COSMHYC Final Event

24th of February 2021

WELCOME

FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

eifer

STEINBEIS 2i

nel

MAHYTEC

ludwig bölkow systemtechnik

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COSMHYC INNOVATIVE H2 COMPRESSION

Program

PART 1

I. H2 compression: what is at stake?
FCH JU, Pietro Caloprisco

II. The hybrid COSMHYC compression principle & challenges
EIFER, Coordinator: David Colomar

III. The COSMHYC Video

PART 2

I. Optimized mechanical compressor prototype
NEL, Mikael Sloth

II. Building up a metal hydride compressor prototype
EIFER, Rami Chahrouri
MAHYTEC, Mathilde Bangoura & Jean-Michel Tisserand

III. Q&A session 1

PART 3

I. Testing and results
EIFER, Coordinator: David Colomar

II. Techno-economic assessment
LBST, Jan Zerhusen

III. Q&A session 2

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COSMHYC - Bringing hydrogen compression to the next level

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COSMHYC
INNOVATIVE H2 COMPRESSION

Stay in touch!

COSMHYC project

David Colomar (Project Coordinator)

www.cosmhyc.eu

Follow us!

@COSMHYC_FCH

COSMHYC and COSMHYC XL

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FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

H2 compression: What is at stake?

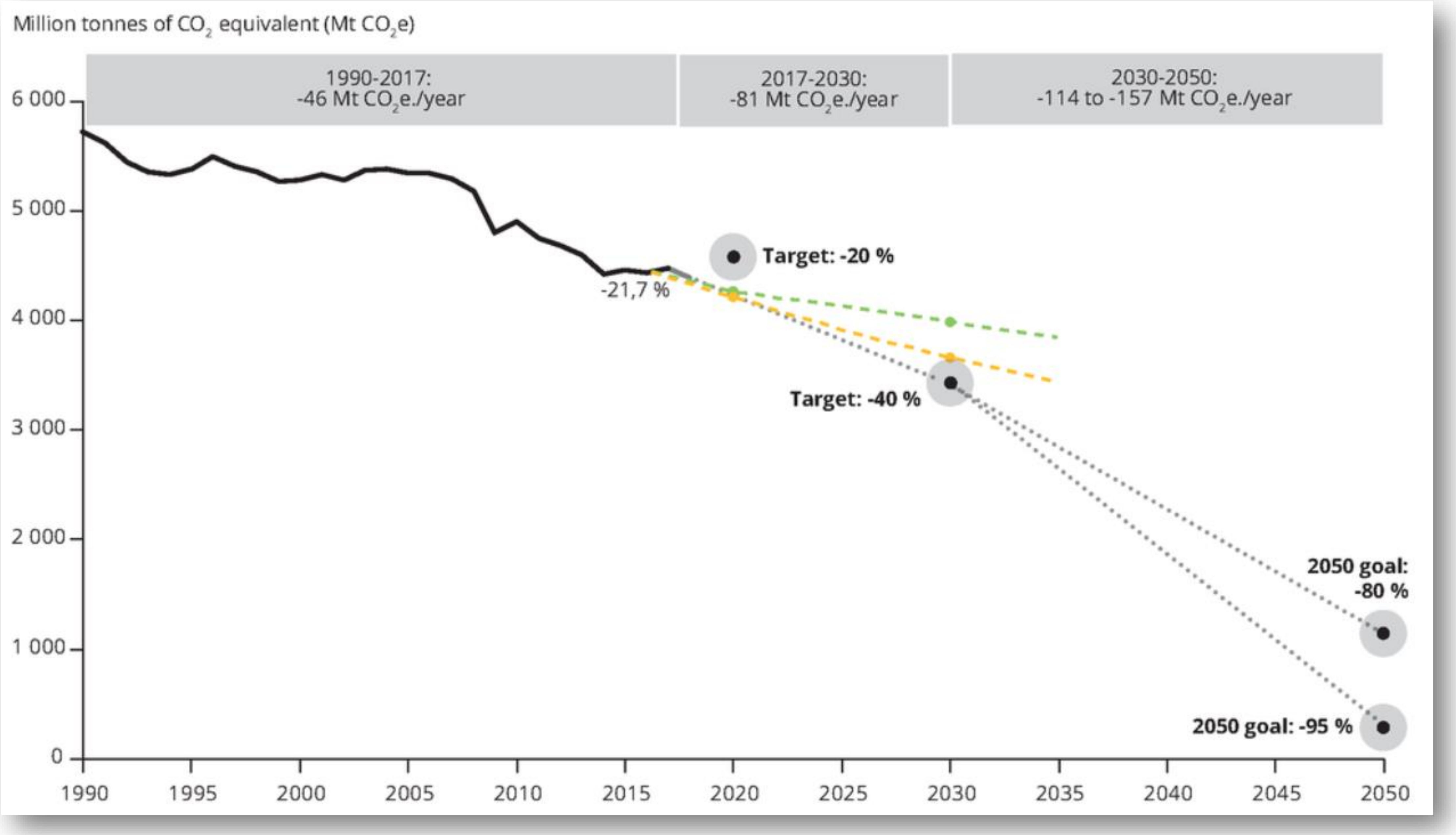
FCH JU

Pietro Caloprisco

COSMHYC final event

EU CO2 emissions

Stepping up the decarbonisation efforts



Source EEA Dec 2019

EU 2020 climate & energy targets:

- **- 20% GHG emissions**
- + 20% Renewable Energy
- +20 % Energy efficiency

EU 2030 climate & energy targets:

- **- 40% GHG emissions**
- + 32% Renewable Energy
- +32.5 % Energy efficiency

EU Green Deal & other com.

