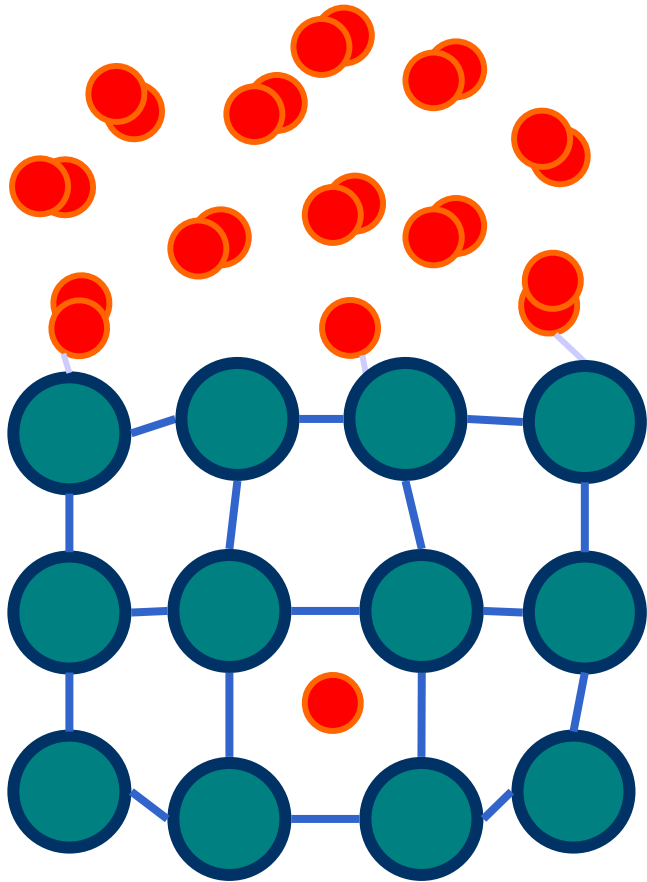


Metal-Hydrogen Reaction



α -phase
(solid solution)

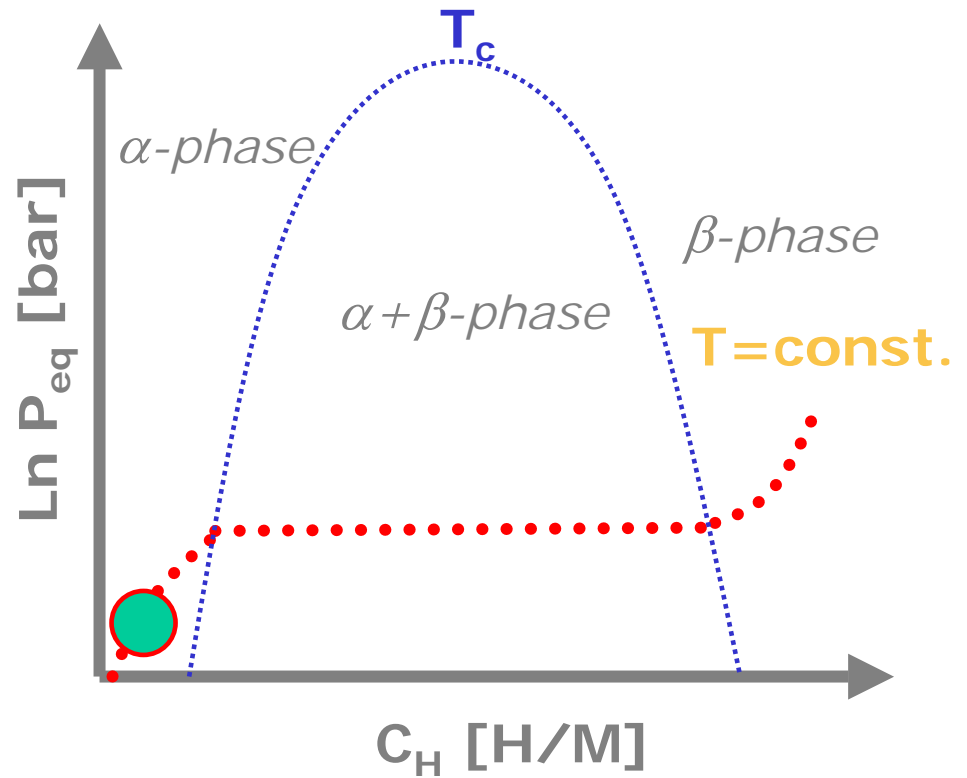
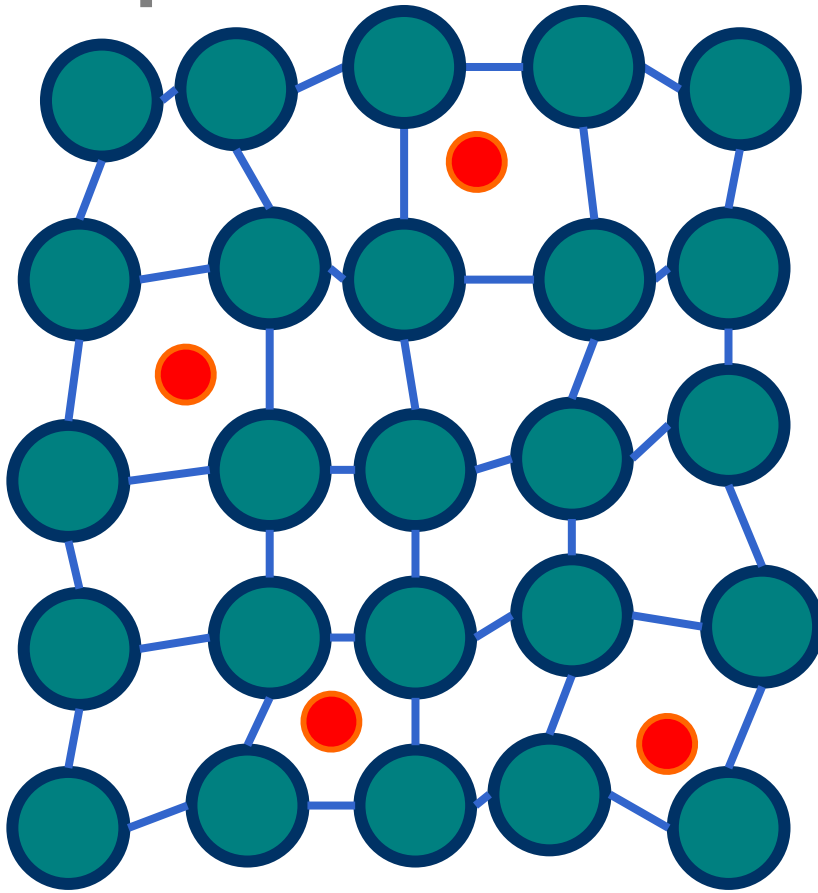
Metal-Hydrogen Reaction



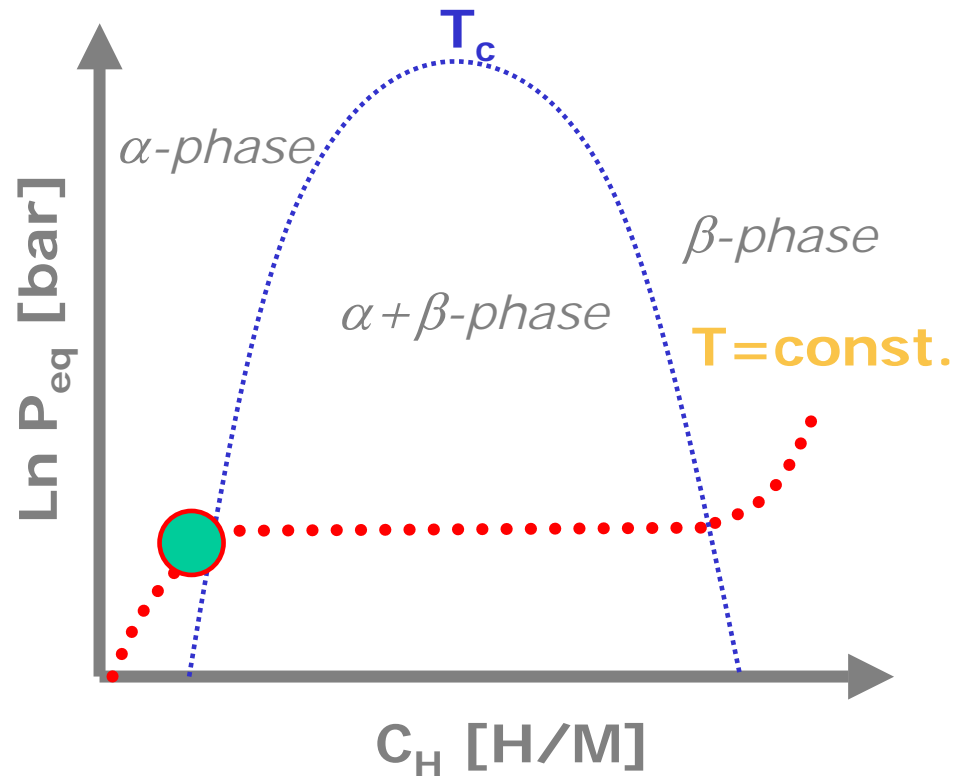
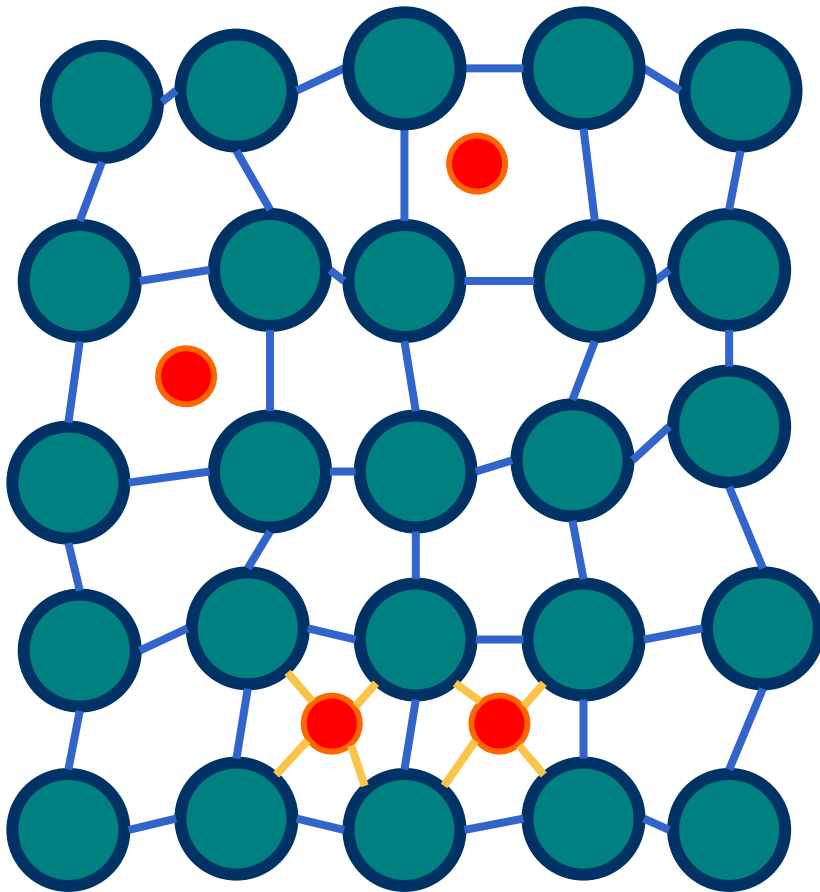
H-diffusion

Solid Solution to Hydride Phase

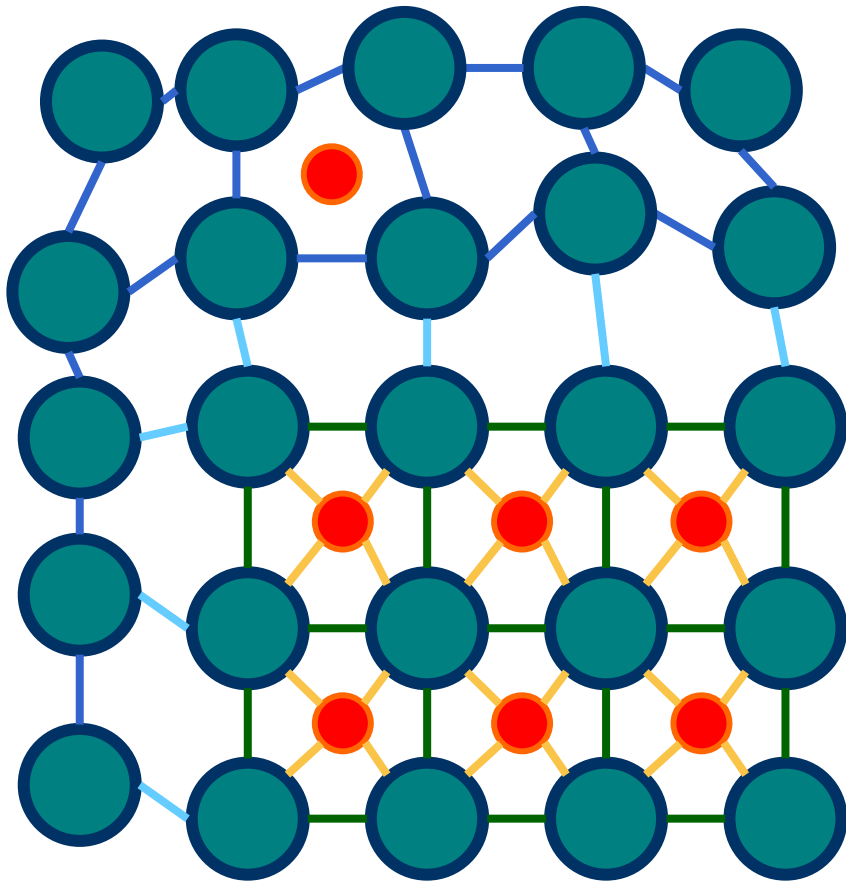
α -phase



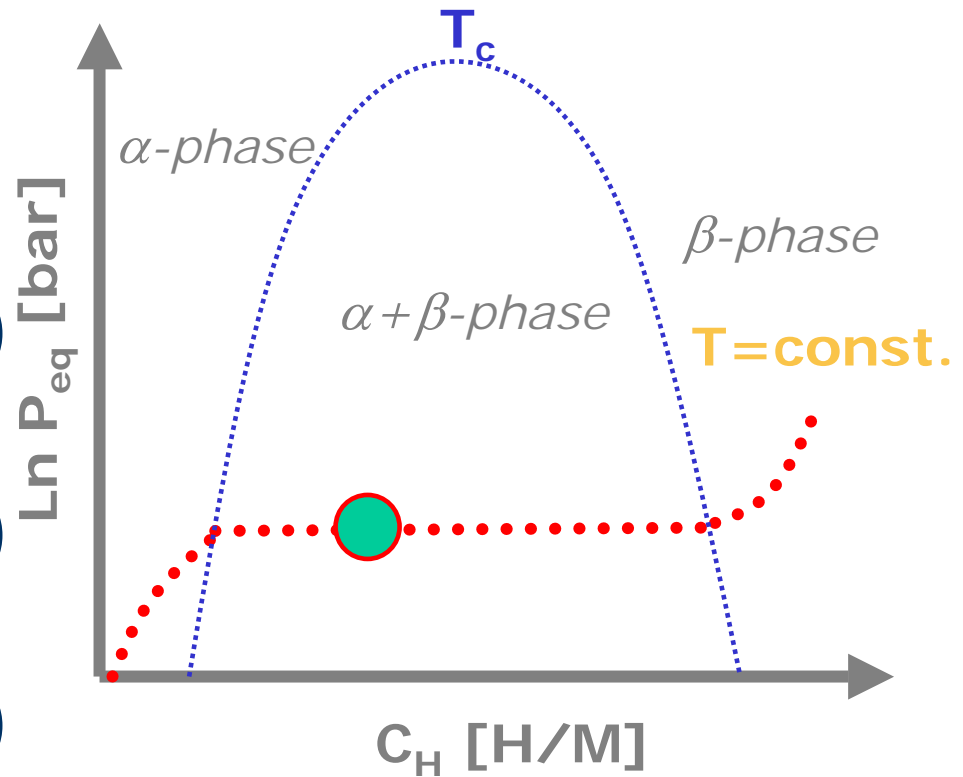
Nucleation of β -phase (Hydride)