-55% GHG emissions by 2030

0% Net GHG emissions by 2050

Transport -90% GHG by 2050

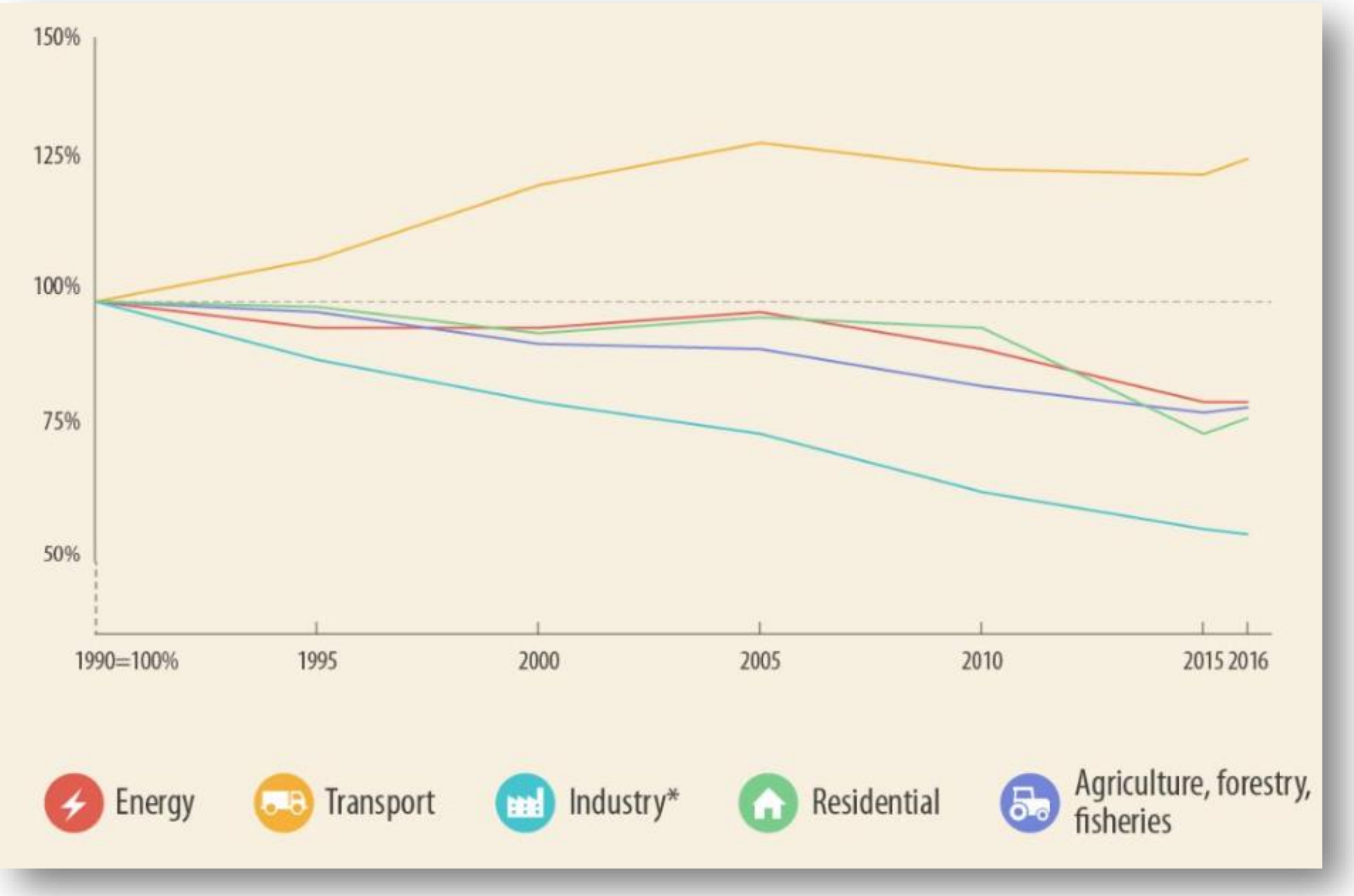
Focus on transport

All transport modes under pressure

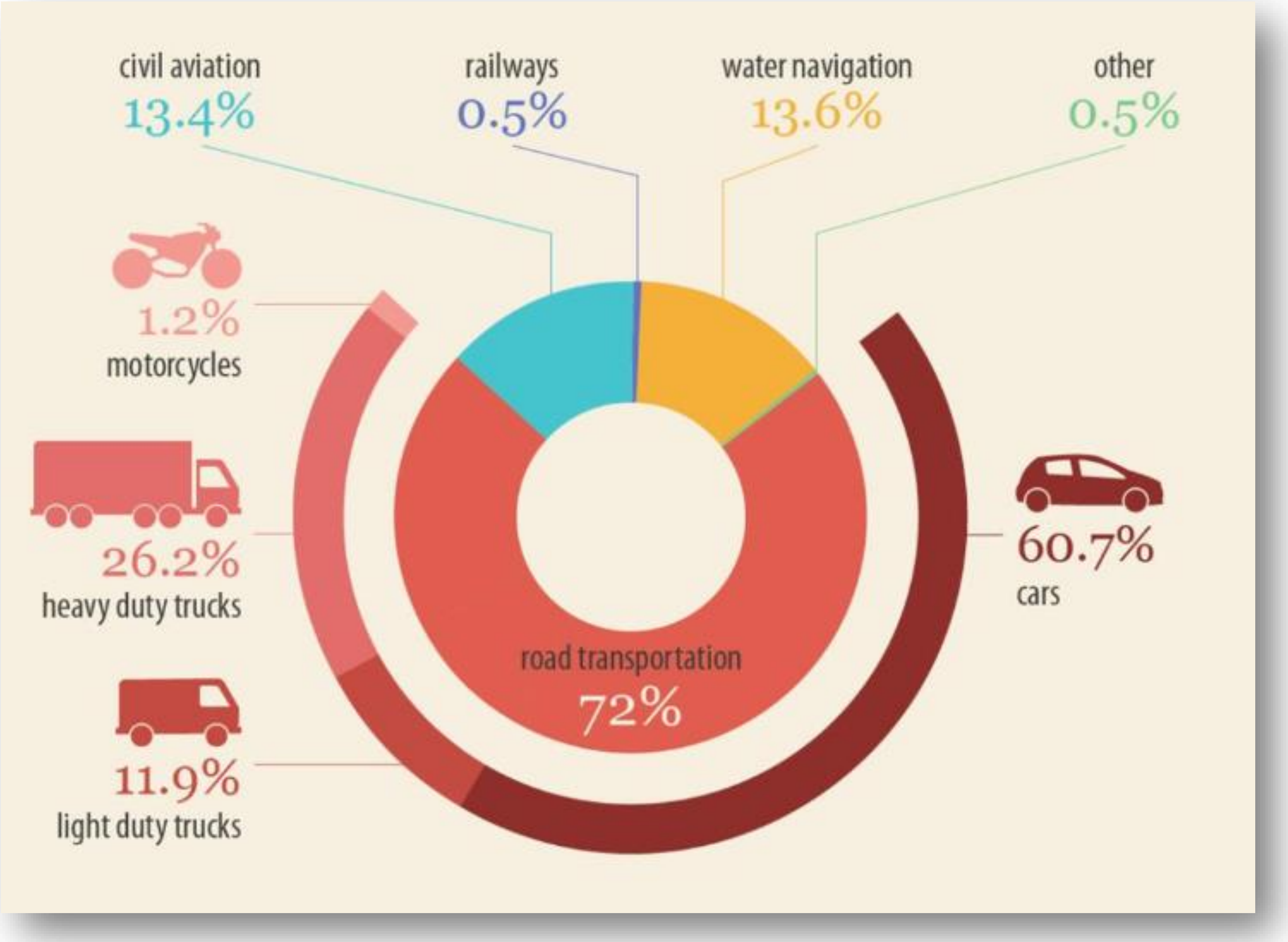
CO2 Emissions per sector

Emission by transport mode

ZEV to be introduced in all transport modes



Source EEA Dec 2019



Source EEA Dec 2019

Supporting ZEVs deployment

A coordinated approach

Energy	Powertrain	Infrastructure
Revision renewable energy directive	CO_2 standards for cars and HD Clean vehicle directive	Revision of the Alternative Fuels Infrastructure Directive

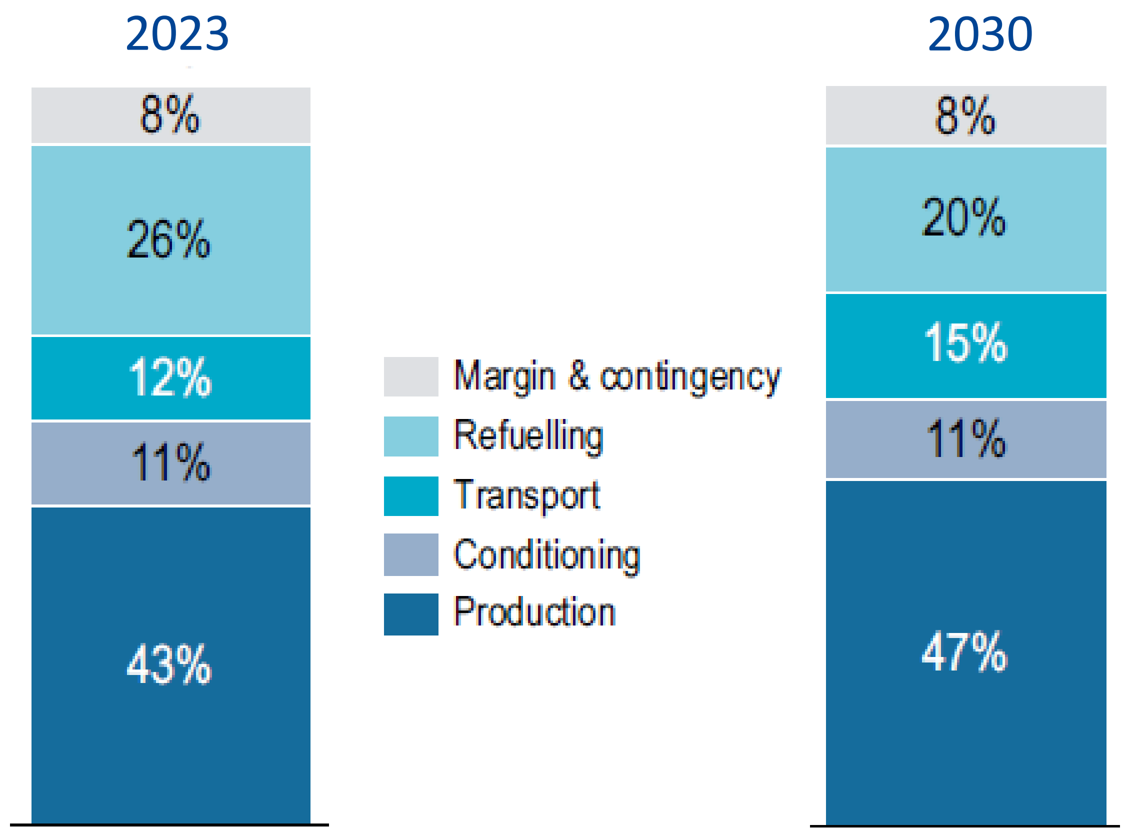
…and more

R&I: FCH JU

Main themes

Old & new priorities

Cost



Dispensed H2 cost estimate breakdown

@ 700 bar, H2 from RES

Capacity

Tractor 4x2

Daily 560 km

KG H2
74

Rigid 6x2

Daily 380 km

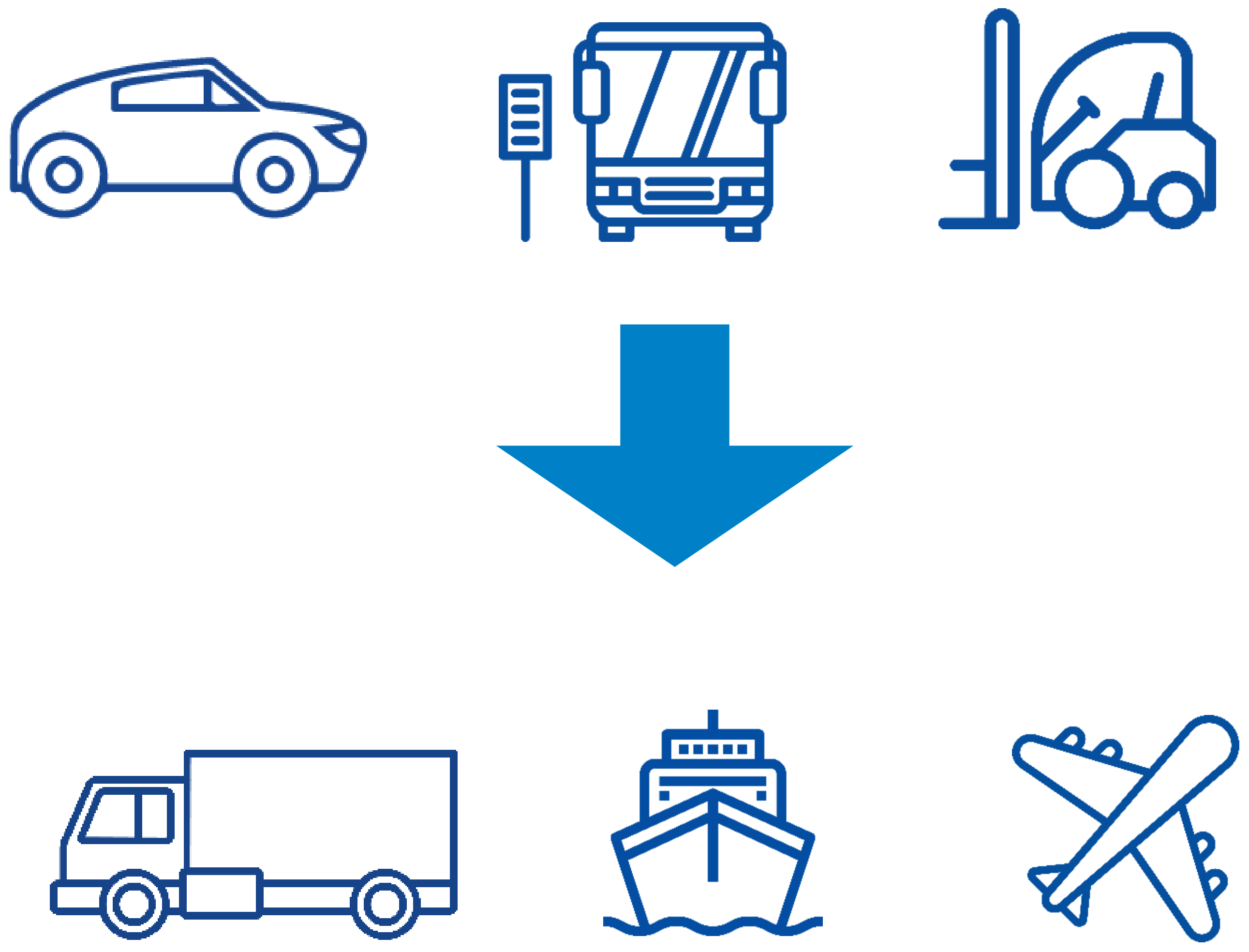
KG H2
45

Rigid 4x2

Daily 250 km

KG H2
26

Filling rate



10-15 min

Compression development remains central

Areas of action

Priorities identified in the SRIA by HE/HER

Early Stage Research Actions (TRL 2-3)
- Efficiency;
- Footprint;
- Noise;
- Cost ;
- V2infrastructure communication;

Development Research Actions (TRL 3-5)
- high throughput stations;
- Innovative components to reduce costs;

Demonstration Actions (TRL 5-7)
- Standardisation & manufacturability components
- Reliability & safety;
- New business models;

Application Flagship (TRL 7-8)
- encourage HRS operators to invest in hydrogen technology and help creating initial networks;

2030

1. -50% cost HRS; **2. 99% reliability** **3. HRS network sustaining HD fleet**

Thanks for your attention

FUEL CELLS AND HYDROGEN
JOINT UNDERTAKING

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FCH JU

COSMHYC Final Event

24th of February 2021

The hybrid COSMHYC compression: principle & challenges

Speaker David Colomar

EIFER

Innovative compression solutions

for efficient hydrogen mobility

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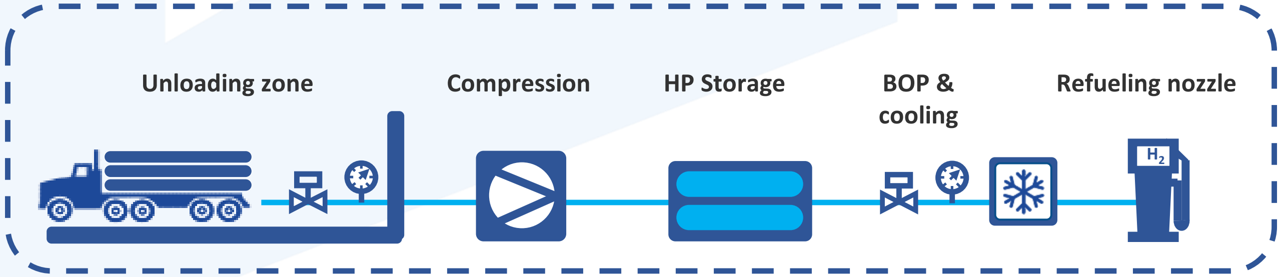
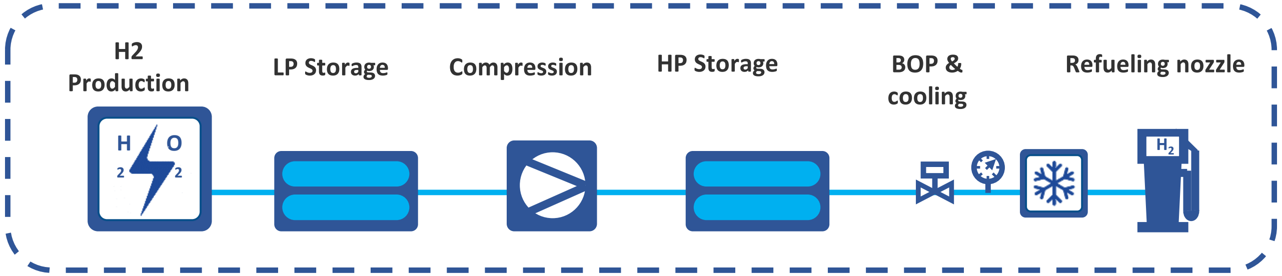
COSMHYC INNOVATIVE H2 COMPRESSION

H2 compression, the other bottleneck of the green H2 value chain

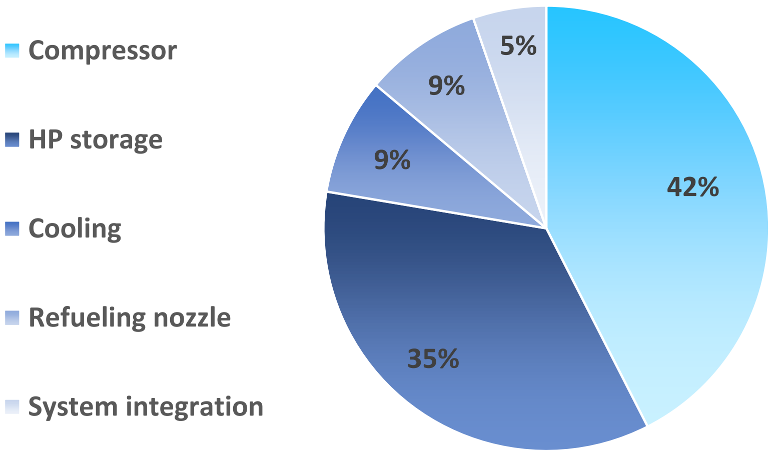
Hydrogen refueling station



Hydrogen refueling station with onsite production



EXAMPLE OF HRS CAPEX DISTRIBUTION



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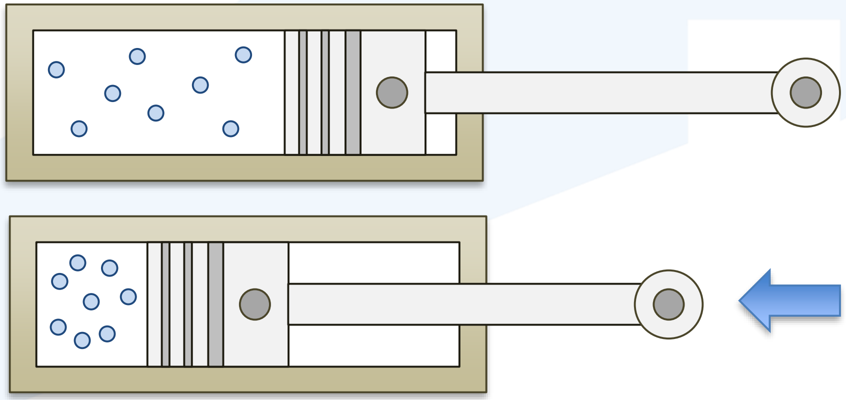
COSMHYC
INNOVATIVE H2 COMPRESSION

The state-of-the art: mechanical compression



$$W_t = C \cdot T_1 \cdot \left[\left(\frac{P_2}{P_1} \right)^d - 1 \right]$$

⇒ **Electricity consumption**

⇒ **Maintenance, wear and tear**

⇒ **Noise disturbance**

⇒ **Flow rate & energy depend on inlet pressure**

The techno-economic constraints are strongly related to the mechanical nature of the compression

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Metal hydride compression: a possible game changer

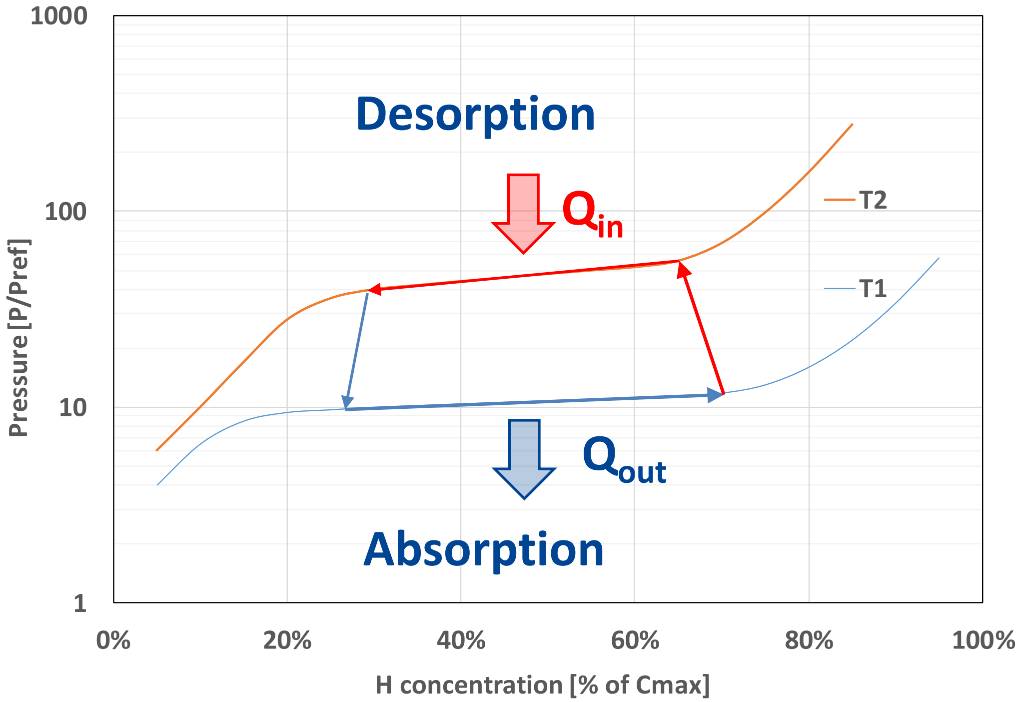
⇒ **Principle: an absorption/desorption effect within a metal alloy**

⇒ **A heat driven process**

⇒ **A correlation between temperature and pressure**

$$M(s) + x/2\ H_2 \underset{desorption}{\overset{absorption}{\rightleftharpoons}} MH_x(s) + Heat$$

Van't Hoff equation: $$\ln P_{eq} = \frac{\Delta H}{RT} - \frac{\Delta S}{R}$$



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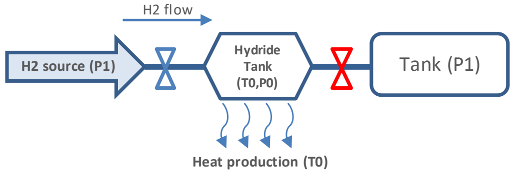
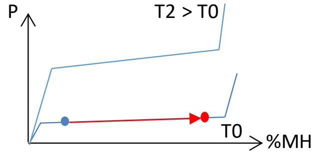
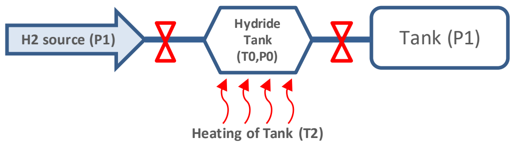
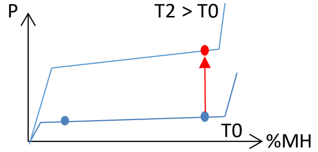
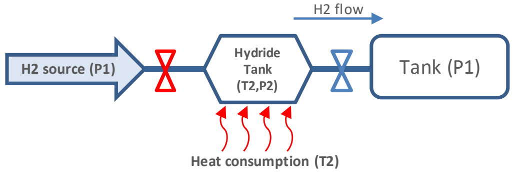
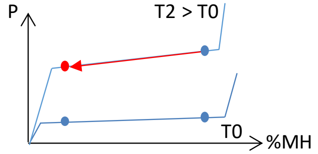
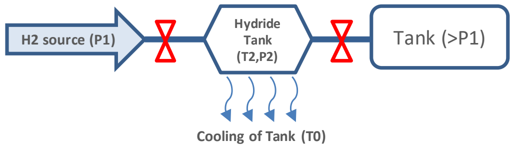
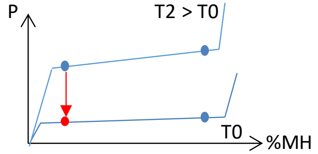
Metal hydride compression: a possible game changer

⇒ **The core of the reactor: metal hydrides**

⇒ **No more mechanical effect: no moving part, no wear and tear, etc.**

Compression phases	Behaviour of the tank	P, T and hydride concentration (%MH) in Tank
Phase 1 : Absorption		
Phase 2 : Heating		
Phase 3 : Desorption		
Phase 4 : Cooling		

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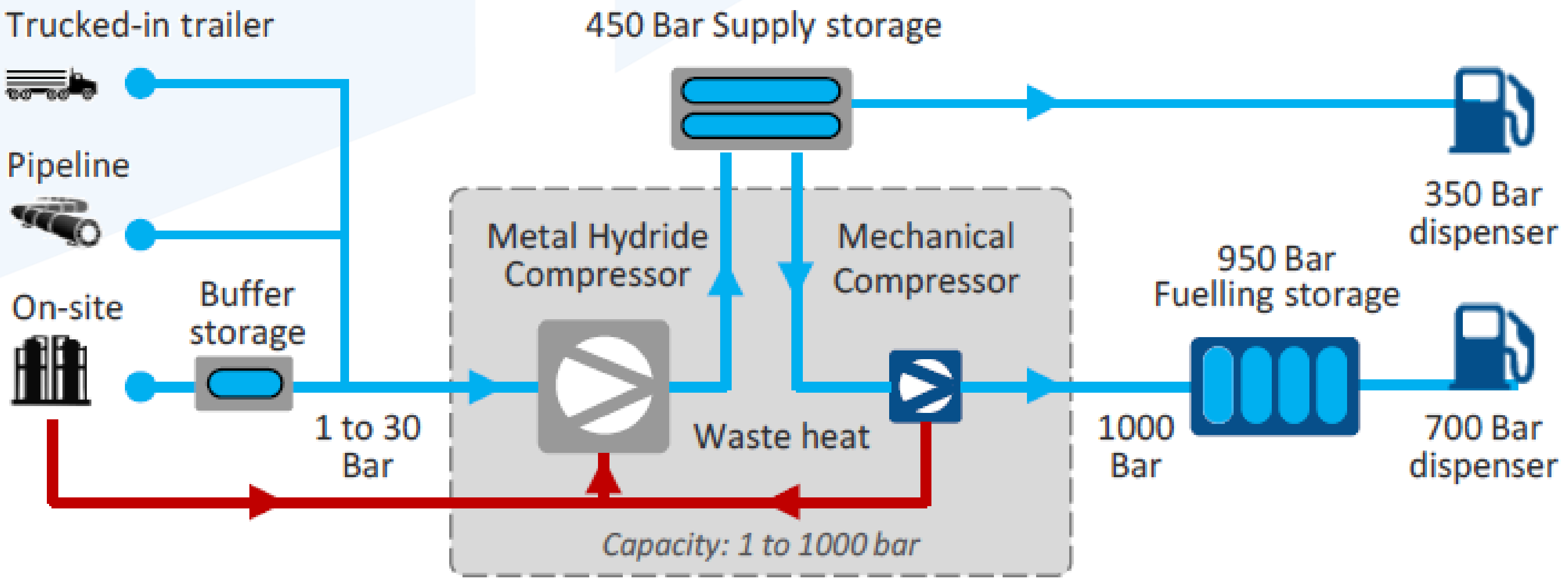
The COSMHYC concept: looking for the best of both technologies