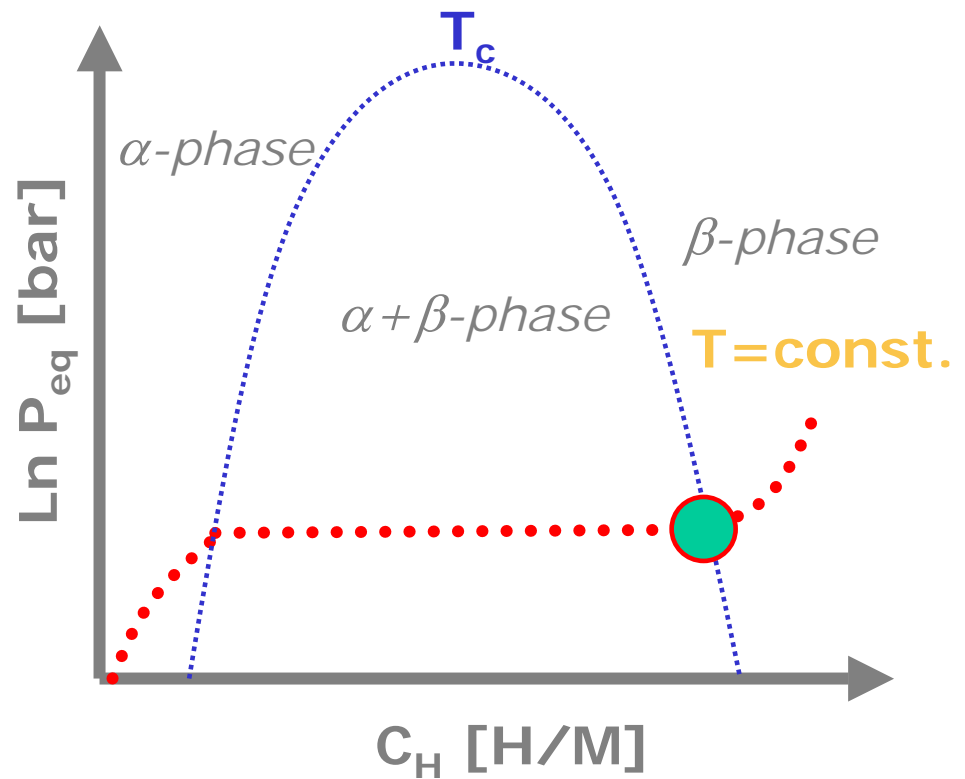
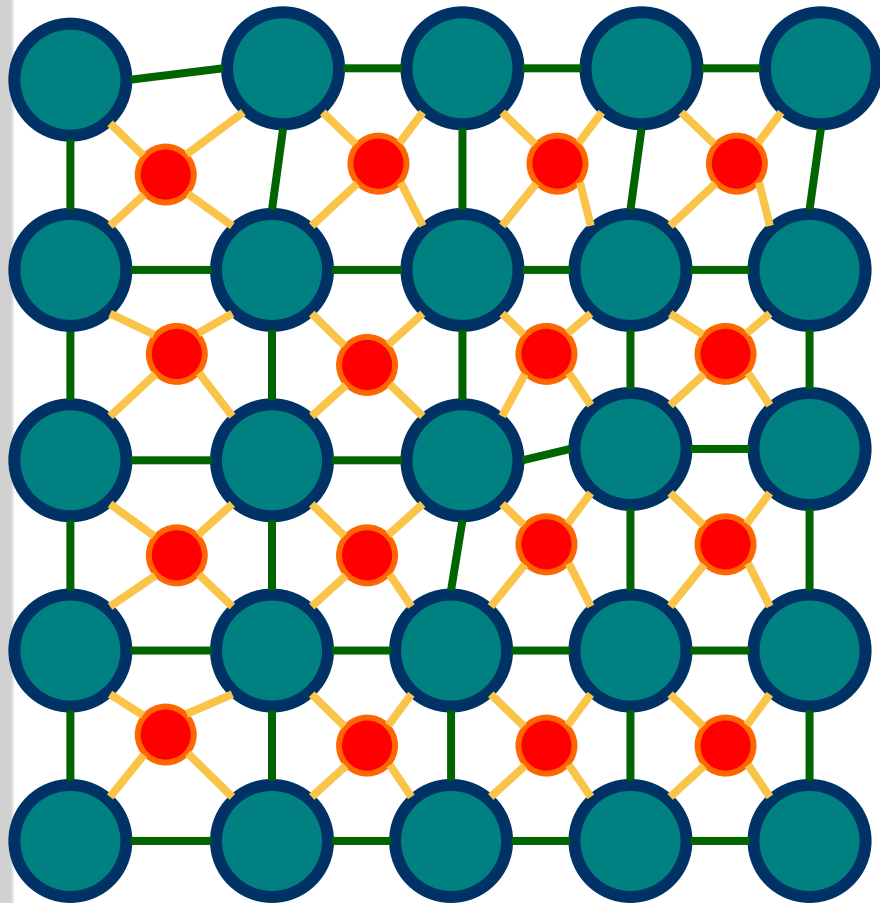
Coexistence of Two Phases



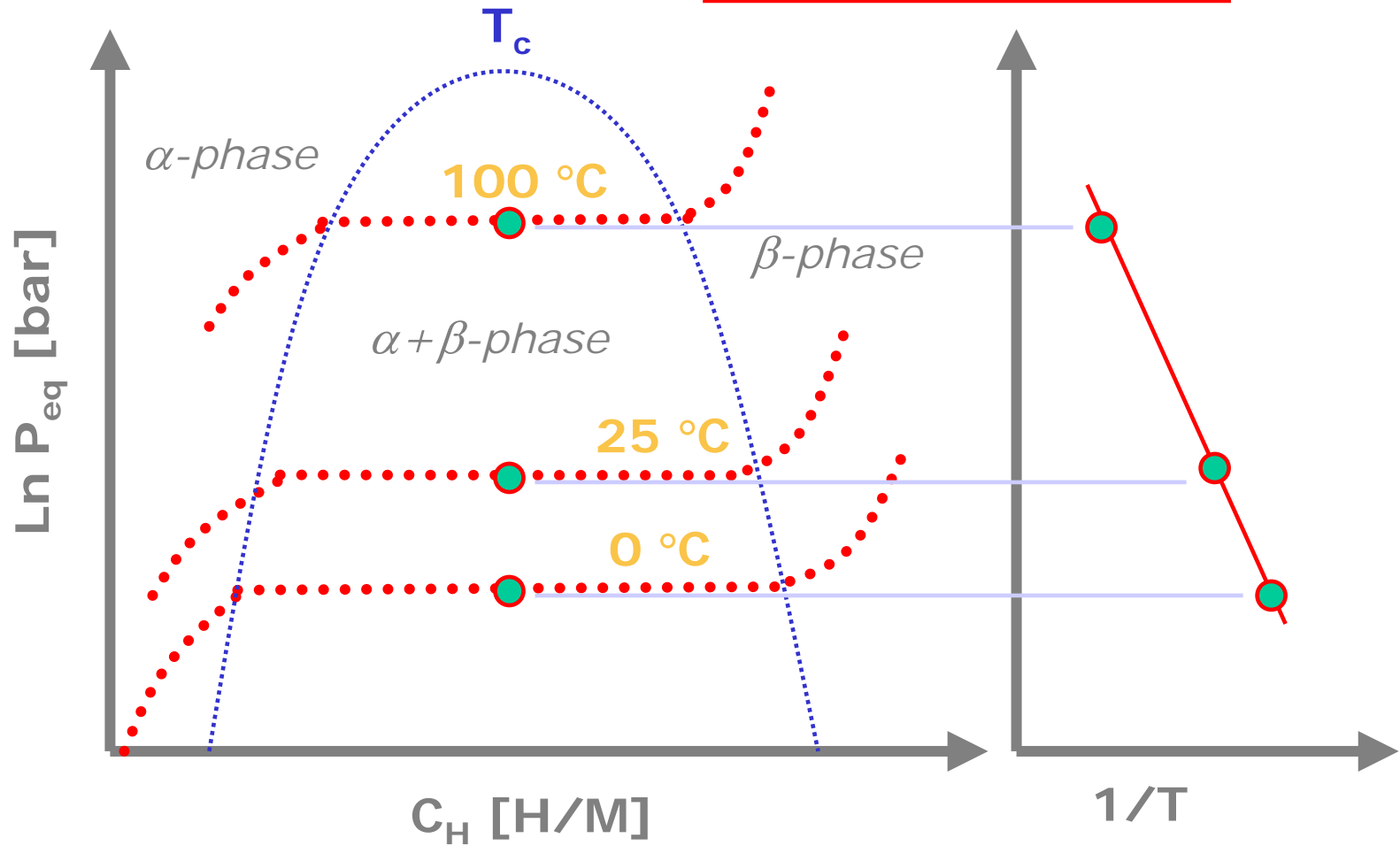
Growth of β -phase



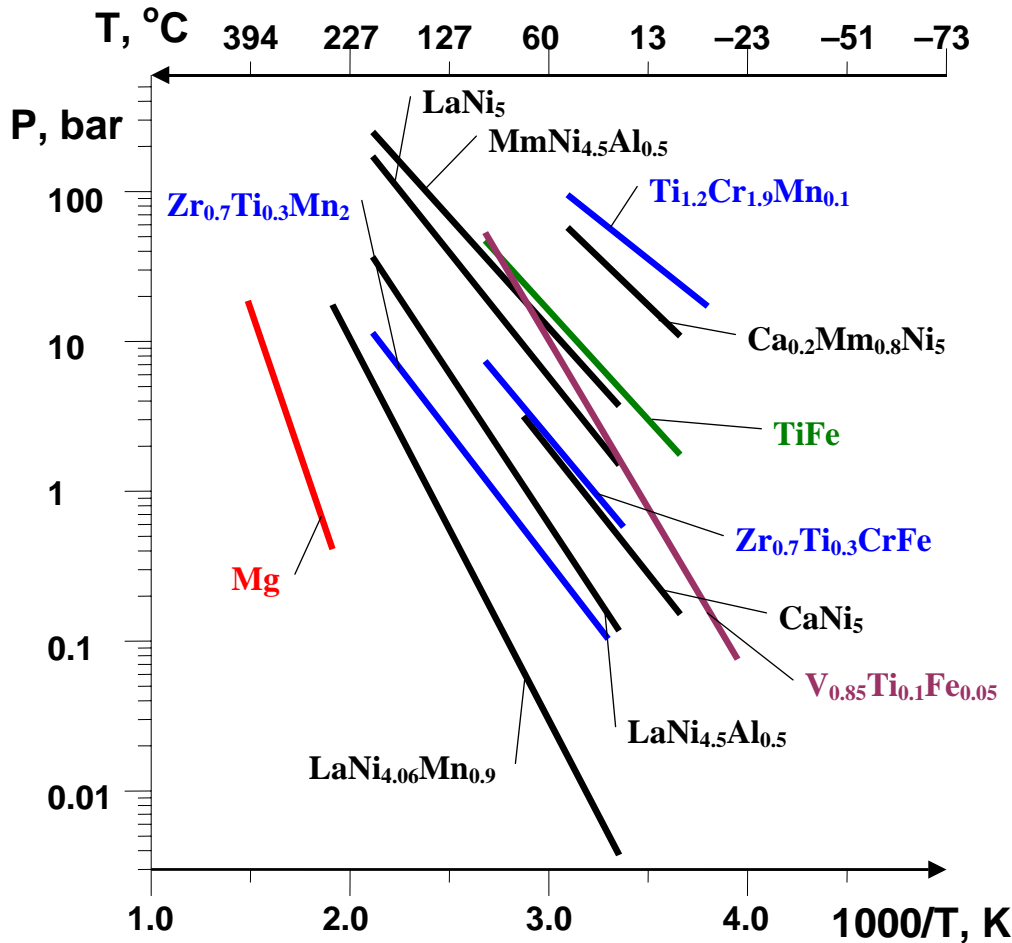
Solid Solution to Hydride Phase



$$\ln P_{eq} = -\frac{\Delta S^0}{R} + \frac{\Delta H^0}{RT}$$



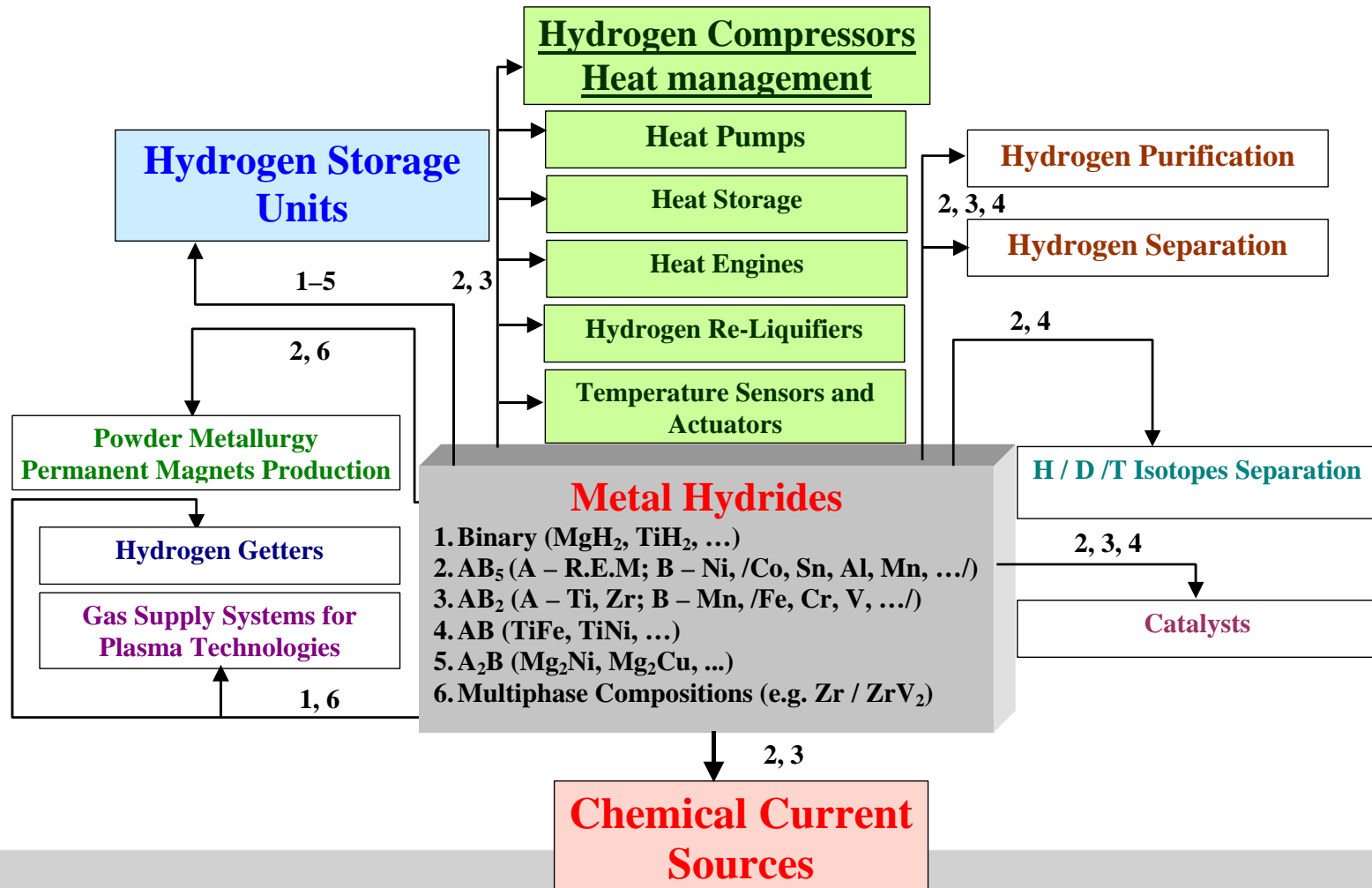
Applied-oriented properties of metal hydrides



- Binary (Mg - based)
- Binary (V - based)
- AB₅ (RE - based)
- AB₂ (Ti, Zr – based)
- AB (Ti – based)

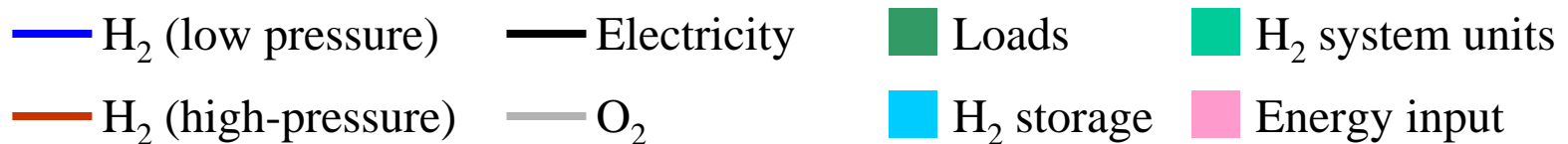
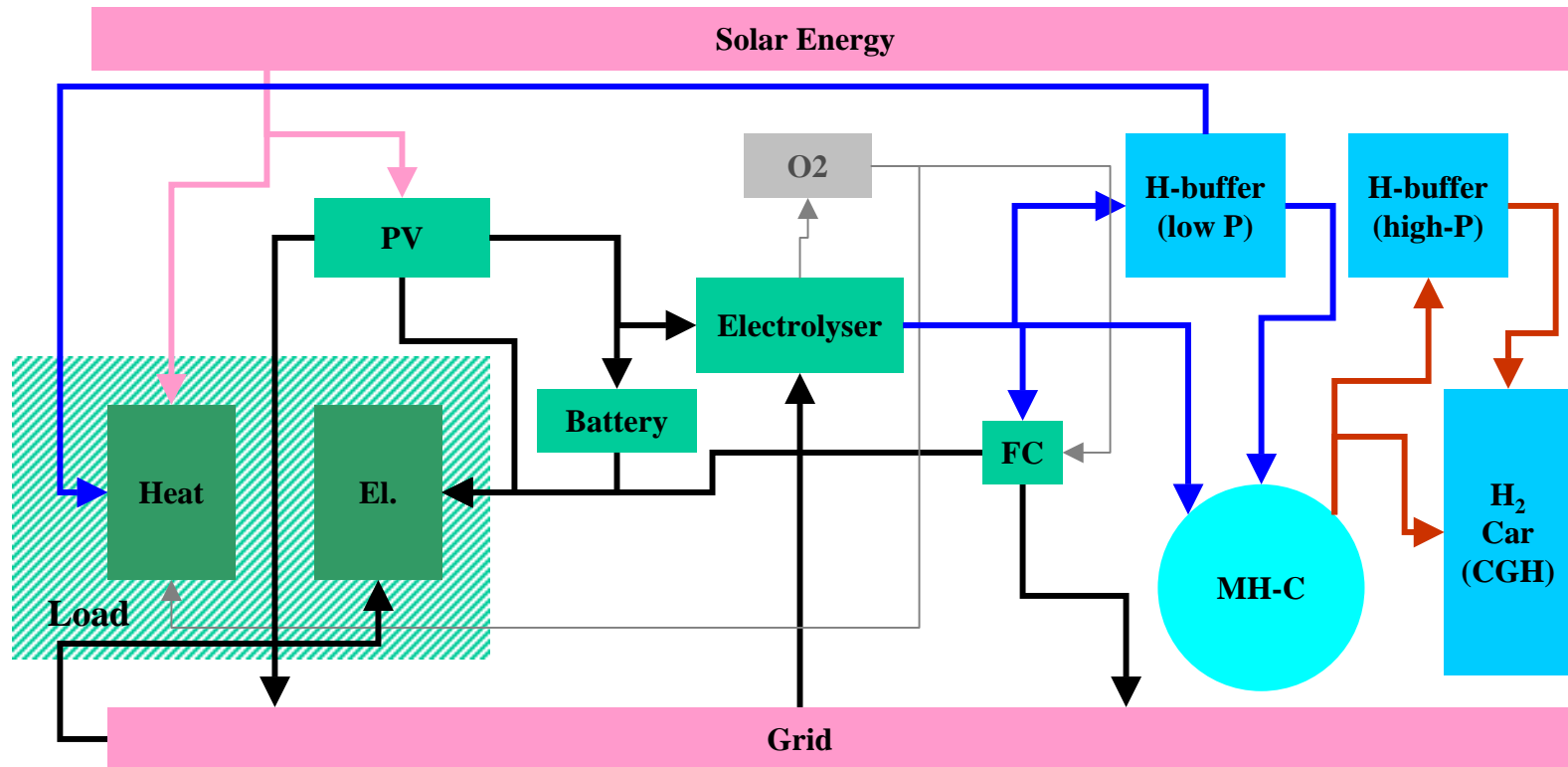
- ✓ Volume density of H in the metal lattice 1.5-2.0 times higher than for LH₂
- ✓ Fast and reversible absorption / desorption of H₂ gas
- ✓ Extremely wide temperature / pressure operation ranges
- ✓ Considerably large heat effects ($Q=20-40$ kJ/mole H₂): hydrogen sorption is accompanied by heating and hydrogen desorption by cooling of the MH bed