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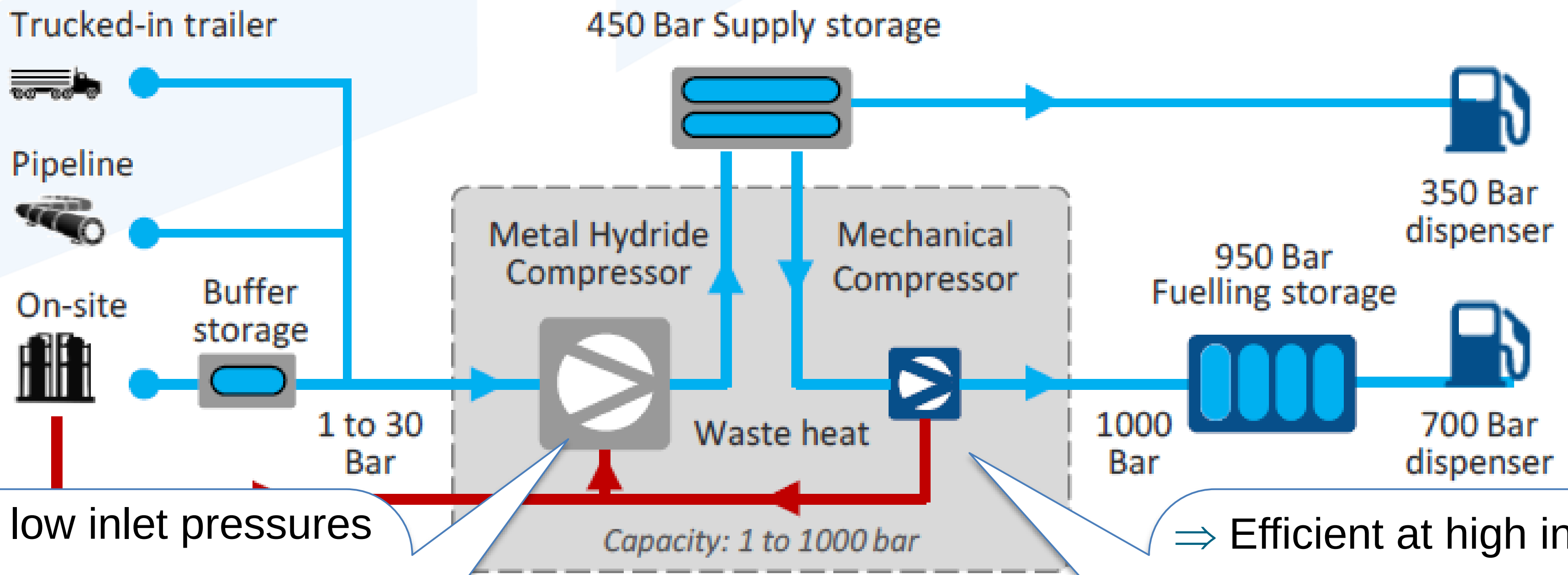

⇒ Efficient at low inlet pressures

⇒ Adapted to baseload

⇒ Using waste heat sources

⇒ Capable of long operating time

⇒ No noise disturbance

Possible common integration between both technologies

⇒ Efficient at high inlet pressures

⇒ Highly flexible

⇒ Using electricity

⇒ High peak flows

⇒ Noise only during the day

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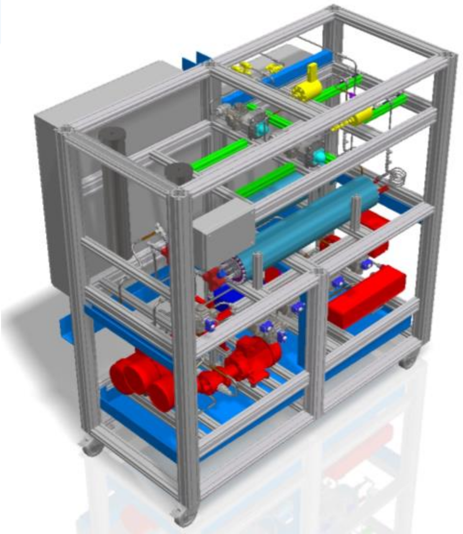
COSMHYC INNOVATIVE H2 COMPRESSION

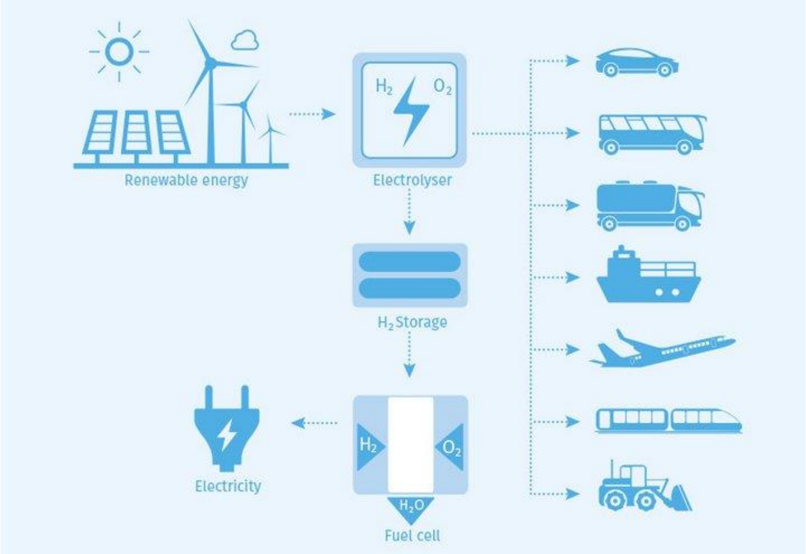
Challenges to meet

⇒ **Getting rid of rare earths: problem of costs & independence**

⇒ **Defining the right product for the right application: P & T optimization**

⇒ **Scaling up: from 1 Nm3/h to > 100 Nm3/h**





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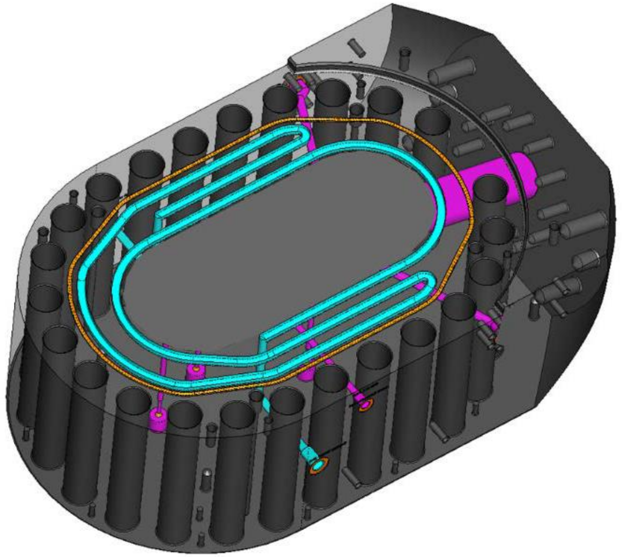
COSMHYC
INNOVATIVE H2 COMPRESSION

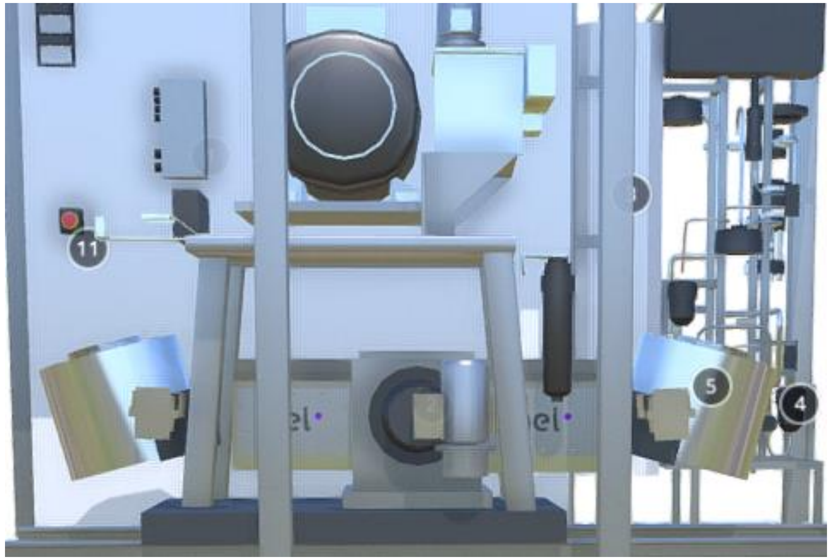
Challenges to meet

⇒ **Improving mechanical compression:**

⇒ **Increasing life time, optimizing design, reducing noise level**

⇒ **Reducing energy consumption and production costs**





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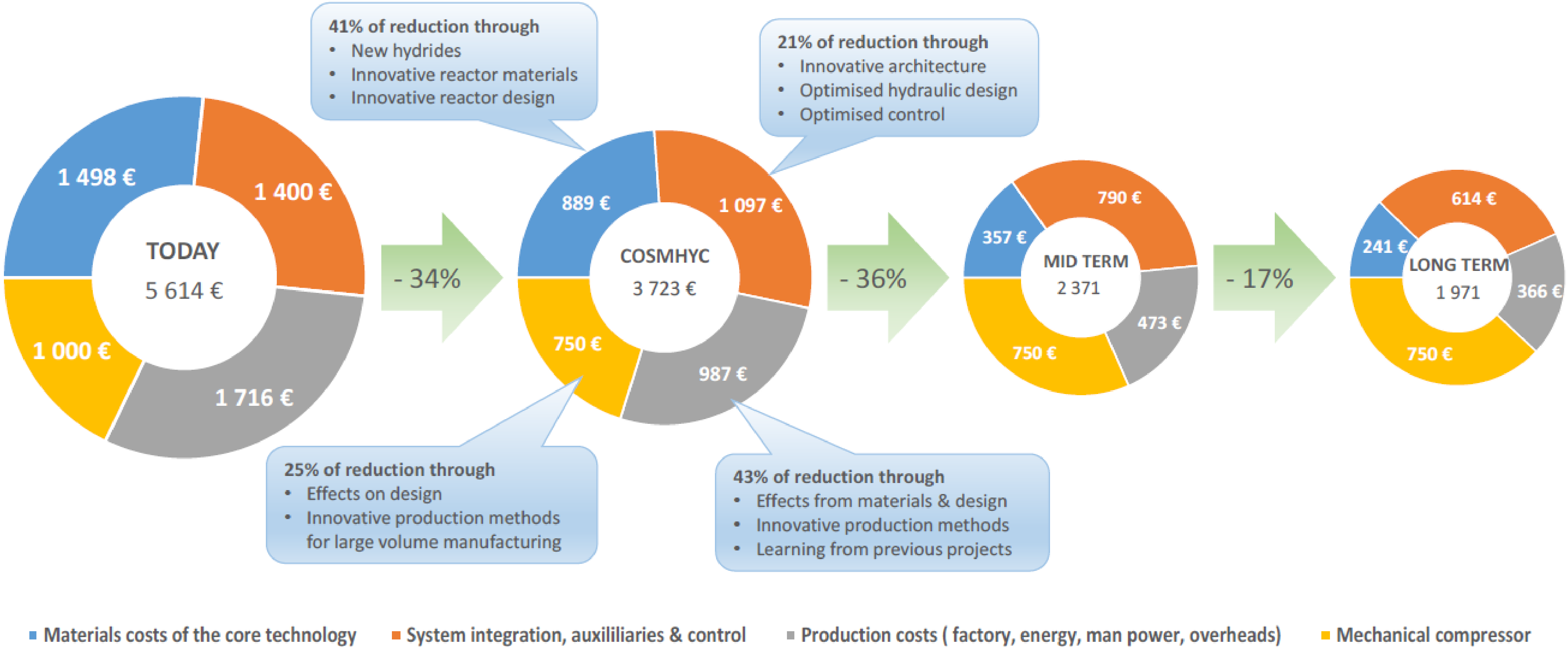
Challenges to meet

⇒ **Increase the level of TRL from 3 to 5 to prepare market introduction**

⇒ **Divide by 2 production costs compared to the state-of-the art**



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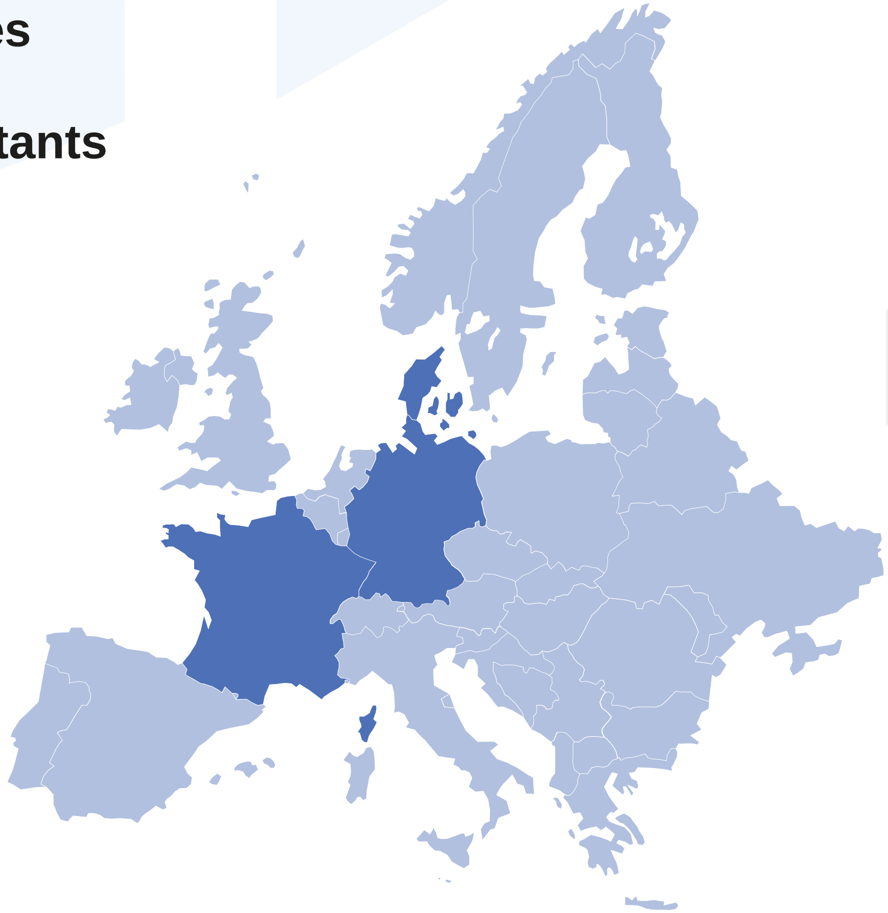
The COSMHYC consortium

⇒ **5 partners from 3 countries**

⇒ **Industry, R&D and consultants**



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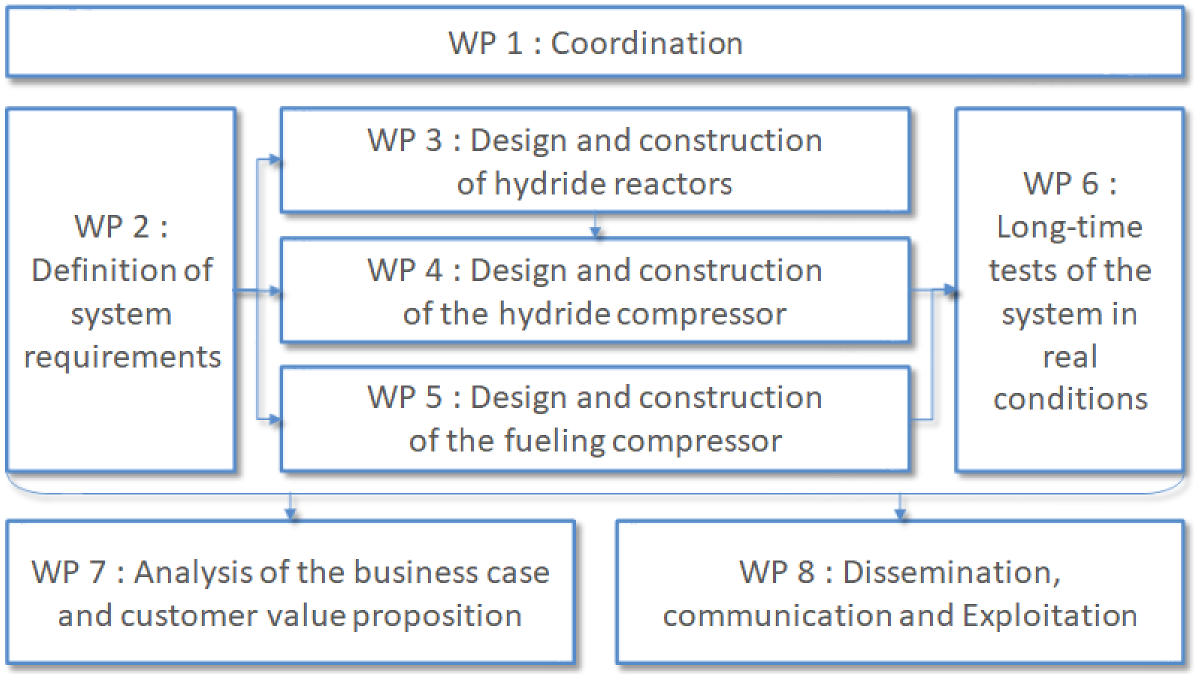
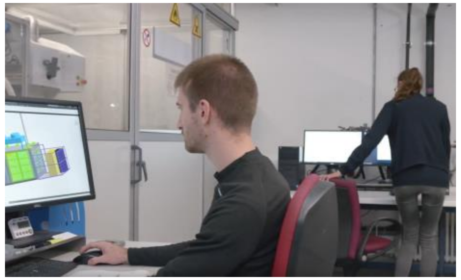
The COSMHYC work plan

⇒ **4 years of intensive activities**

⇒ **Research, Development, Lab & field tests**

⇒ **Techno-economic analysis, communication, dissemination, exploitation**





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Thank you for your attention !

Contact: colomar@eifer.org

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COSMHYC
INNOVATIVE H2 COMPRESSION

COSMHYC Final Event

24th of February 2021

Optimized mechanical compressor prototype

Speaker Mikael Sloth

Nel Hydrogen

nel

Innovative compression solutions

for efficient hydrogen mobility

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COSMHYC INNOVATIVE H2 COMPRESSION

Objectives – Mechanical Compressor (MC)

Objective has been to improve state-of-the-art mechanical diaphragm compression technology (MCH on a range of parameters through R&D, achieving the following targets:

Targets
5% efficiency improvement from 1,25 kWh/kg to 1,18 kWh/kg for 450bar inlet & 1000 bar outlet
Improve diaphragm lifetime from 50 million to 100 million cycles
Reduce noise level from 85dB to <60dB at 5 meters
-25% cost reduction for a manufacturing volume of 50 units from €140/kg to €105/kg at peak capacity of 60kg/h

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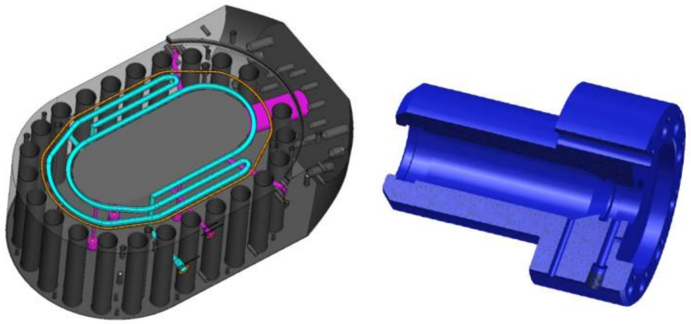
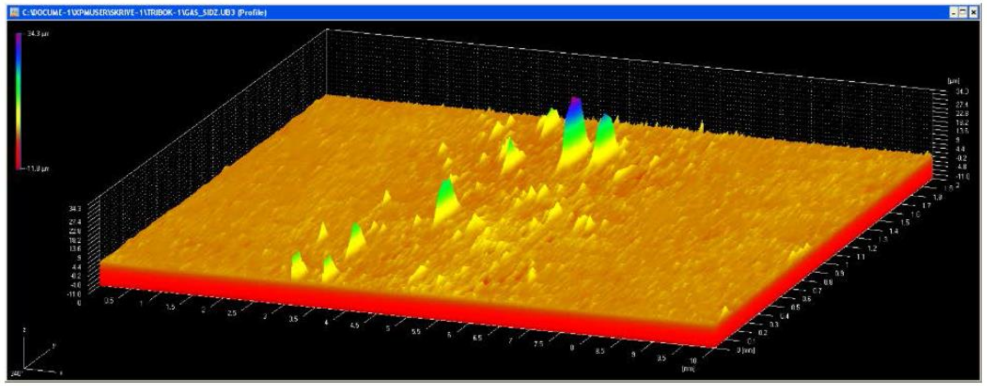
Development – Mechanical Compressor

Key development efforts

- Advanced CFD and FEA models of the MC used for developing and optimizing component designs
- Applying of internal cooling to compressor head and piston rod seal house, to reduce wear
- Improved materials and surfaces for diaphragm in order to increase lifetime (# of cycles)



Internal cooling of components



Diaphragm surface profile

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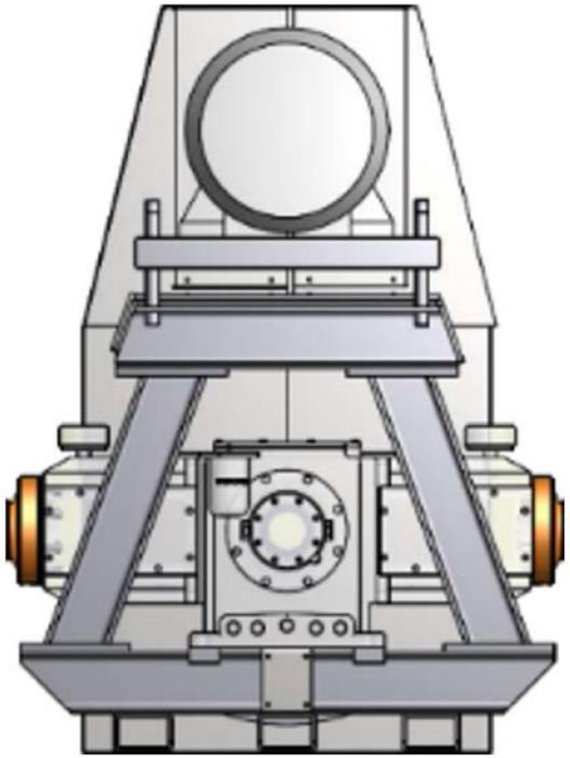
Prototype design – mechanical compressor