Some Applications (by Michael Lototsky)

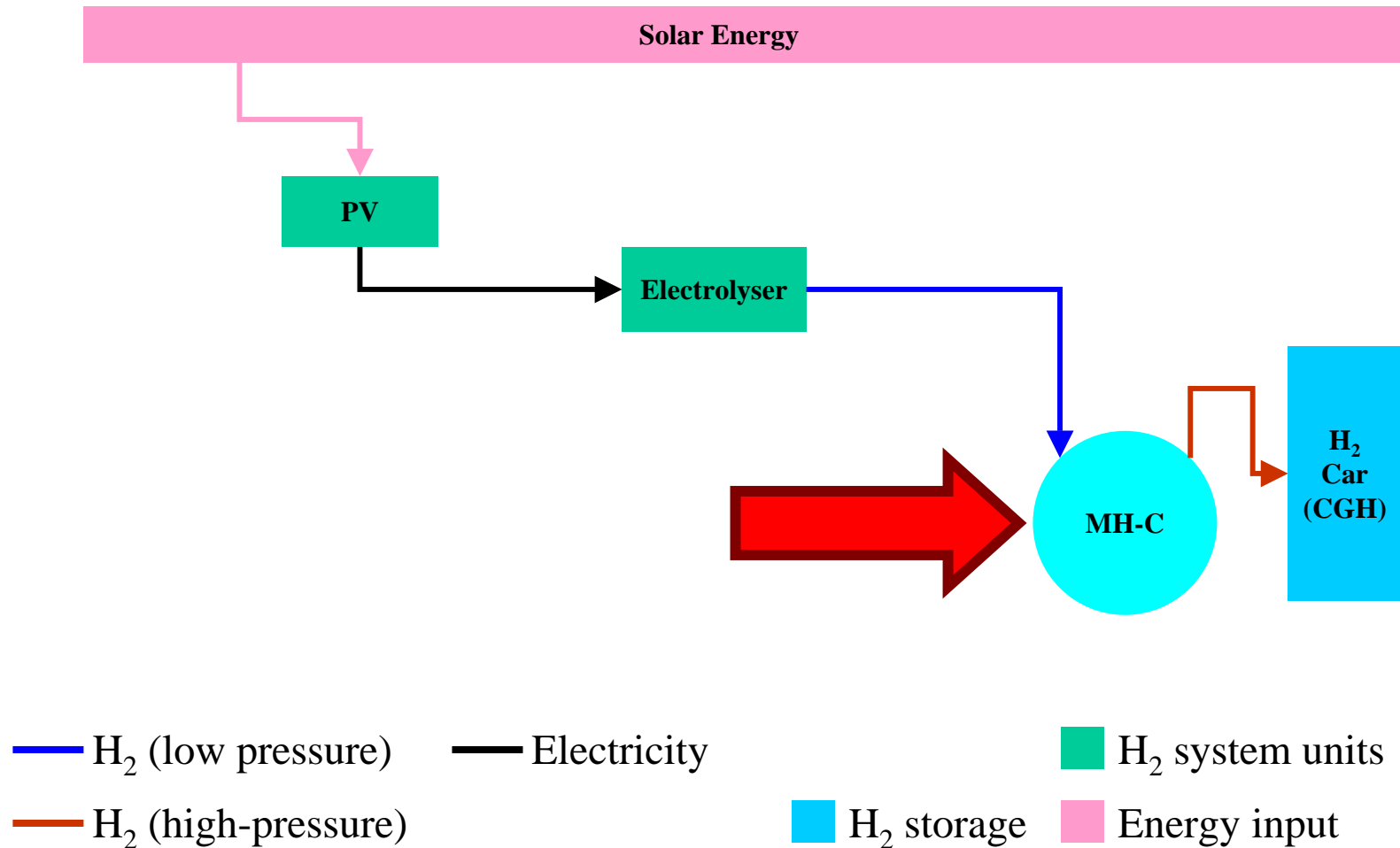


Thermal Sorption Compressors

Advanced energy system



Hydrogen to car system



Compressed Gas Car: TOYOTA FCHV



Ni-MH
Secondary Battery
Unit



~ 16-18
elements
in stack

Prismatic Module



Panasonic EV Energy Co., Ltd.

Voltage	: 7.2 V
Capacity	: 6.5 Ah
Power	: 1000 W/kg
Energy	: 46 Wh/kg
Weight	: 1020 g

Fuel Cell: TOYOTA FC Stack

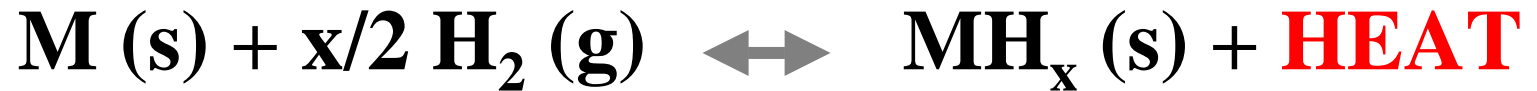
H₂ Storage: 350 bar H₂/composite cylinder with 2.0-2.5 kg H₂ (64-80 l)

Battery: Ni-MH (Mm-based AB₅ type)

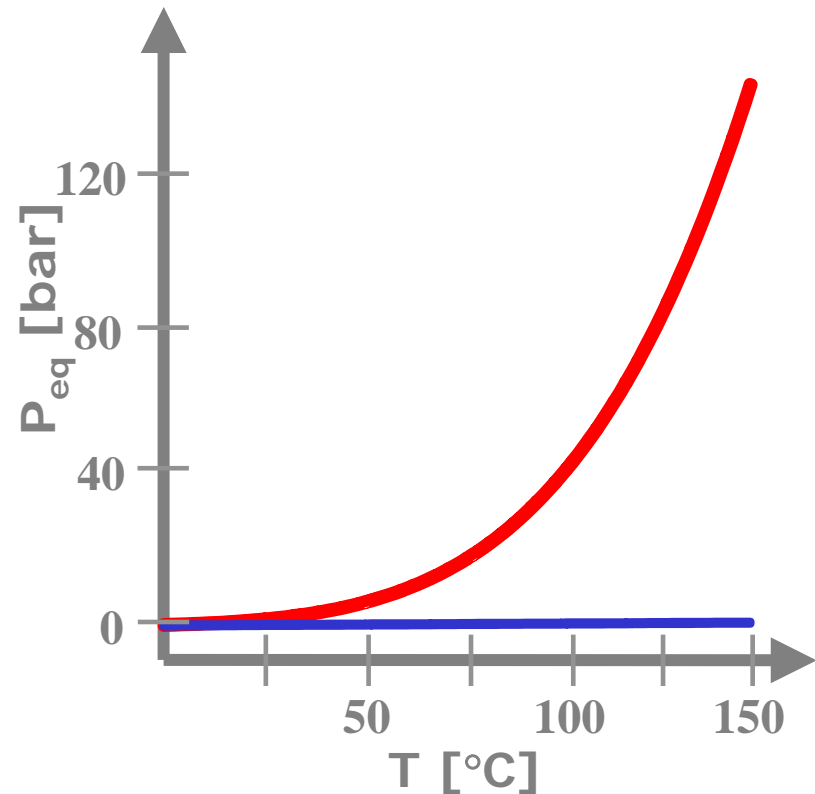
Speed limit: 155 km/h;

Cruising Range: 300 km

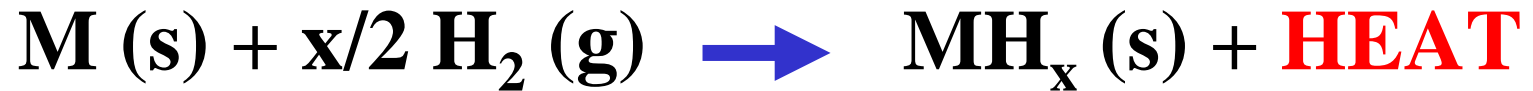
Principles of MH Compression (1)



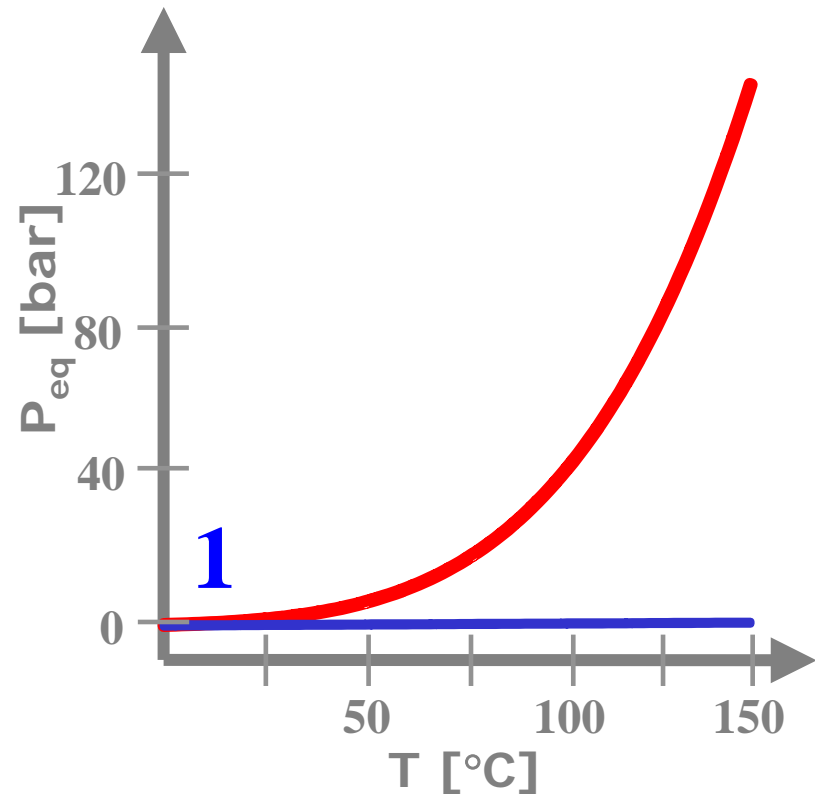
	LaNi ₅ H _x	Cylinder
0 °C	0.4	1.00
50 °C	3.51	1.18
100 °C	17.24	1.37
150 °C	58.18	1.55
200 °C	151.82	1.73



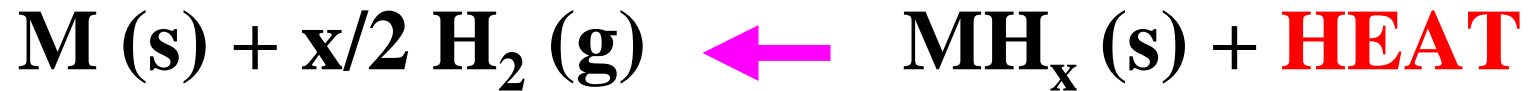
Principles of MH Compression (1)



1 - H₂ sorption at low temperature and low pressure (heat release)

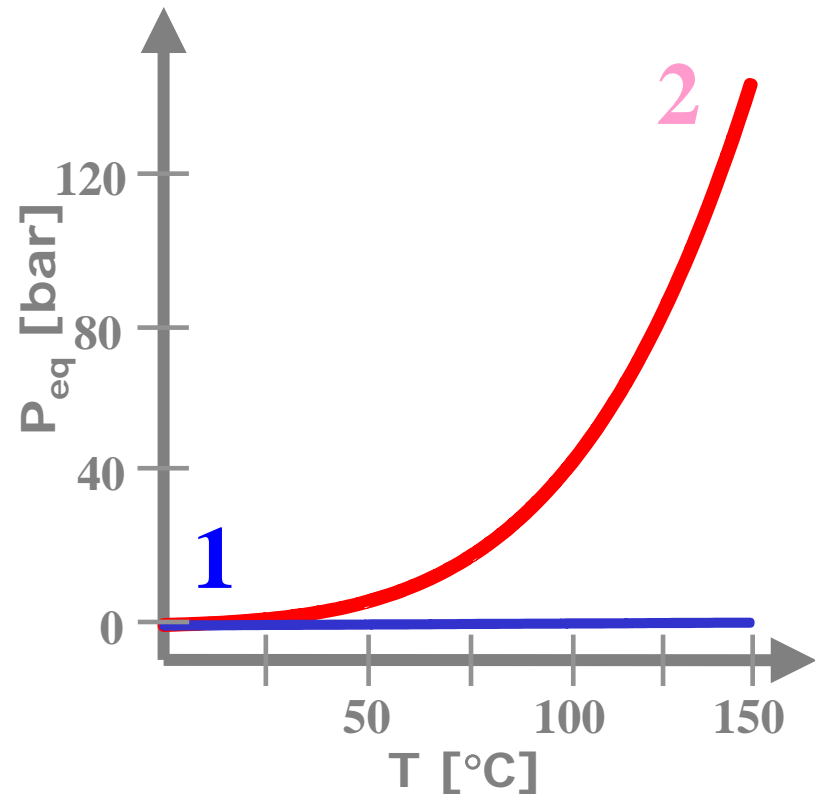


Principles of MH Compression (1)



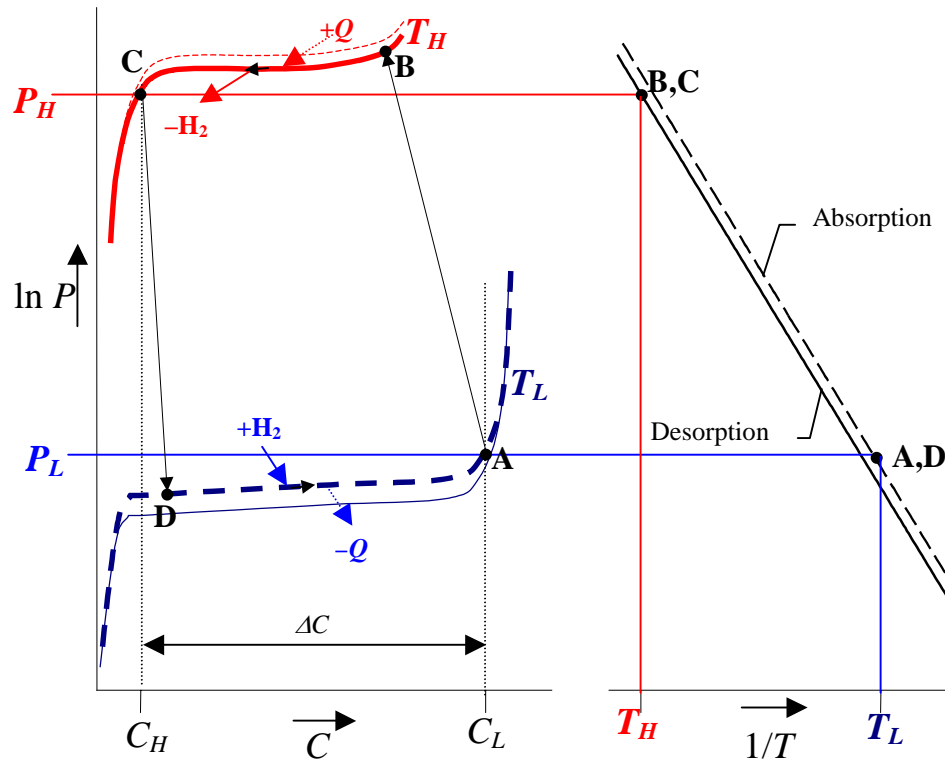
2 - H₂ desorption at high temperature and high-pressure (heat consumption)