Design of a complete compressor prototype for laboratory use

- New proprietary low-noise hydraulic relief valve developed
- Development of supporting balance-of-plant components
- Compressor power-frame developed integrating all submodules:
  - Compressor head
  - Crank-case,
  - Electrical motor
  - Supporting balance of plant components



Compressor power-frame

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Laboratory testing – mechanical compressor

Extensive laboratory testing of the MC prototype at NEL in Denmark

- More than 4000 hours of tests performed
- Cold and hot tests from -10degC to +50degC
- Capacity tests with up to 60kg/hour demonstrated
- Energy tests: Validated reaching of the targeted 1,18 kWh/kg
- Endurance tests: achieved 100 million cycles diaphragm lifetime
- Noise tests: confirmed ability to reach <60dB in a HRS setting

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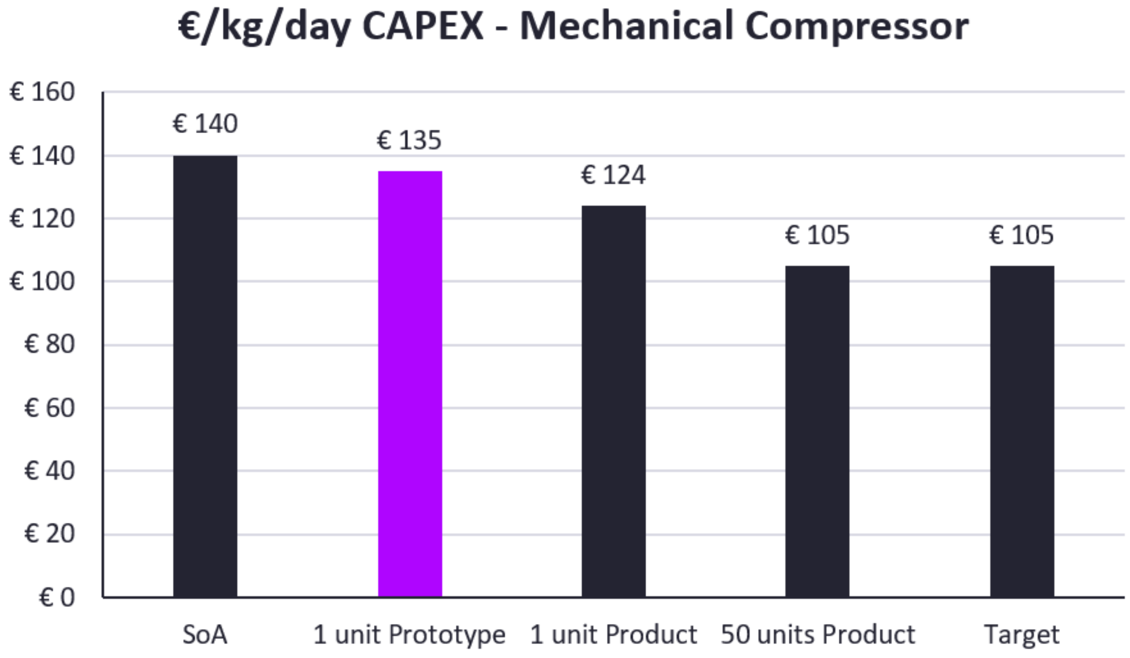
Cost reduction assessments – mechanical compressor

- **Pathway identified to achie €105/kg/day target**
- Experienced cost on Prototype, already 3,6% cheaper than SoA (commercial industrial compressor in volume manufacturing)
- 1st unit of product design expected to reduce costs with further 7,4% due to lower labor costs (design optimized for assembly)
- 50 unit/year volume manufacturing to further lower costs with 16%, due to both lower labor and components costs



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Final Event
Building up a metal hydride compressor prototype pt. 1 - MAHYTEC

Speakers Jean-Michel TISSERAND
Mathilde BANGOURA

Event Final Event, 24/02/2021

Location On-line

Innovative compression solutions
for efficient hydrogen mobility

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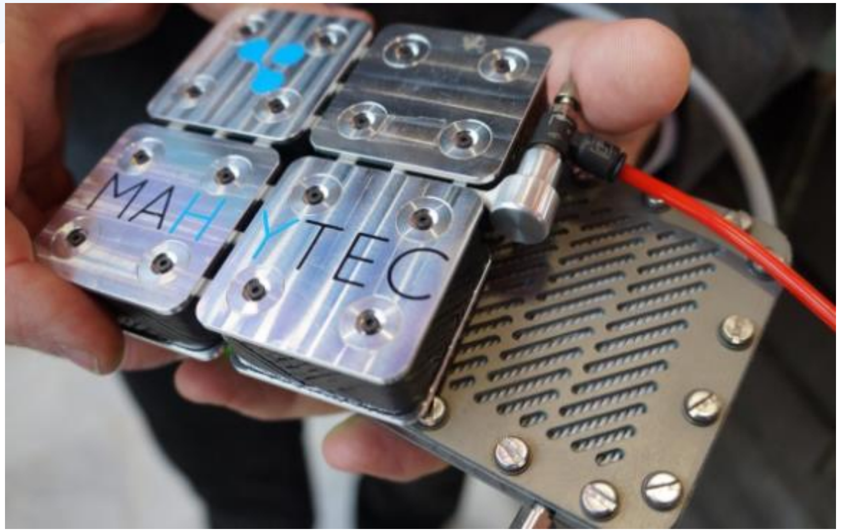
Hydride application

Hydride tank can be used to store small or large amount of hydrogen for various applications.

- Small fuel cell vehicle
- Electricity generator



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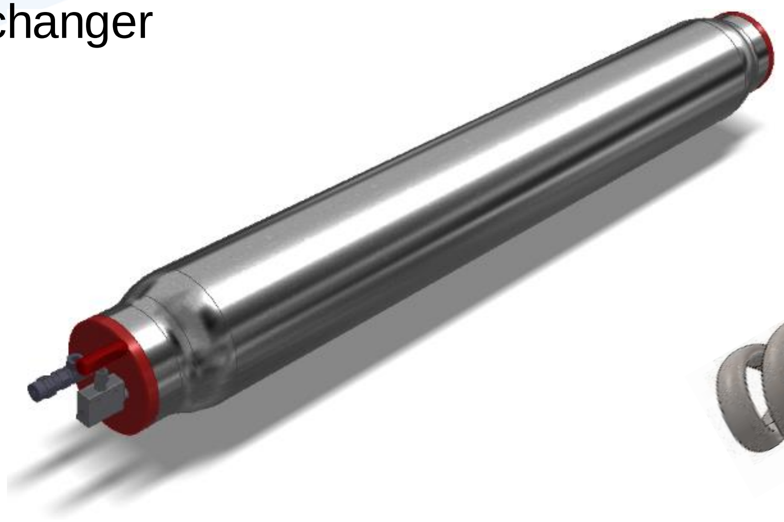
Metal hydride reactor

A metal hydride reactor is composed of:

- Metal hydride
- A shell
- A heat exchanger



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Selection of adapted metal hydride

Hydride selection for compression application

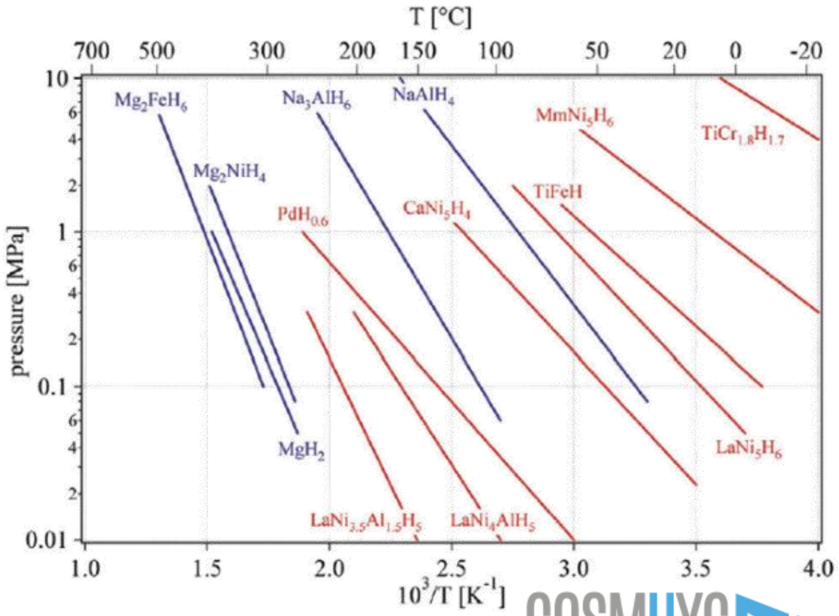
Storage ≠ Compression

For hydrogen storage, a perfect hydride would stay at the same pressure when temperature increases.

For hydrogen compression, a perfect hydride would increase grandly its pressure with a small temperature increase.

Pressure and temperature are not the only parameters.

- To perform well over the time: cyclic stability, impurity
- To be competitive over other technology: H-Capacity and cost
- To be efficient: thermal capacity, thermal conductivity, enthalpy



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INNOVATIVE H2 COMPRESSION

Selection of adapted metal hydride

Environmental impact

Most alloys implemented in competitors compressor use rare earths.

Rare earths hydride are well known, offer good performance and ease of activation but…

We chose not to use rare-earths because:

- They are expensive
- Extraction and purification process ➔ pollution
- Can be subject to commercial limitation

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Selection of adapted metal hydride

Hydride combination

The compression ratio of an hydride will depend on its own characteristics and on the temperature range.

If compression ratio isn't large enough to reach the desire pressure, hydride can be cascade.

First stage will compress hydrogen from H2 source to the second stage input.
Second stage will compress hydrogen for the third stage
…
Final stage will reach the desire pressure

Overlapping is an important parameter for hydrides selection

Hydride	Pressure (bara)												
	0				20				100				500
A1													
A2													
A3													

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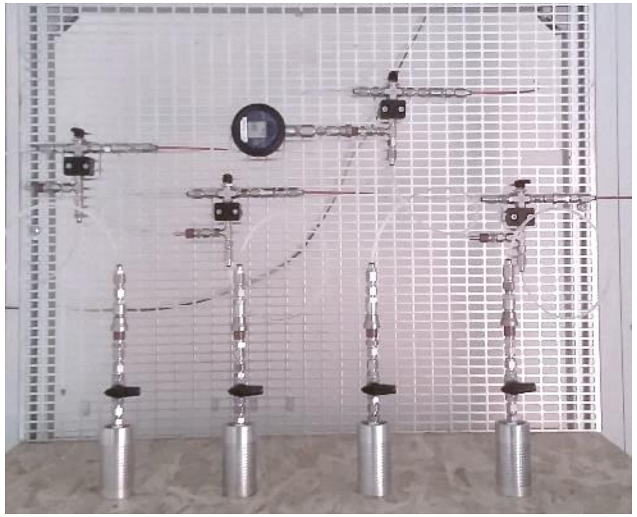
Selection of adapted metal hydride

Hydride test

For each parameter, tests such as PCT, cycling test, kinetics, compression… need to be performed by manufacturer.