1 - H₂ sorption at low temperature and low pressure (heat release)

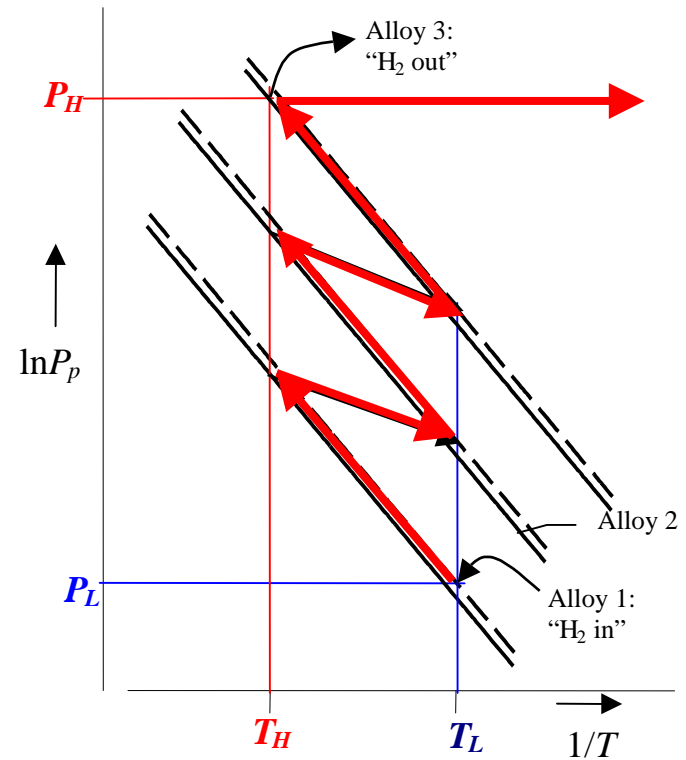


Principles of MH Compression (2)

Single-stage operation



Multi-stage operation

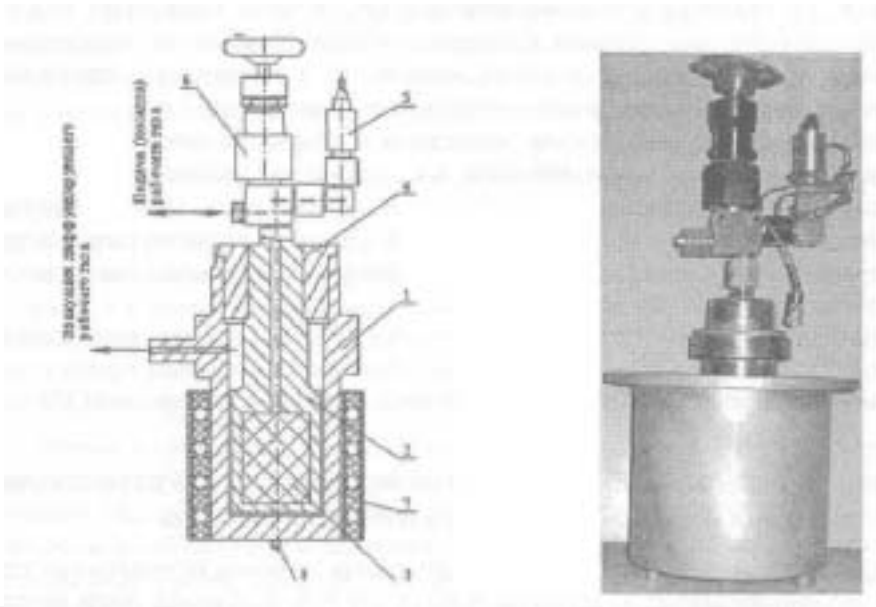


$$\ln P_p = -\frac{\Delta S^0}{R} + \frac{\Delta H^0}{RT}$$

Russian Federal Nuclear Center, Russian Research Institute of Experimental Physics, Nizhni Novgorod Region, Russia

Compressing hydrogen isotopes (protium, deuterium, tritium) up to 5000 bar

- Vanadium dihydride; charge ~100 bar / 20 °C; discharge **5000 bar** / 500 °C
- Special material and design of the high-pressure vessel
- Periodic operation

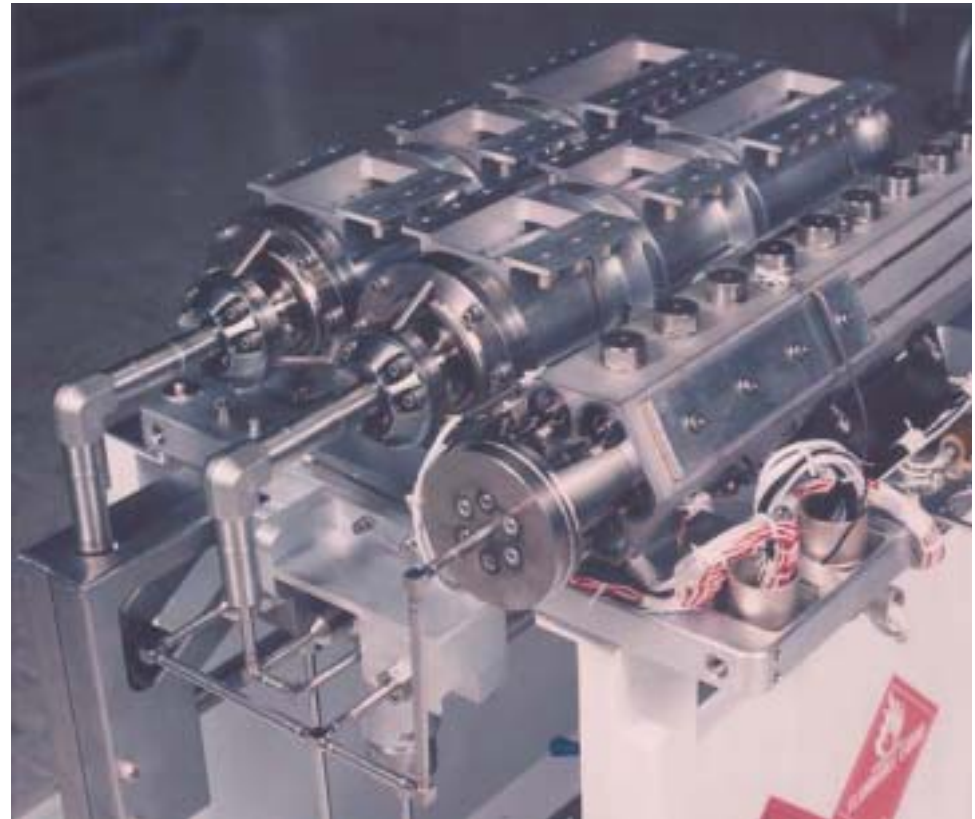


A.A. Yukhimchuk, R.I. Il'kaev, V.N. Lobanov.
In: Interaction of Hydrogen Isotopes with Structural Materials IHISM'01, – Proc. Int. Workshop, Sarov, Russia, 2001, pp.16-38

A.N. Golubkov, S.K. Grishechkin, A.A. Yukhimchuk. *Int. J. Hydrogen Energy*, 26 (2001) 465-468

Examples of cryocoolers

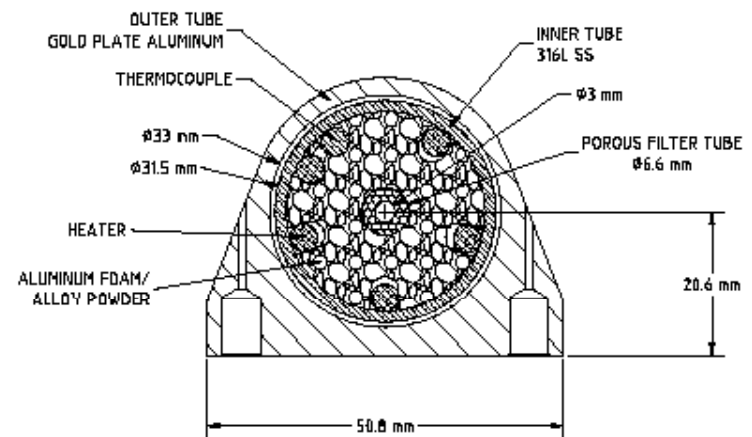
- BETSCE cryocooler
 - First space-flight demonstration of sorption cryocooler Shuttle Mission STS-77 (Orbiter Endeavour, 1996)
- Three MH-beds
 - Fast, Low P., High P.
- T_{\min} : 9.44 K



R.C.Bowman, Jr., B.D.Freeman and J.R.Phillips, J.Alloys Comp., 357-357, 2003, 789-793

Examples of cryocoolers

- MH Compression Element for the Planck Engineering Bread Board Cryocooler
 - Gas gap actuator ($\text{ZrNiH}_{\sim 1.5}$)
 - Cooling capacity – up to 2W @ 20 K
 - H_2 flow rate – up to 30 mg/s



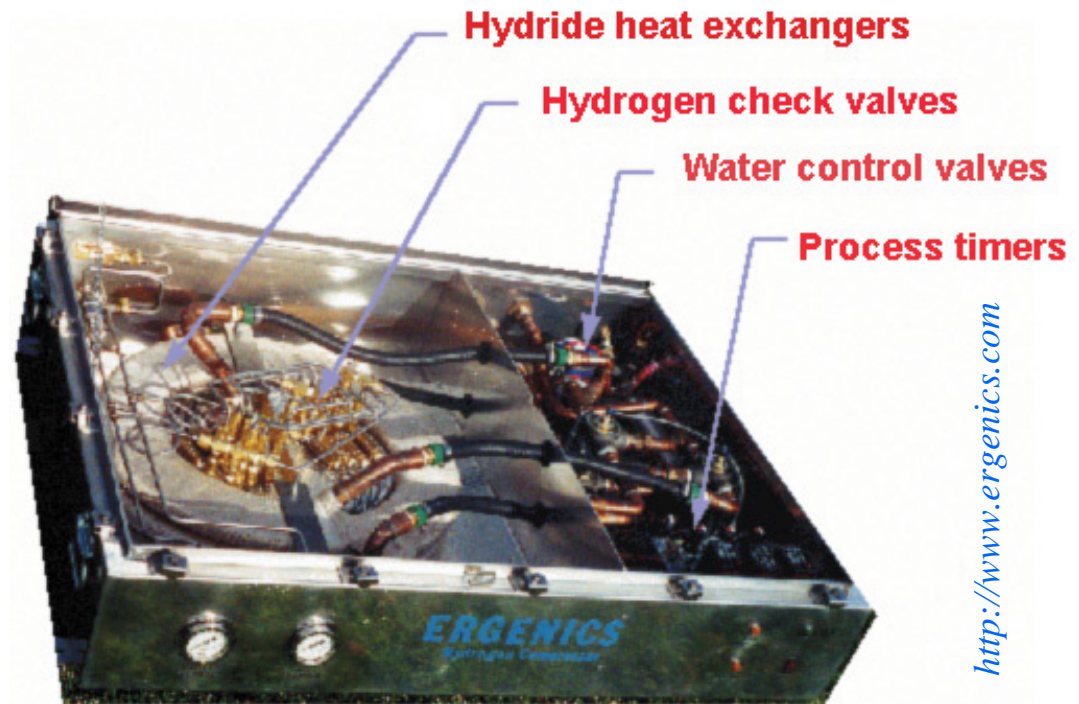
R.C.Bowman, Jr., B.D.Freeman and J.R.Phillips, J.Alloys Comp., 357-357, 2003, 789–793

And there exists others...for example...

Ergenics (US)

- Four stage commercial unit
- 200 bar
- 2.5 m³/h
- Ergenics bought by HERA

...and ...



**Hydrogen Components (US), Japan Steel Works,
NASA, ESA, IPMach (Ukraine), ...**

MH TSC: State of the Art –Summary

- Reach 200–250 bar discharge pressure of a MH TSC using low-potential heat in the temperature range 10–100 °C.
- There exists a technical possibility to make an industrial-scale MH TSC having a productivity of dozens of m³/h.
- Custom layout according to the consumer specification.
- Creation of a high-pressure (more than 300 bar discharge) MH TSC is feasible
- Commercial MH TSC rated for output pressure up to 700 bar has been recently created (heating temperature is not announced).

...and

- Results in high purity hydrogen (good for PEM)
- Almost no moving parts – High reliability
- Can utilise waste heat as energy input
- Liquefying hydrogen (P~50 bar, then Joule-Thompson valve)

TASK

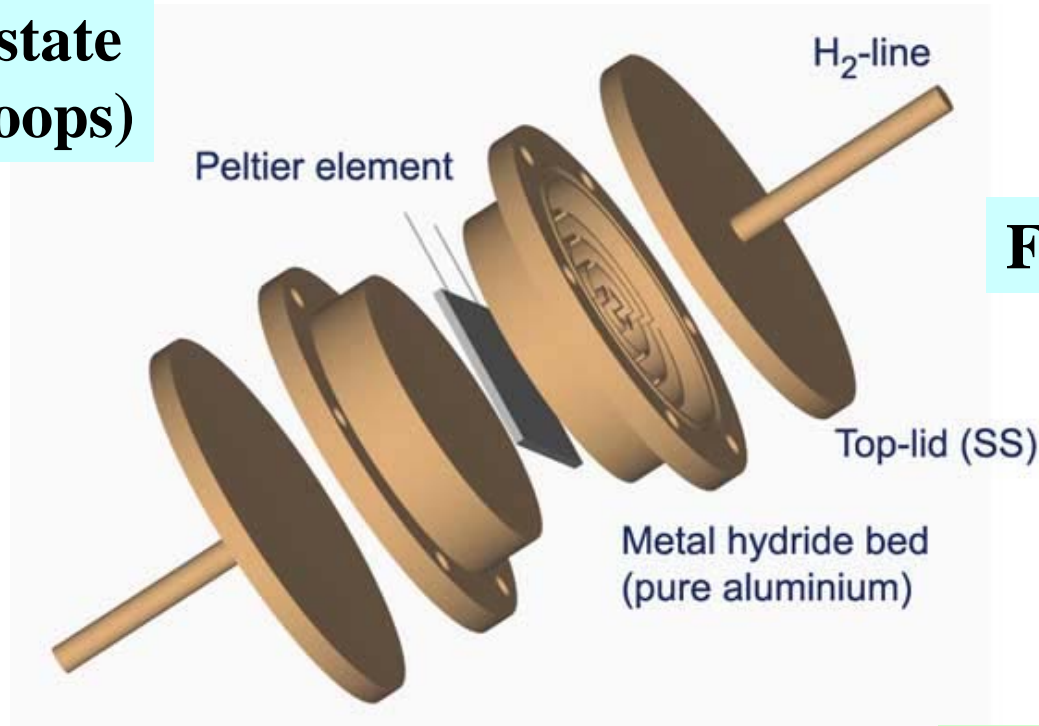
Make a hydrogen compressor using metal hydrides

- Replace fluid type system with solid-state system
 - Peltier element (Thermo-Electric, TE) for forced cooling and heating.
- Build a setup for testing the compressor and future compressors

IFE prototype: fast response compression system



**Only solid-state
(no water loops)**



Fast response

High operational control

No moving parts!

The Peltier Effect / Thermoelectricity

Theory of Operation (1 of 2)

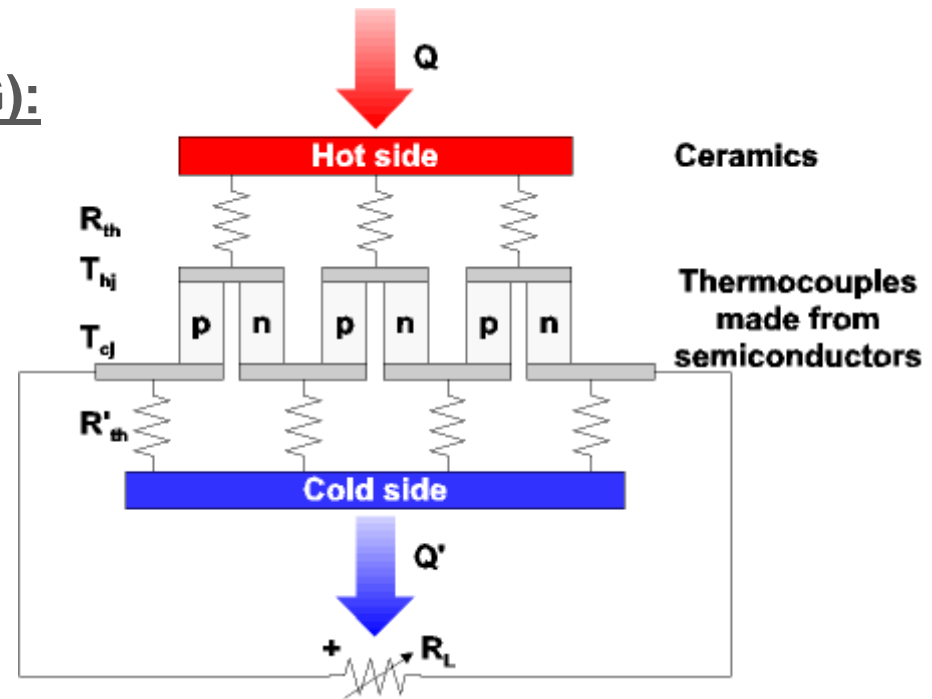
- Thermoelectric Generator (TEG):

A TEG consists of several n - and p -type semiconductor pellets connected electrically in series and thermally in parallel

Electrical power is derived from the movement of electrical carriers brought on by heat flow through the semiconductor pellets

Positive carriers (holes), move to the cold side of the p -type pellet making that junction electrically positive. Similarly, electron flow in the n -type pellets results in a net negative charge at the cold side of the n -type pellet

The electrical potential of the n - and p -type semiconductor pellets are series-added



Theory of Operation (2 of 2)

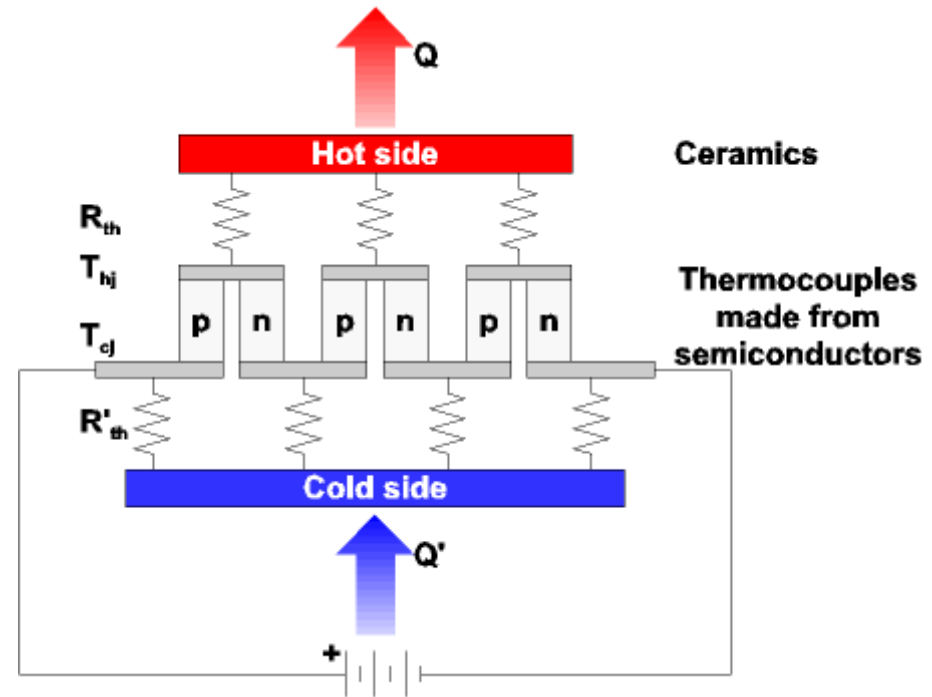
- Thermoelectric Cooler (TEC):
(might also be regarded as a heater)

Similar **configuration** as for TEGs

...but...

When exposed to a **DC current**, **heat** will be moved (or 'pumped') in the direction of **charge carrier movement** through the **semiconductor** pellets (actually, it is the charge carriers that transfer the heat)

Reversing the **DC polarity** makes the **heat flow** in the **opposite direction**



A man with glasses and a beard is shown in profile, looking at a complex mechanical assembly on a workbench. The assembly consists of various metal parts, pipes, and a cylindrical component. The background shows a workshop environment with shelves holding tools and other equipment. The text "Building the Unit" is overlaid in orange on the image.

Building the Unit

18.11.2004

Images of the unit

Flange (SS)

Filter

O-ring

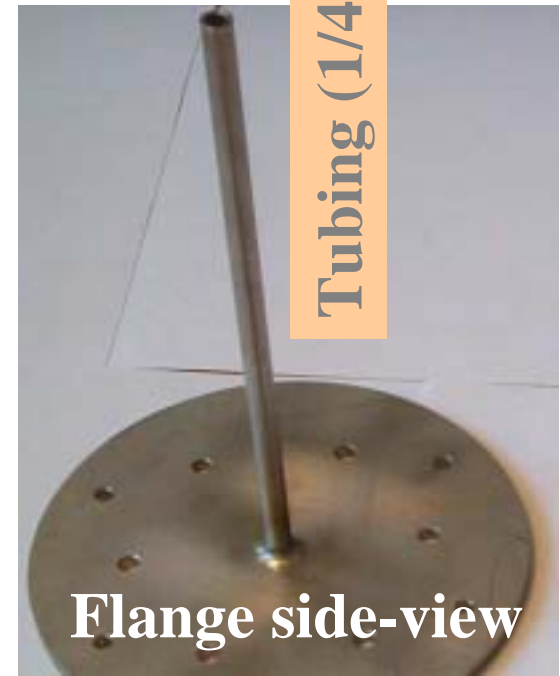
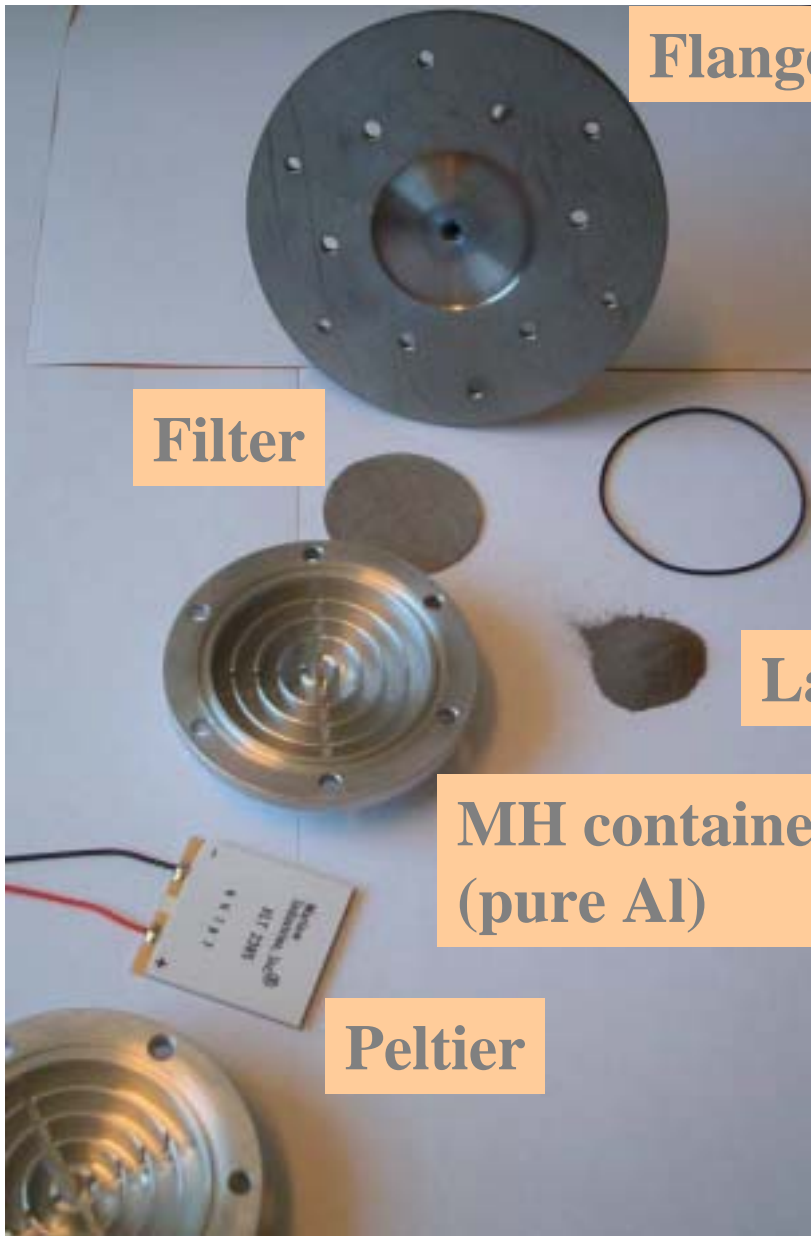
$\text{LaNi}_{5-x}\text{Al}_x$

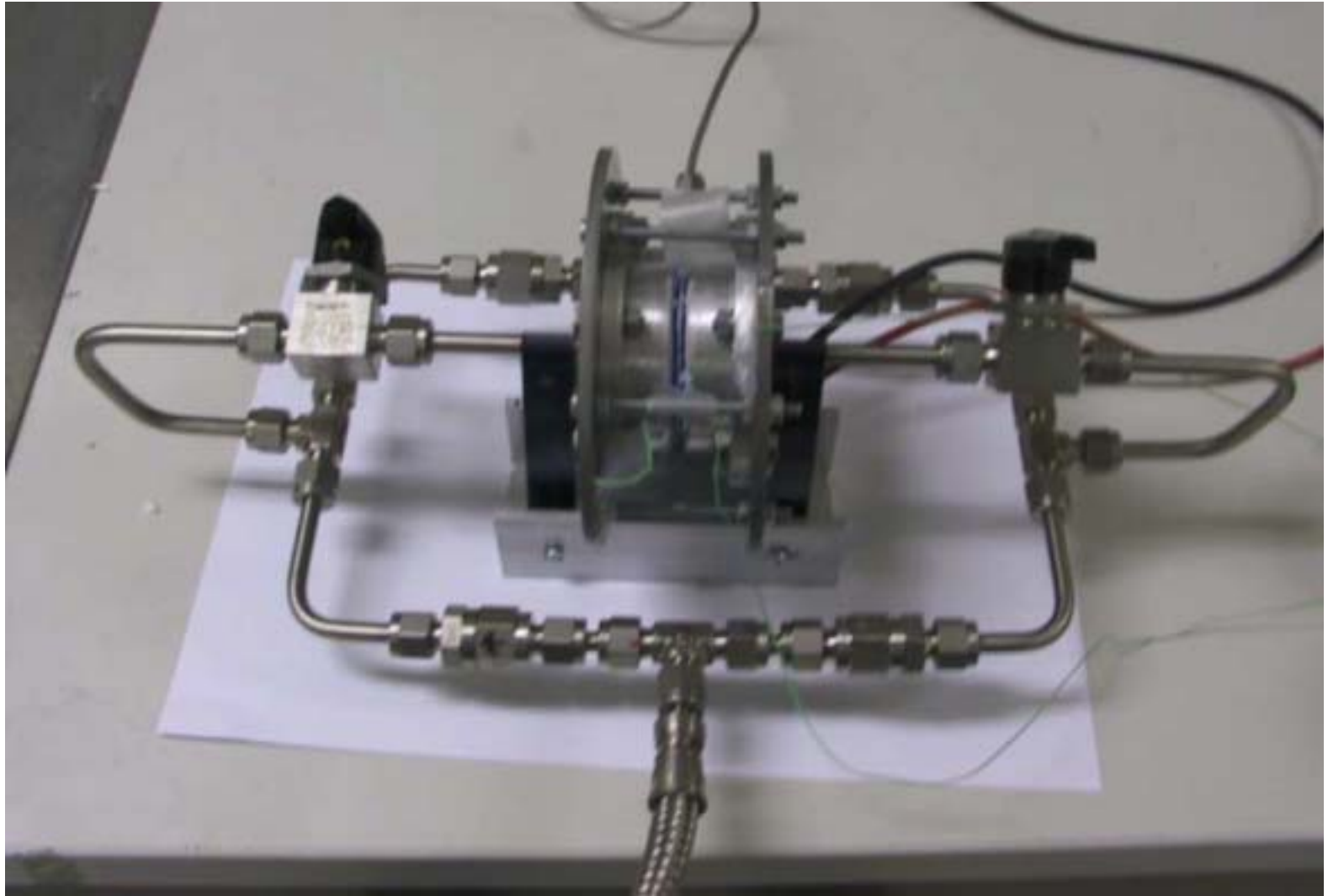
MH container
(pure Al)

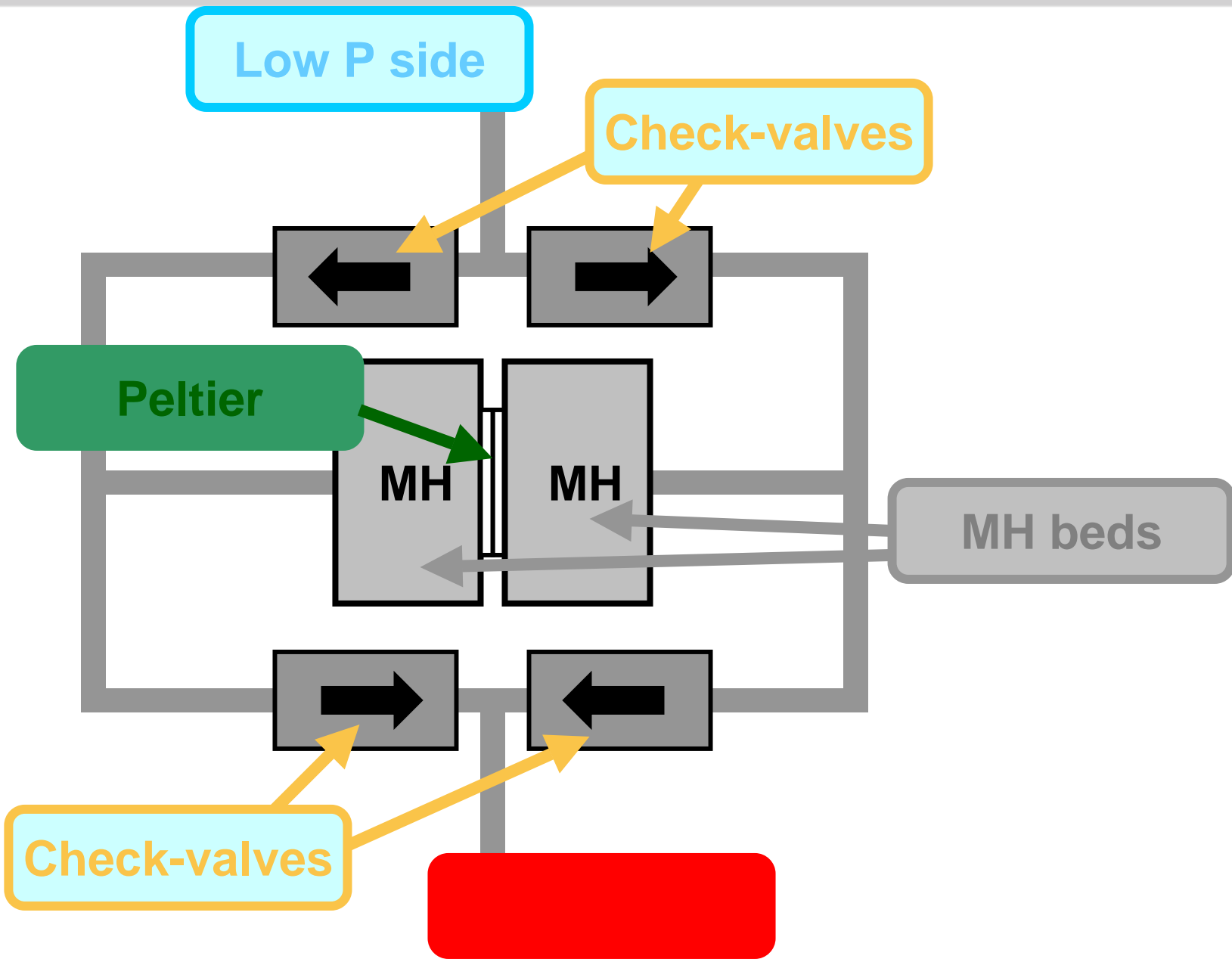
Peltier

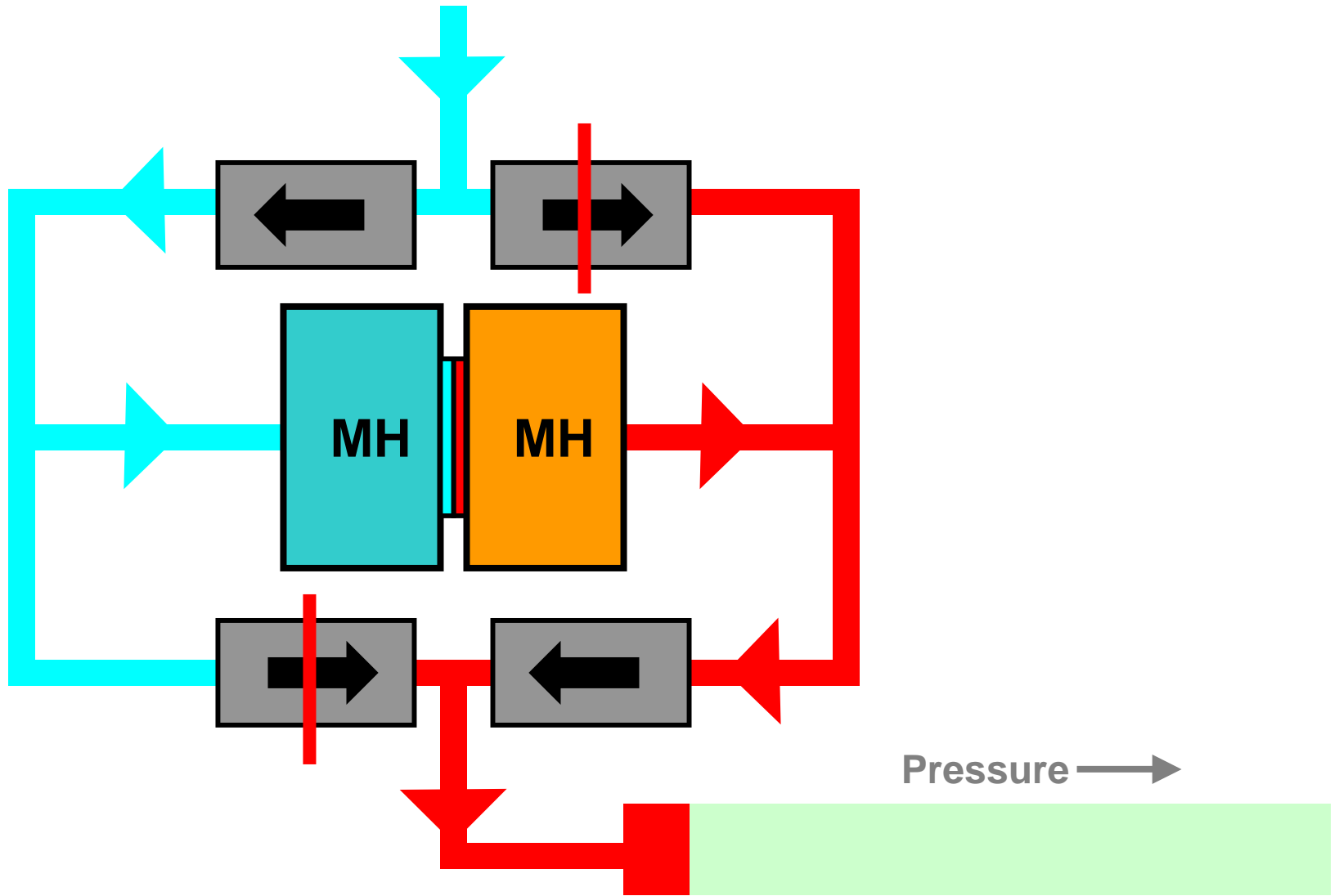
Tubing (1/4"SS)