Hydride selection requires a huge amount of work and time



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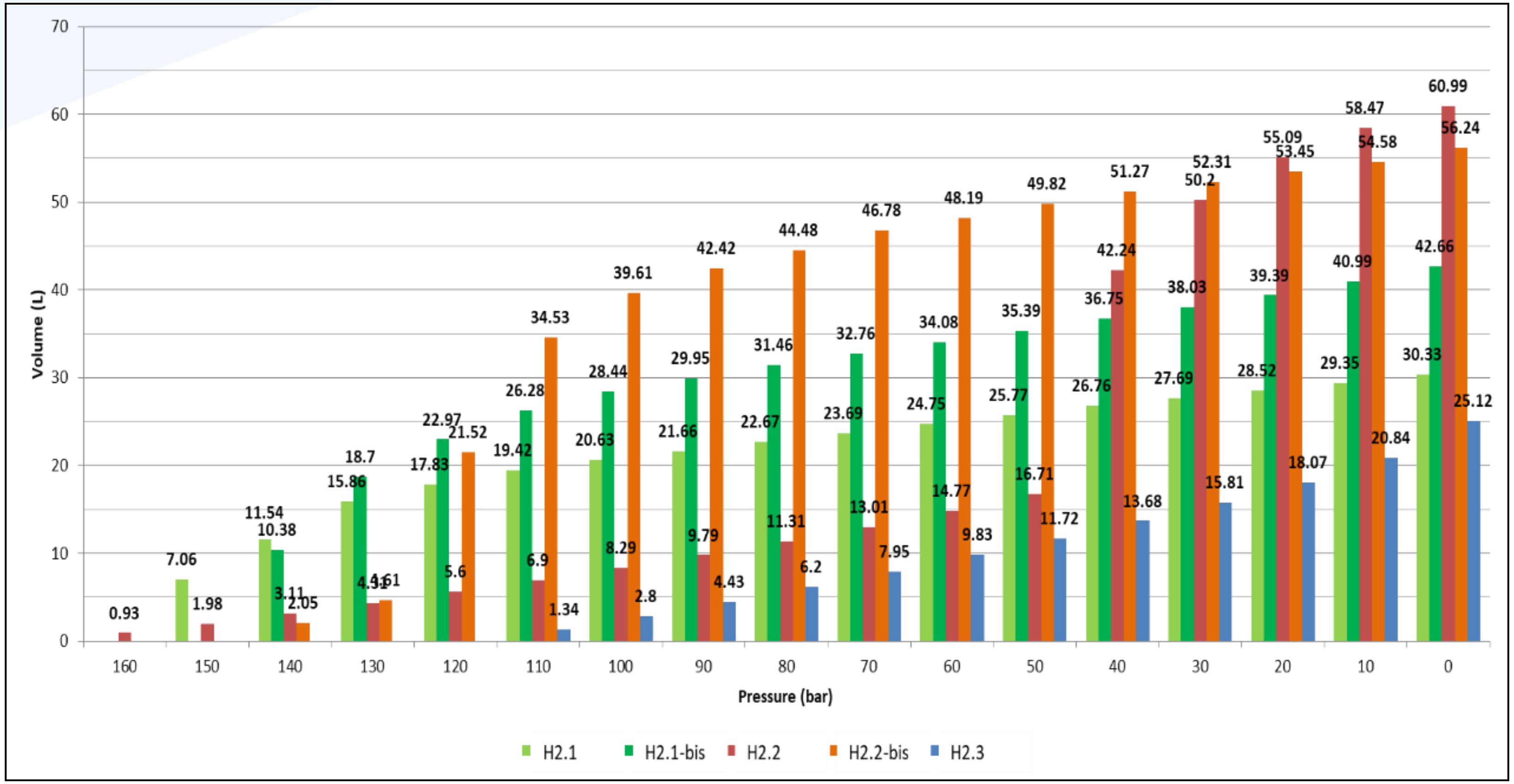
Selection of adapted metal hydride

Preselected hydride comparison

Some hydride will reach higher pressure, but with an average capacity.
Other will reach a better capacity but compress at a lower pressure
And some will just be… bad



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Hydride manufacturing

Cast

Crush

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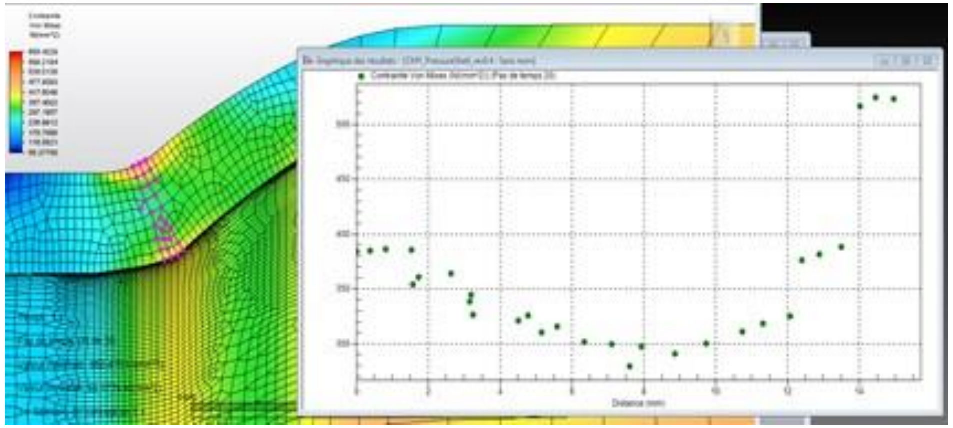
Reactor design

Shell

Compressor shells are complex due to many constrains:

- Safety: the shell needs to withstand pressure up to 450 bar.
- Temperature: the reactor will operate up to 180°C.
- Weight: low thermal inertia.
- Be Price-competitive
- Compatibility with hydrogen



Diameter : 226 mm
Length : 1700 mm

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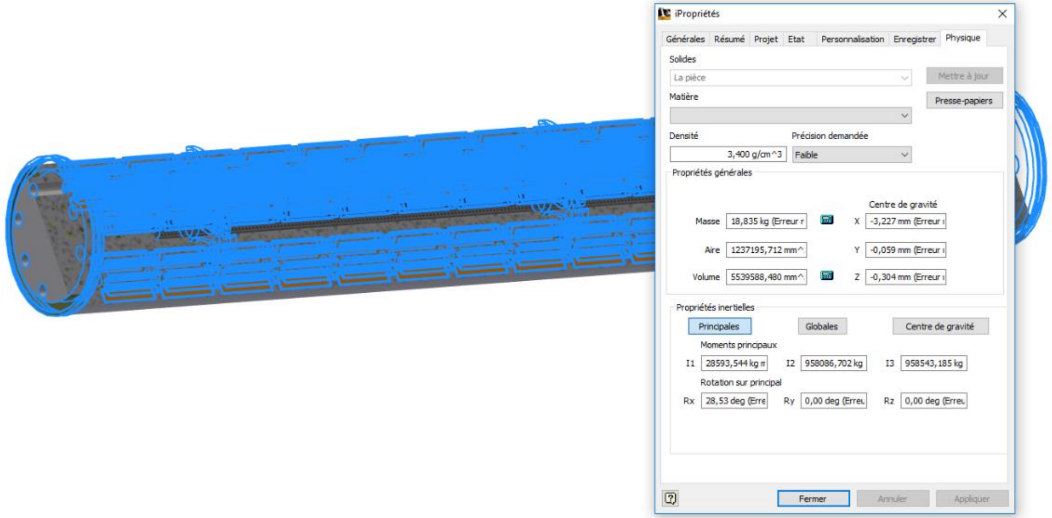
Reactor design

Heat exchanger

Heat exchangers have huge impact on system efficiency.
Reducing cycling time by 50% will increase H2 flow by 2

But heat exchanger complexity is alike to its importance.
It must :

- Reduce distance between powder and heat exchanger
- Fast heating/cooling property
- Resistance to the pressure
- Hydrogen compatibility
- Hydride expansion (compartmentation)
- No poisoning of the hydride
- Working from -40 to 180°C
- Have Low thermal inertia
- Be Easily filled
- Be Compact
- Be Price-competitive
- …



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Reactor approval

Approval

As compressors are pressured devices, all stages have been tested and approved according to DESP 2014/68/UE

- Hydrogen compressor
- Serial number of the tank: **CMY200-N-000** or **CMY440-N-000**
- Test date: AAAA/MM
- Test pressure (PT): 644barg
- Maximum filling pressure: **20barg** or **100barg**
- Minimum filling temperature: +10°C
- Pressure min/max : **-1barg/200barg** or **-1barg/440barg**
- Operating temperature: -40°C/180°C
- Service temperature: +10°C/160°C
- Hydrogen only: Group 1 fluid
- Valve pressure: **200barg** or **440barg**

Bureau Veritas SA is a BUREAU VERITAS 1828 *Notified Body under the number 0062*

BUREAU VERITAS

CERTIFICAT DE CONFORMITE

CERTIFICATE OF CONFORMITY

selon Module G de la directive équipements sous pression 2014/68/UE

as per Module G of pressure equipment directive 2014/68/EU

N° CE-0062-PED-G-MAH 005-20-FRA

Bureau Veritas SA, agissant dans le cadre de sa notification (numéro d'organisme notifié 0062) , certifie que l'équipement sous pression identifié ci-après a été conçu, fabriqué et testé de façon satisfaisante selon les prescriptions du module G de l'annexe III de la directive "Équipements sous pression" N° 2014/68/UE.

Bureau Veritas SA, acting within the scope of its notification (Notified Body number 0062) for module G according to annex III of the Pressure Equipment Directive 2014/68/EU, certifies that the design and manufacturing examination and the tests have been carried out on the equipment below identified, with satisfactory result.

Fabricant (Nom) */ Manufacturer (Name):*	MAHYTEC
Adresse */ Address:*	6 RUE LEON BEL 39100, DOLE, France
Mandataire (Nom) */ Authorised representative (Name):*	/
Adresse */ Address:*	/

EQUIPEMENT */ EQUIPMENT*

Item */ Item:*	CMY200-A-006
Description de l'équipement */ Equipment description:*	Ensemble CMY200

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Final Event
Building up a metal hydride compressor prototype pt. 2 - EIFER