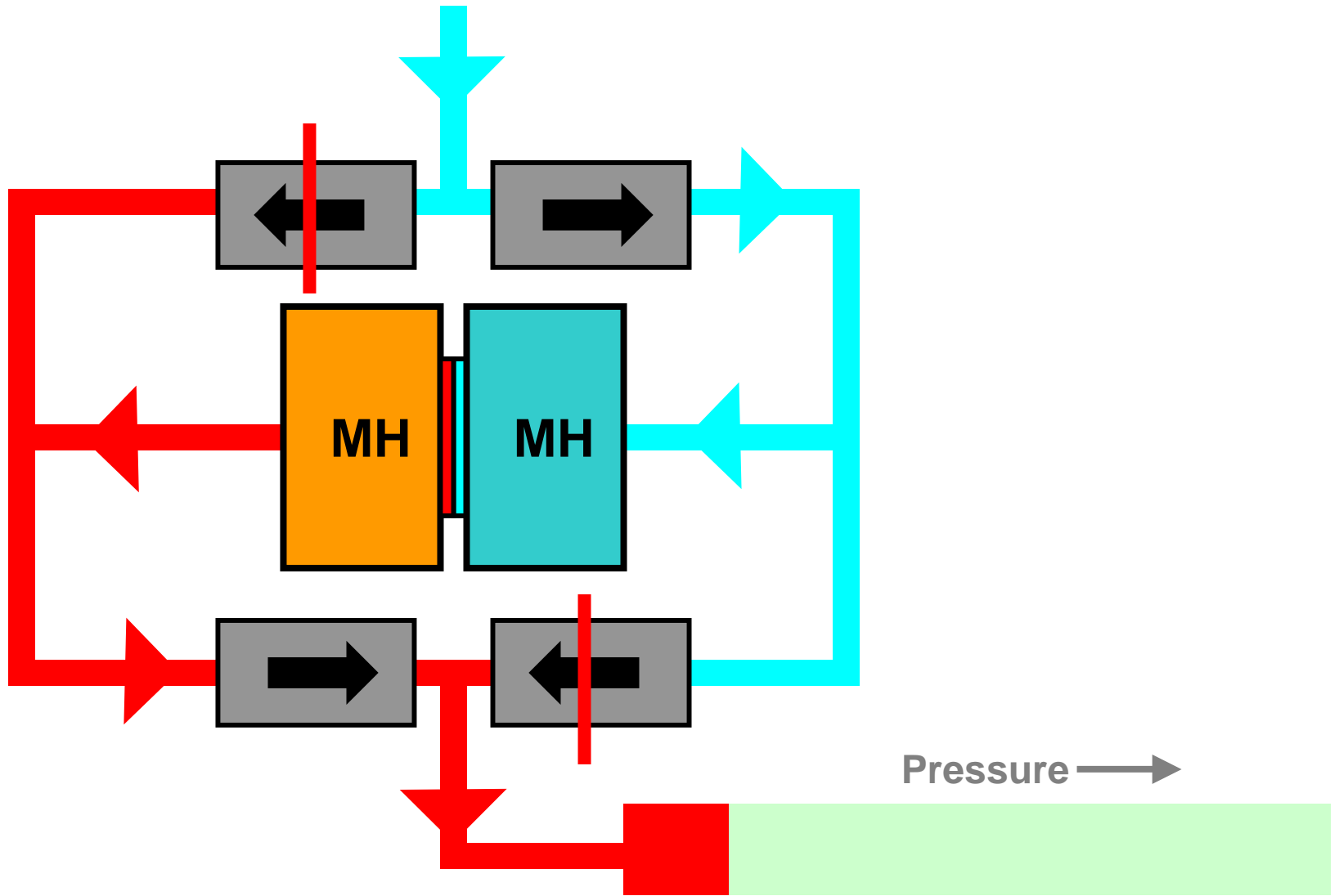
Flange side-view

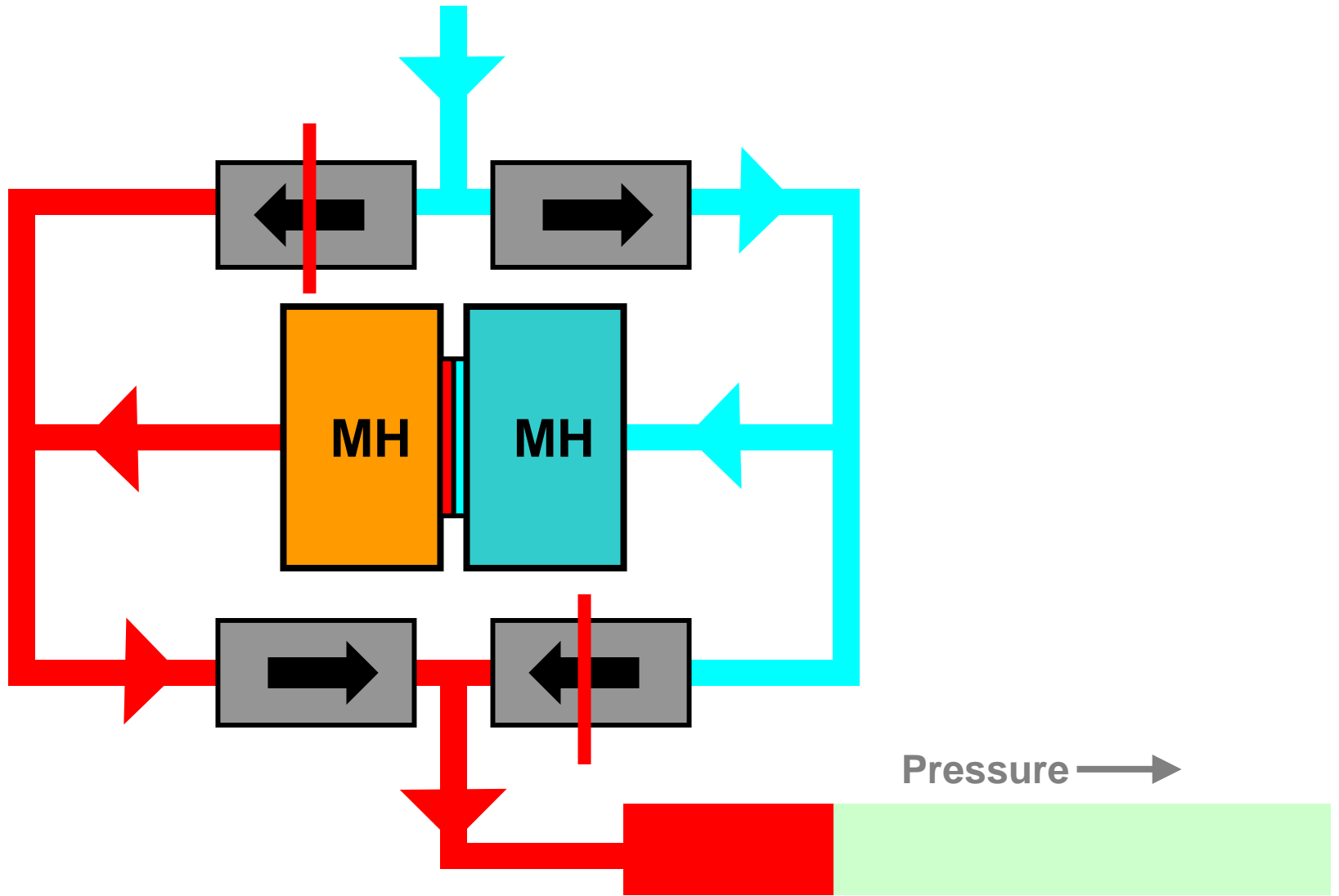


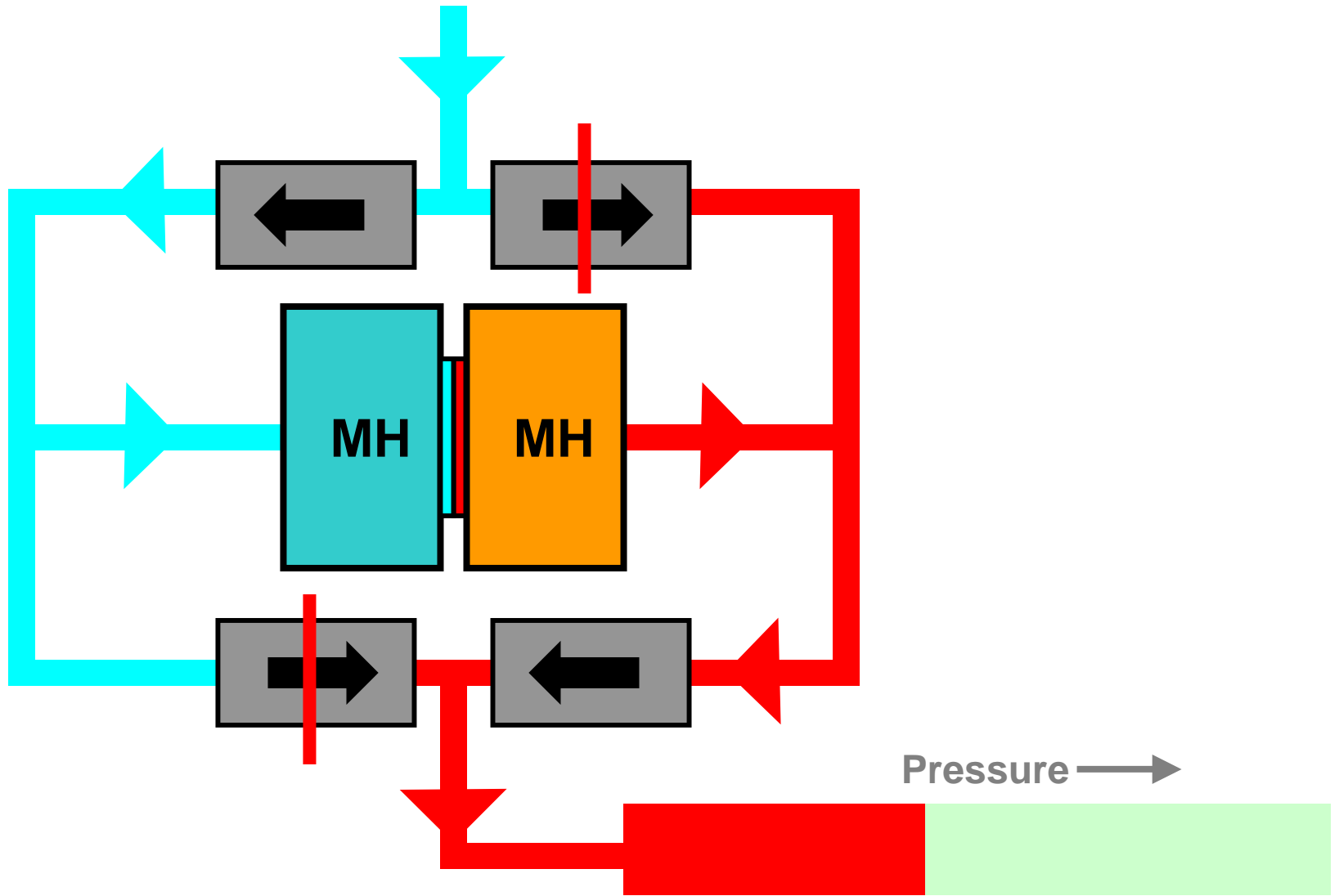


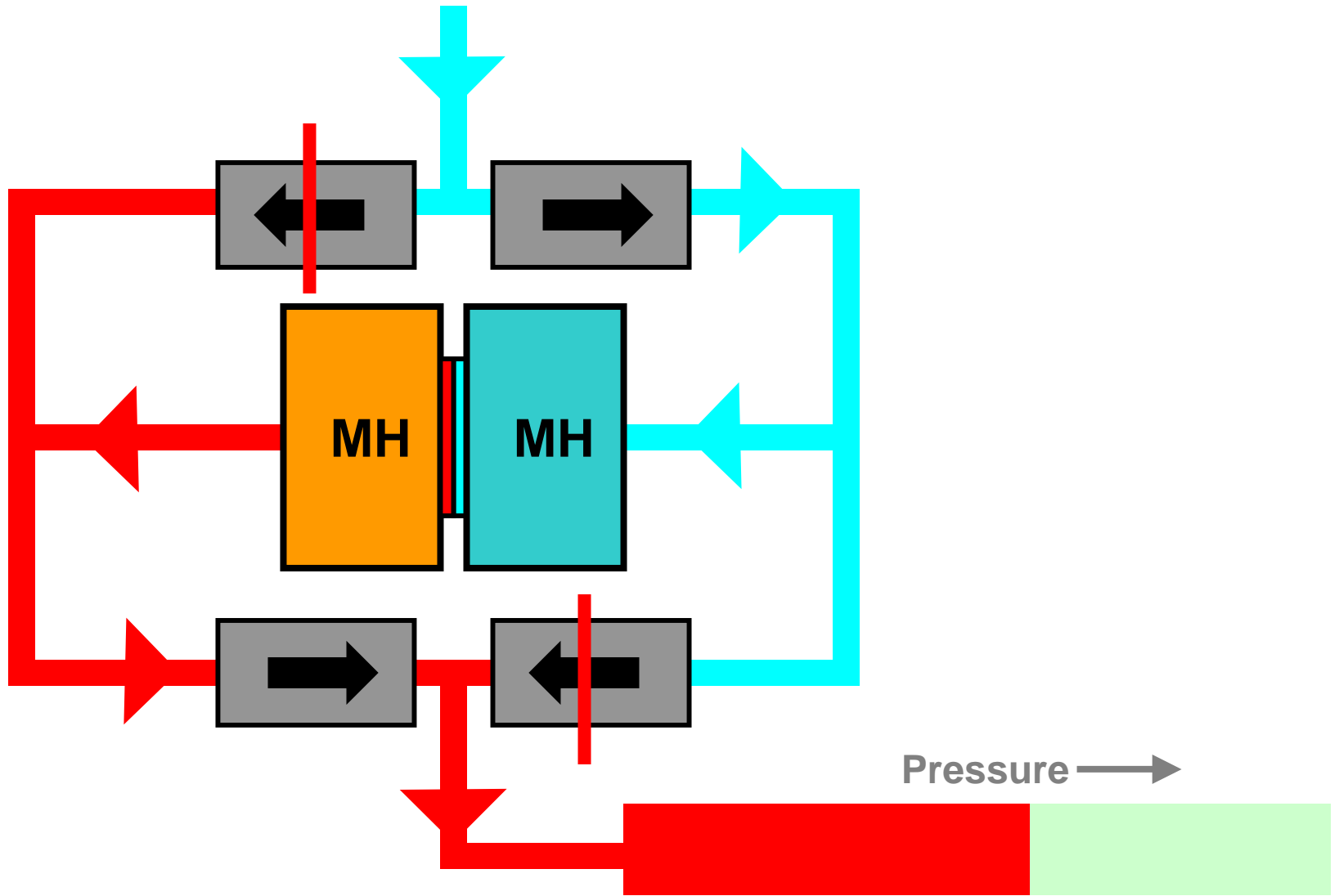


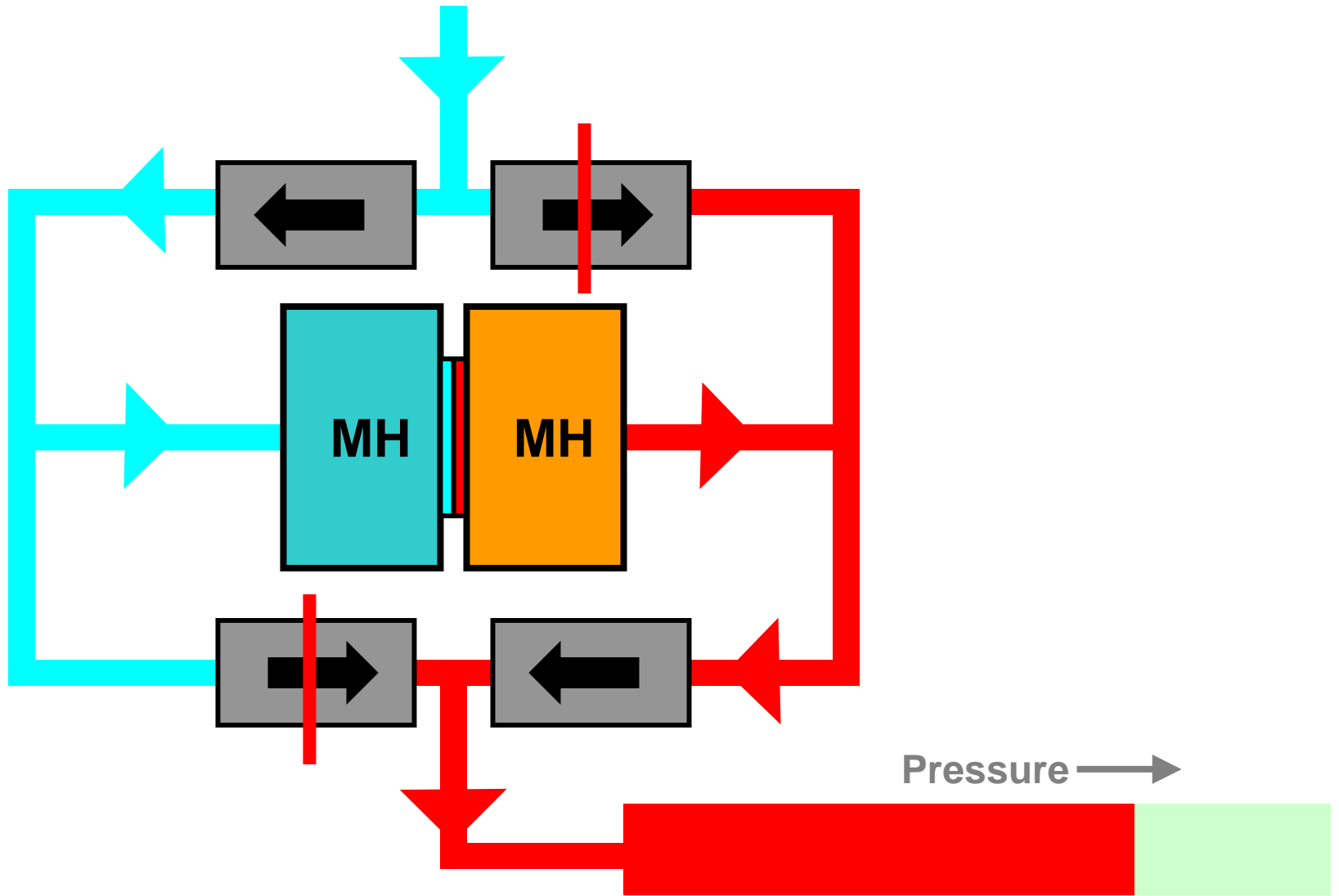


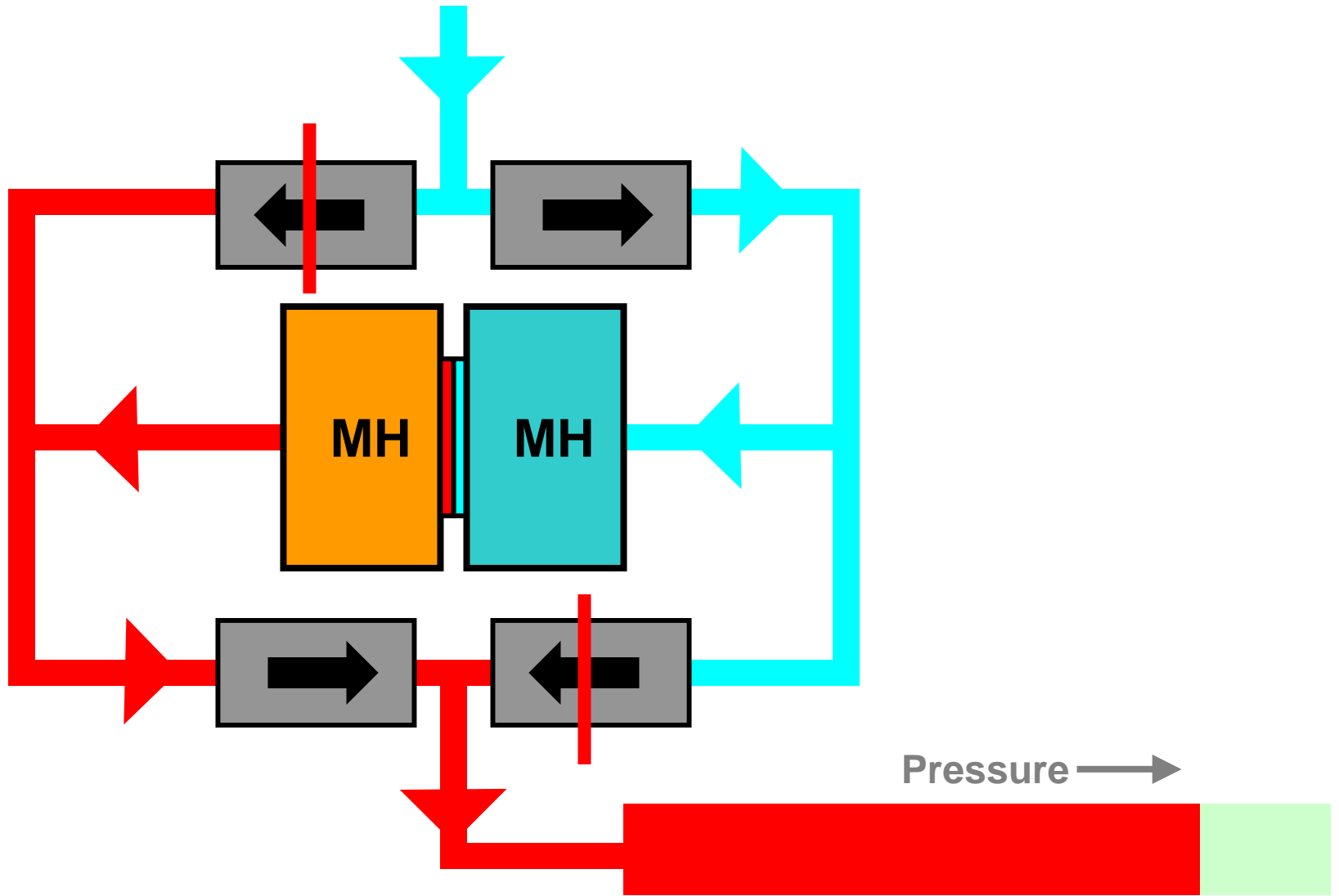


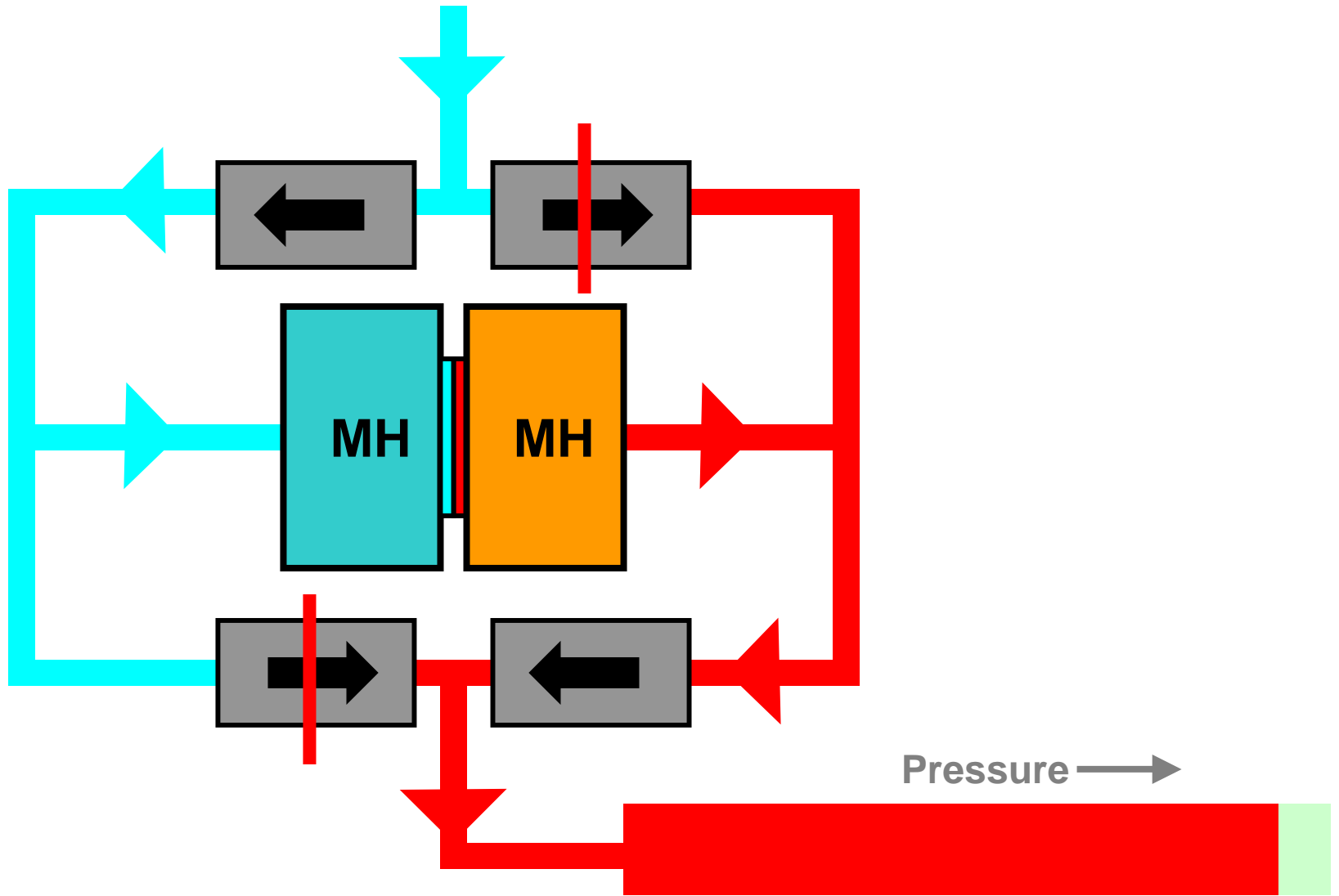


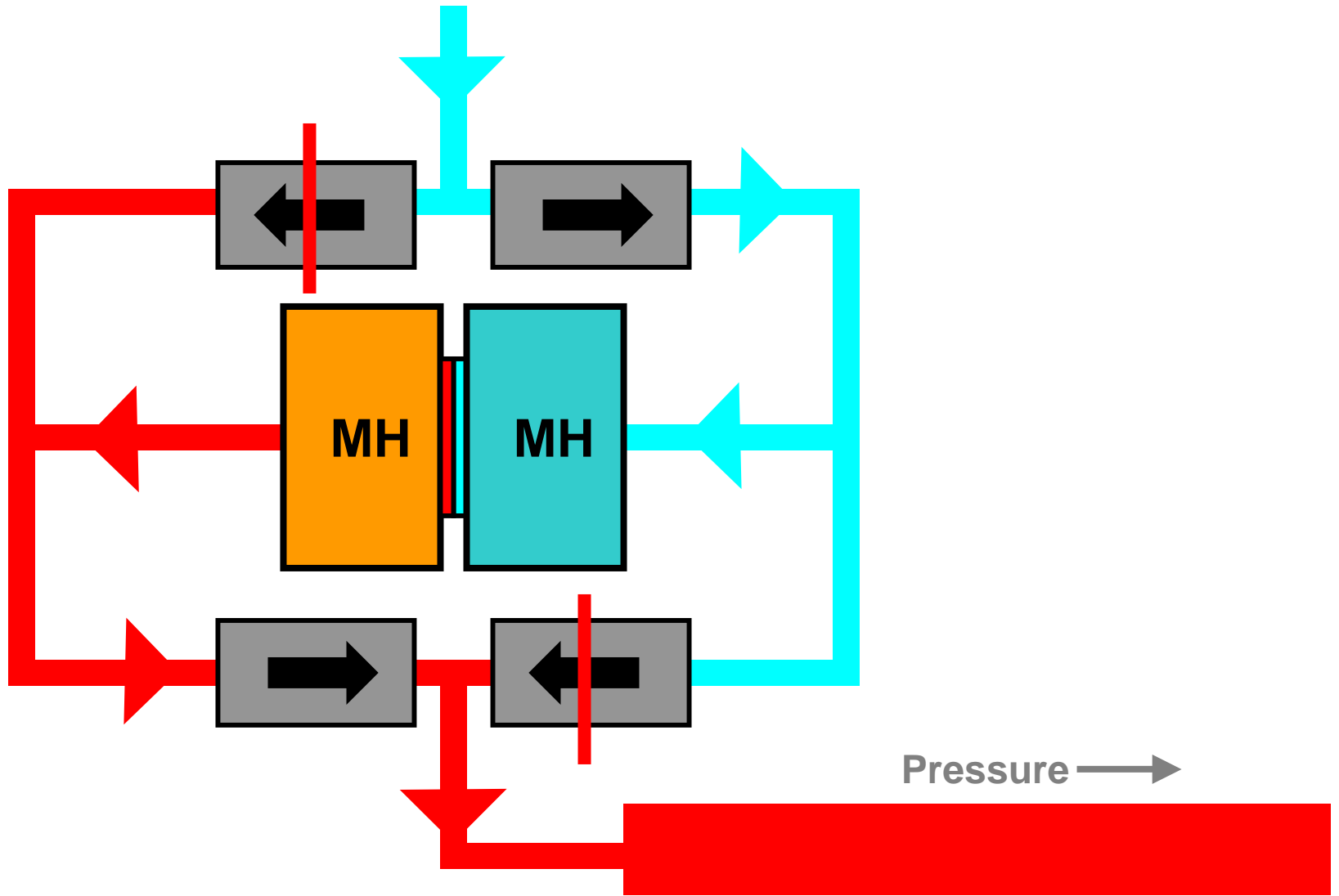


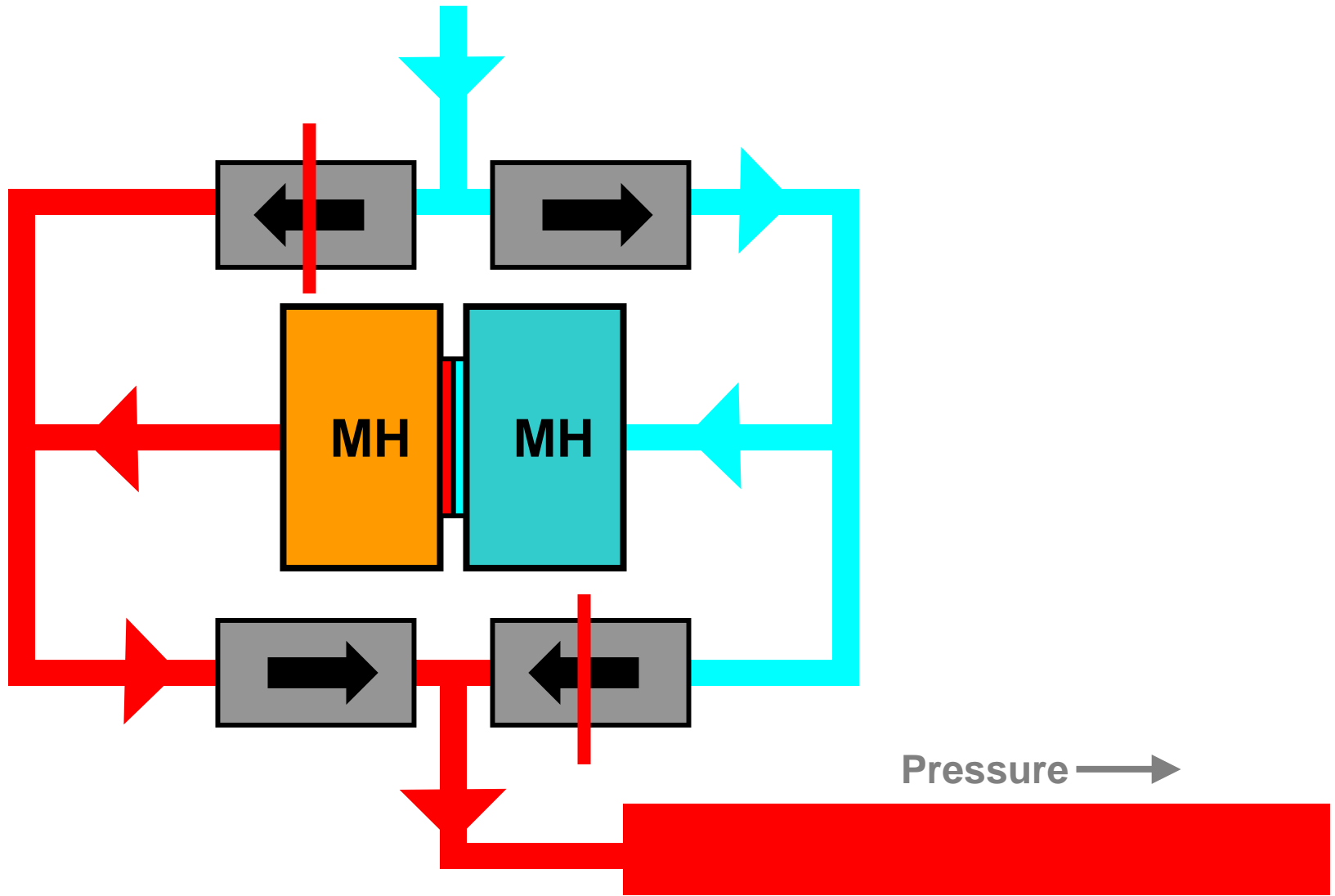










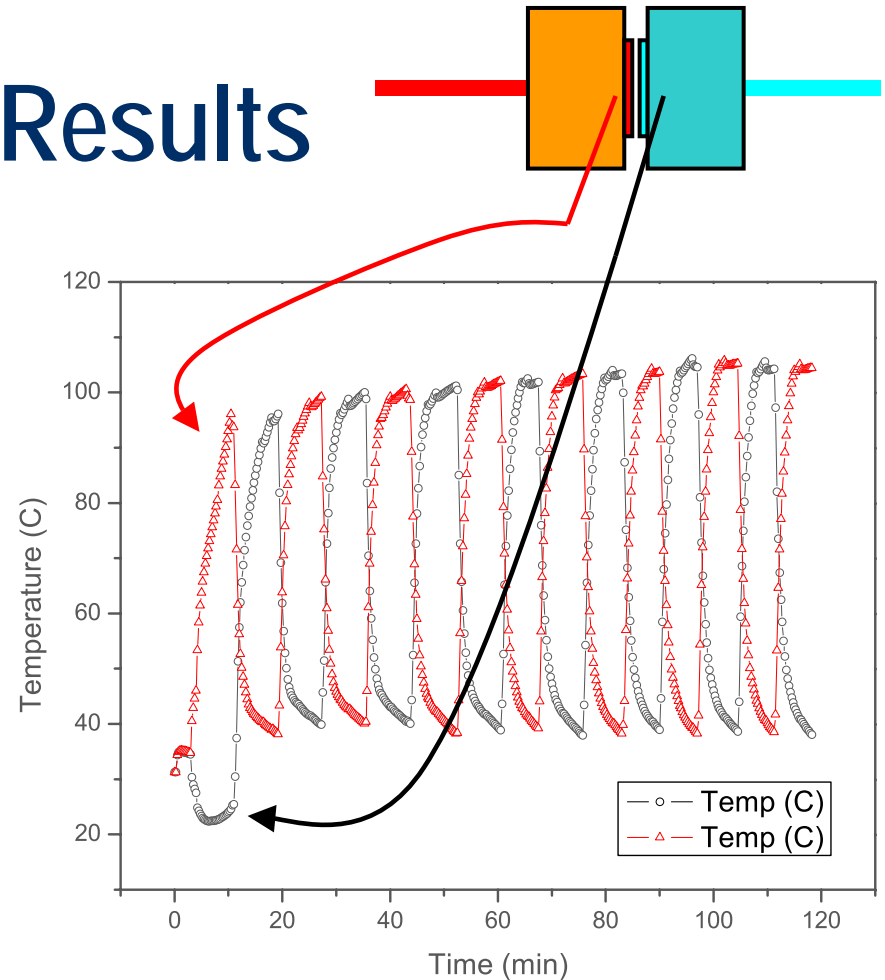
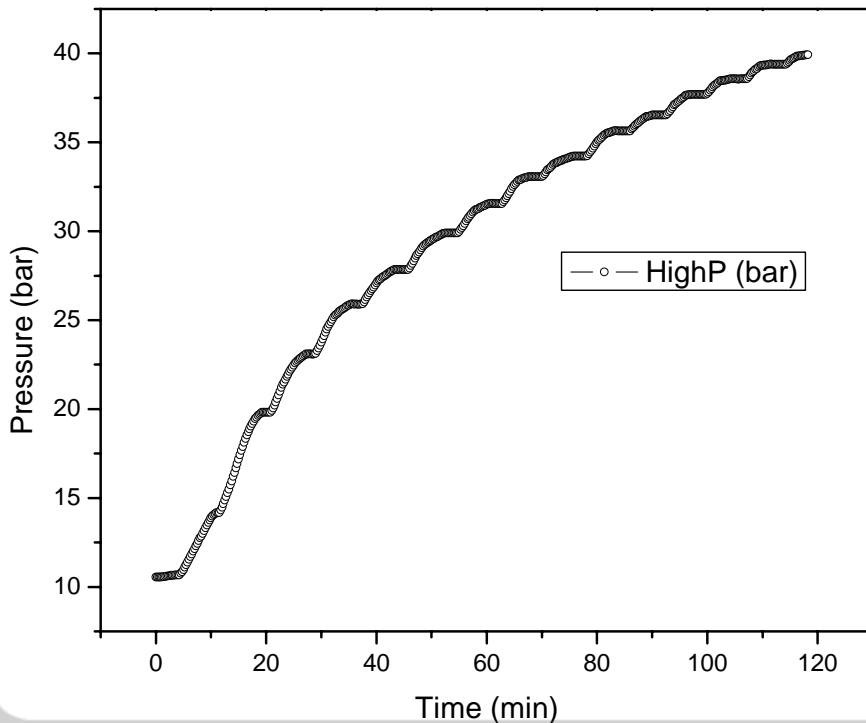


Some Results

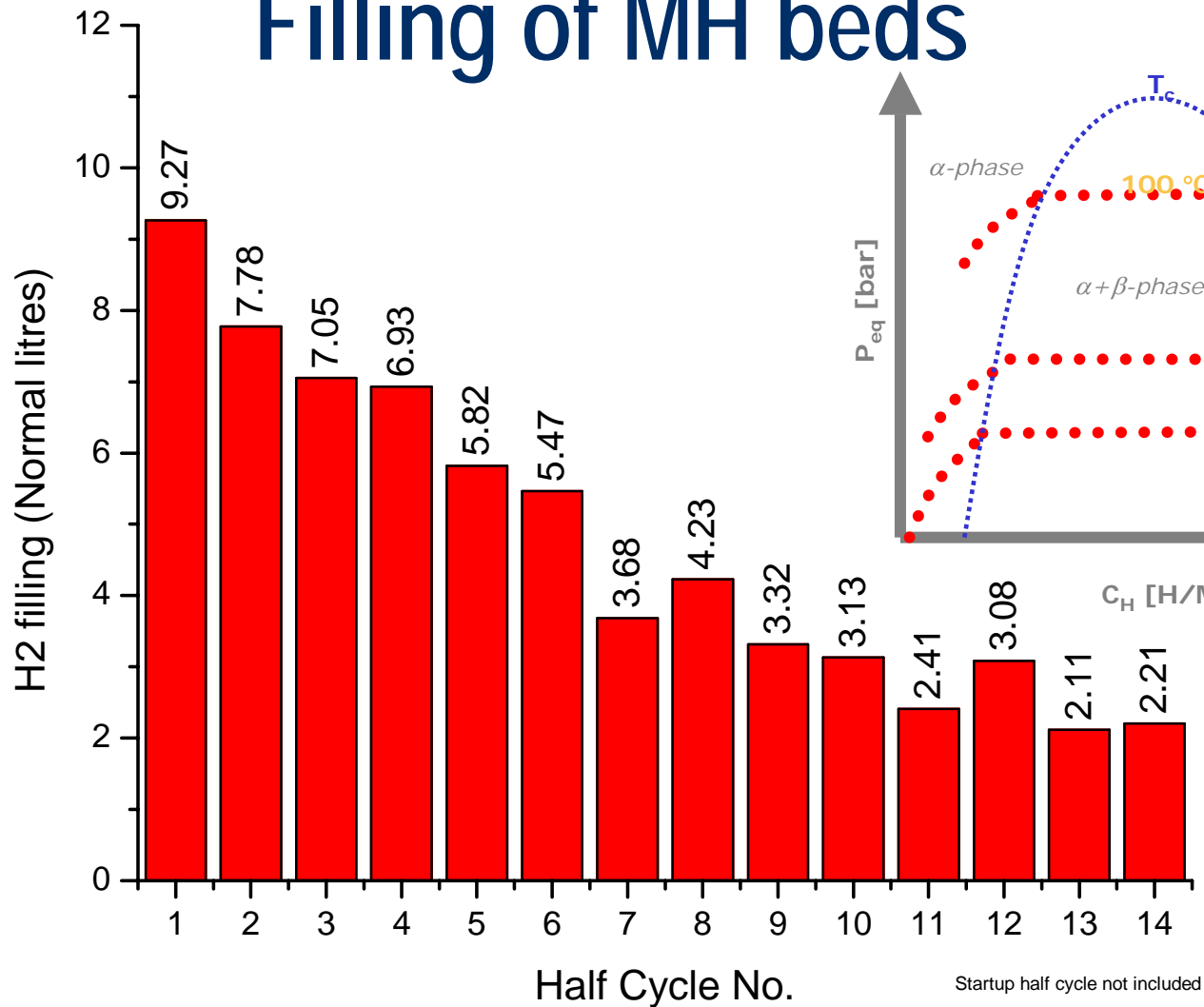
High-pressure cylinder: ~4 litres

P_1 ("low pressure"): 10 bar

Target pressure: 40 bar

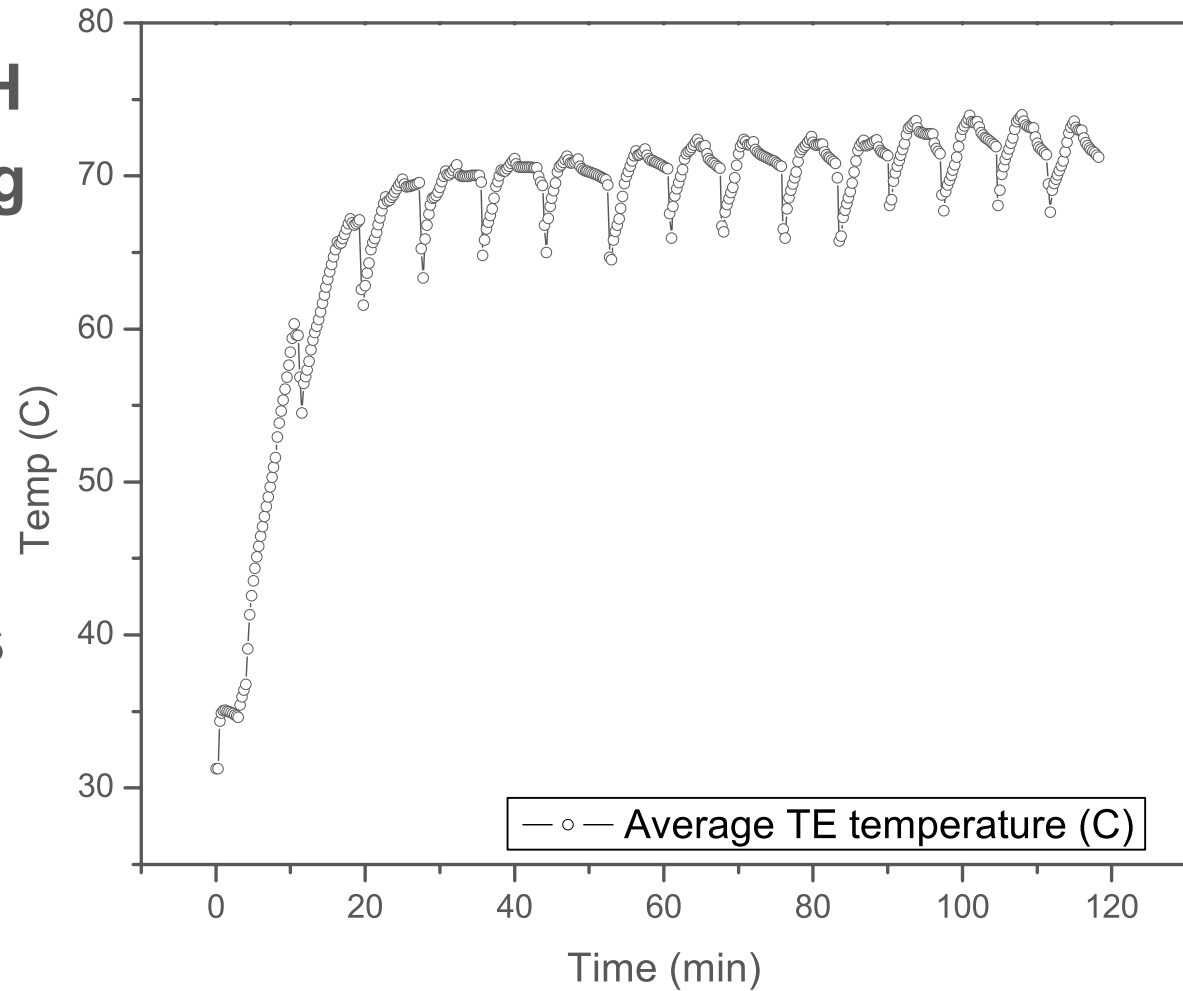


Filling of MH beds



Temperature Increase

- Heat from MH
- Joule Heating
- High T MH
- Peltier works better at higher T



Concluding Remarks

- Compression of hydrogen: an important piece in the hydrogen society puzzle
- Short introduction to H compression using MH-TSC
- Prototype:
 - Solid-state
 - Fast response, semi-continuous
 - No moving parts (except the check-valves)
 - It works!
 - But will work better with high-T MH (desorption T of 200°C)

Acknowledgments



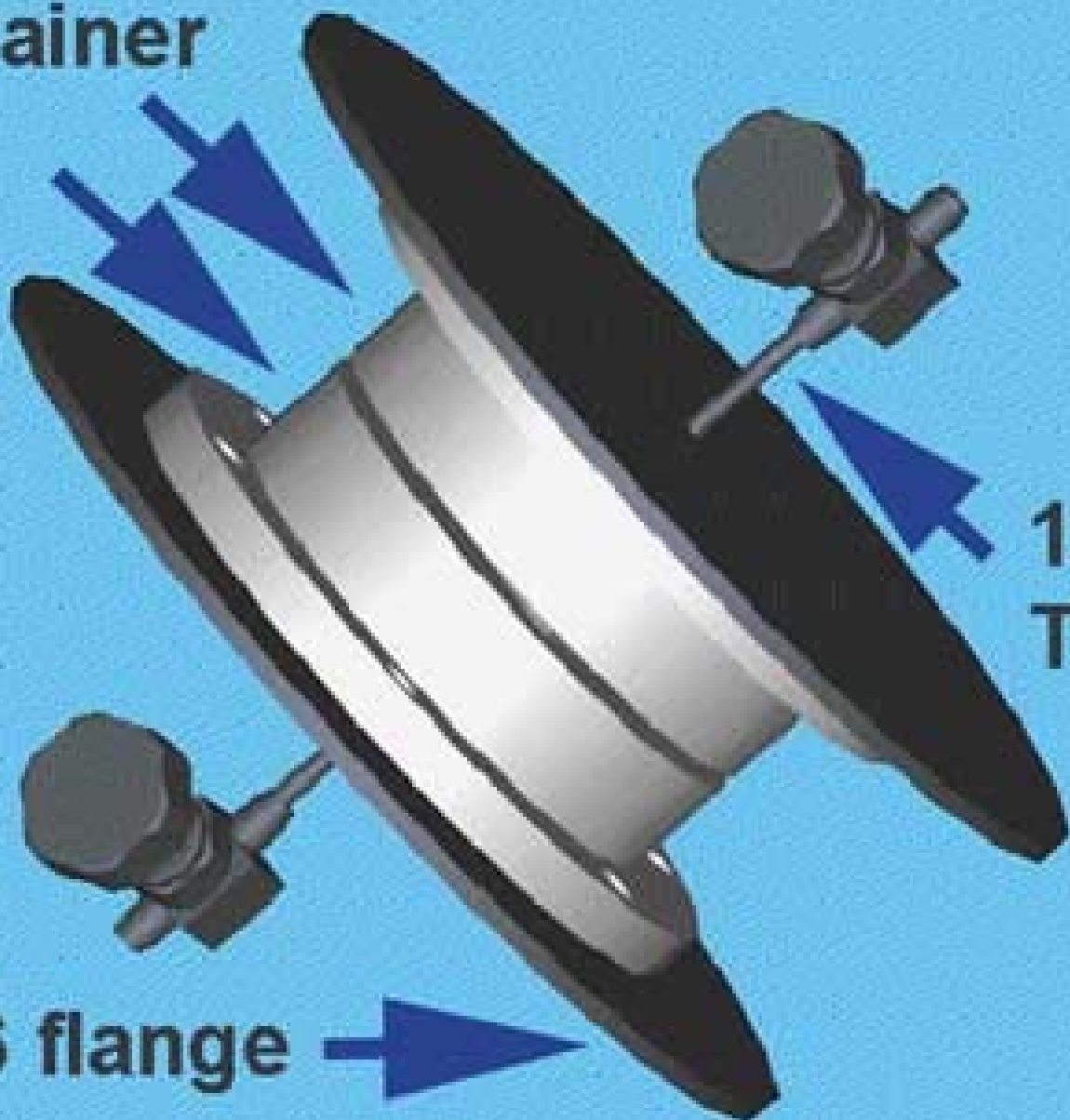
Nordic Energy Research, NORSTORE

Volodymyr A. Yartys, IFE

Michael Lototsky, IFE / Inst. Probl. Mat. Sci. of National
Academy of Sciences of Ukraine

Jon Eriksen, IFE

**Al container
(MH)**



**1/4 " SS
Tubing**

Valve

SS-316 flange

Thank You for Your Attention !