Speaker Rami CHAHROURI

Event Final Event, 24/02/2021

Location On-line

Innovative compression solutions
for efficient hydrogen mobility

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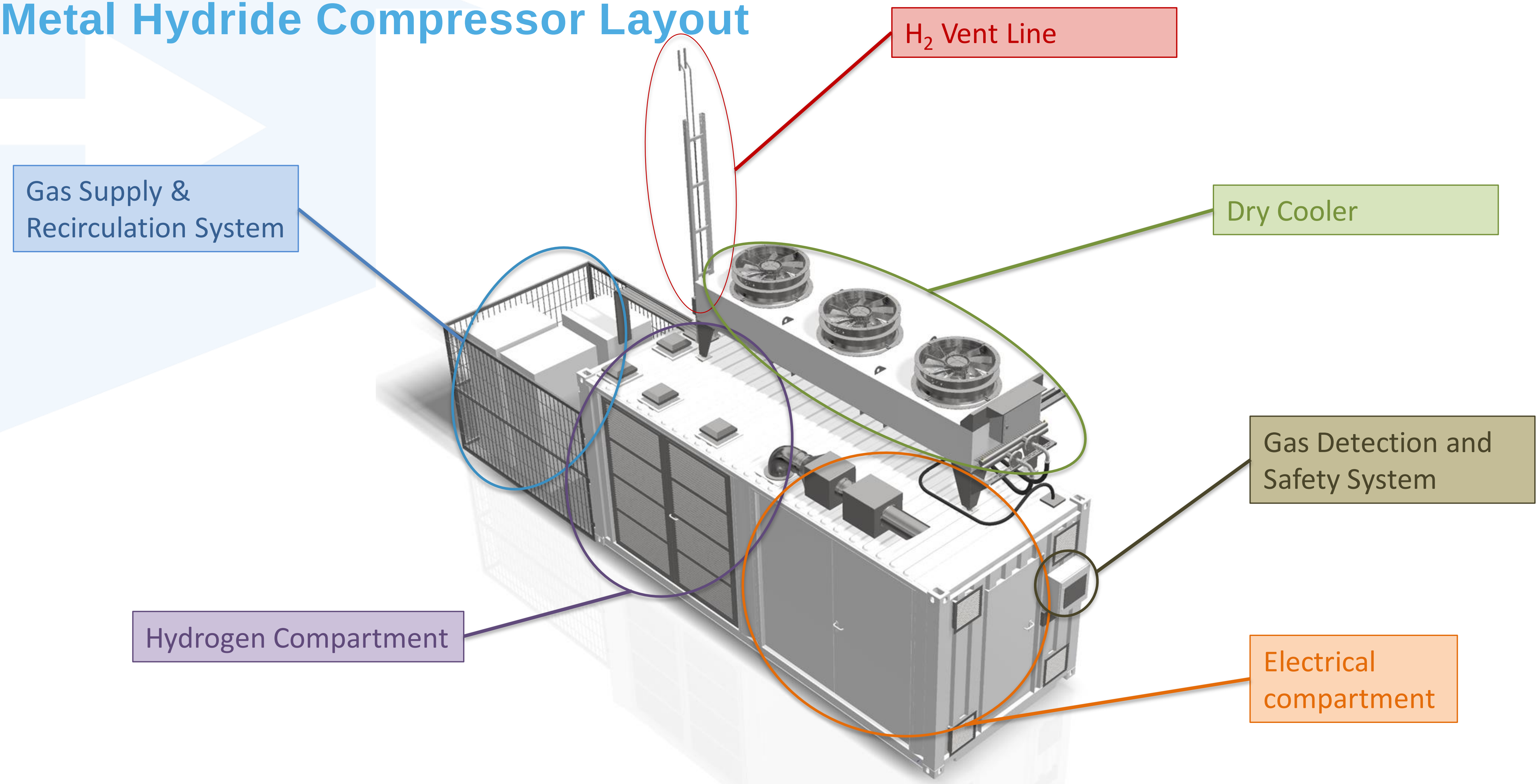
Metal Hydride Compressor Layout



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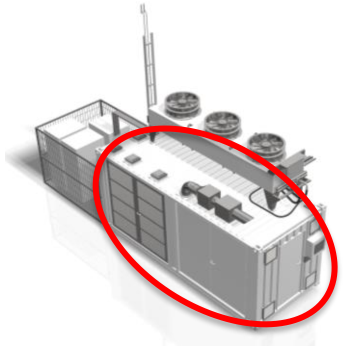
Container Delivery



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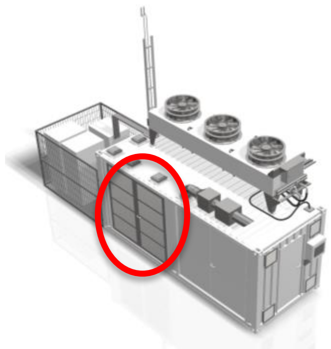
COSMHYC
INNOVATIVE H2 COMPRESSION

Hydrogen Compartment



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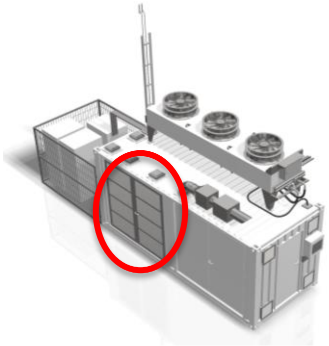
Hydrogen Valve Panel



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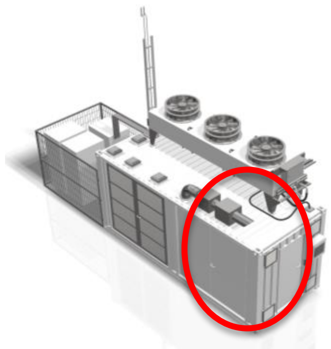
Electrical Compartment



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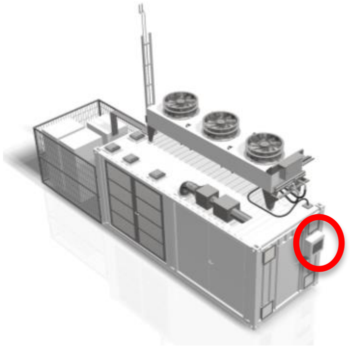
Gas Detection & Safety System



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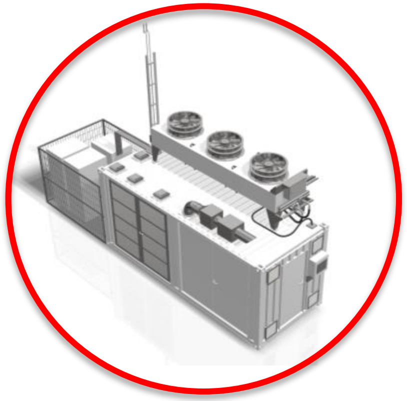
MHC Compressor



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COSMHYC
INNOVATIVE H2 COMPRESSION

COSMHYC Final Event

24th of February 2021

Tests and results of the COSMHYC compressors

Speaker David Colomar

EIFER

Innovative compression solutions

for efficient hydrogen mobility

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COSMHYC

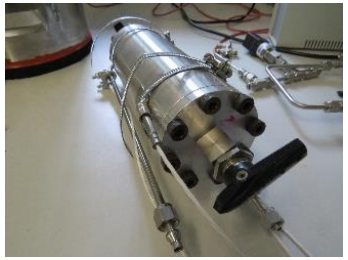
INNOVATIVE H2 COMPRESSION

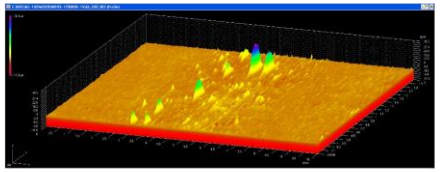
Different tests were performed along the project

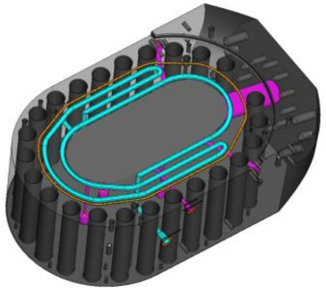
Tests on materials

Tests on sub-systems

Tests on prototypes







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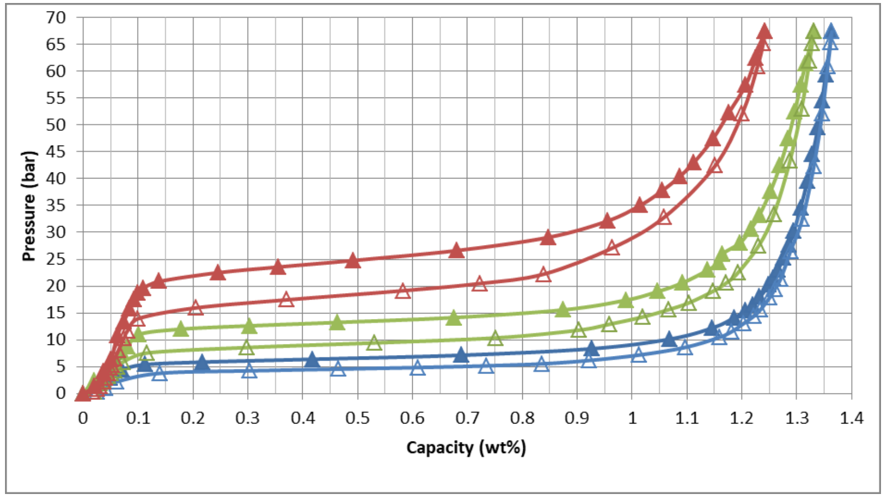
Testing on materials : new hydrides and membrane materials

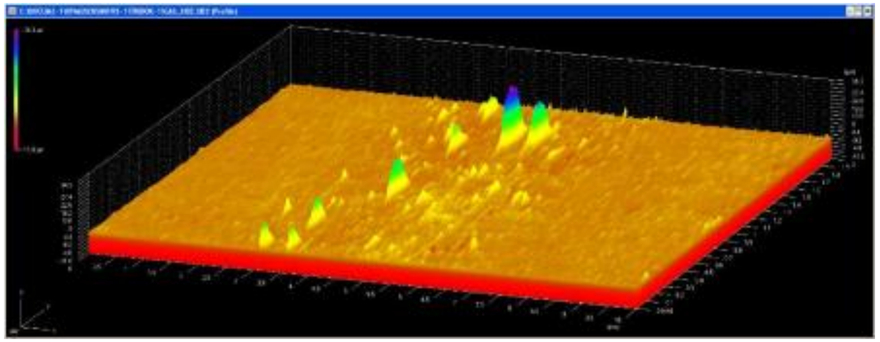
⇒ **Tests performed on 11 different rare earths free hydrides**
- PCT curves, to determine compressor capacity and relationship between temperature and pressure
- Main issues encountered: activation, contamination with impurities, heat exchange

⇒ **Main result: Appropriate hydrides were identified for compression from 5 bar to 450 bar**



⇒ **Investigating compressor membranes**
- Assessing the impact of roughness on life time
- Proposing improvement strategies: surface treatment, new materials

⇒ **Main results: several 10th of millions cycles demonstrated without failure**



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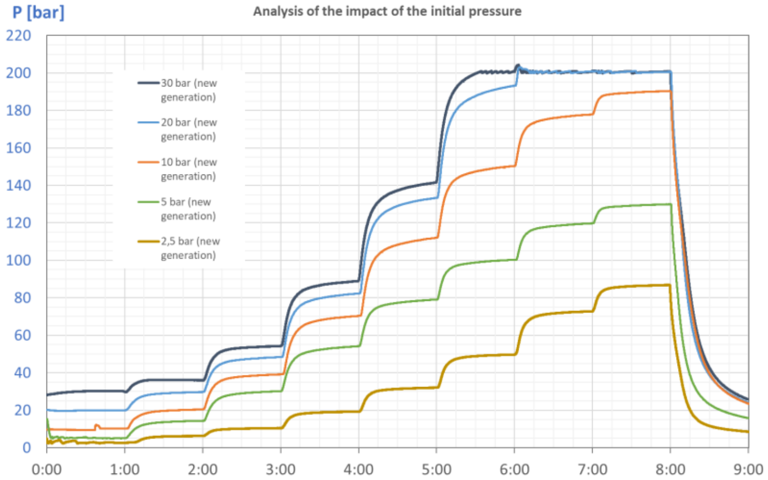
Testing innovative subsystems: metal hydride tanks

⇒ **Different tank concepts were developed and tested**

- Increasing mechanical resistance while reducing thermal inertia
- Optimising capacity while enabling a good reaction kinetics
- Reaching appropriate flow rates and compression ratios
- Validating at representative scale the performances expected at material level

⇒ **Main results:**

- Performances at material level confirmed
- Exponential increase in P with growing T: an expected challenge for optimization
- Compression ratios of 10 to 35 demonstrated for 1 stage !



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INNOVATIVE H2 COMPRESSION

Testing innovative subsystems: metal hydride tanks

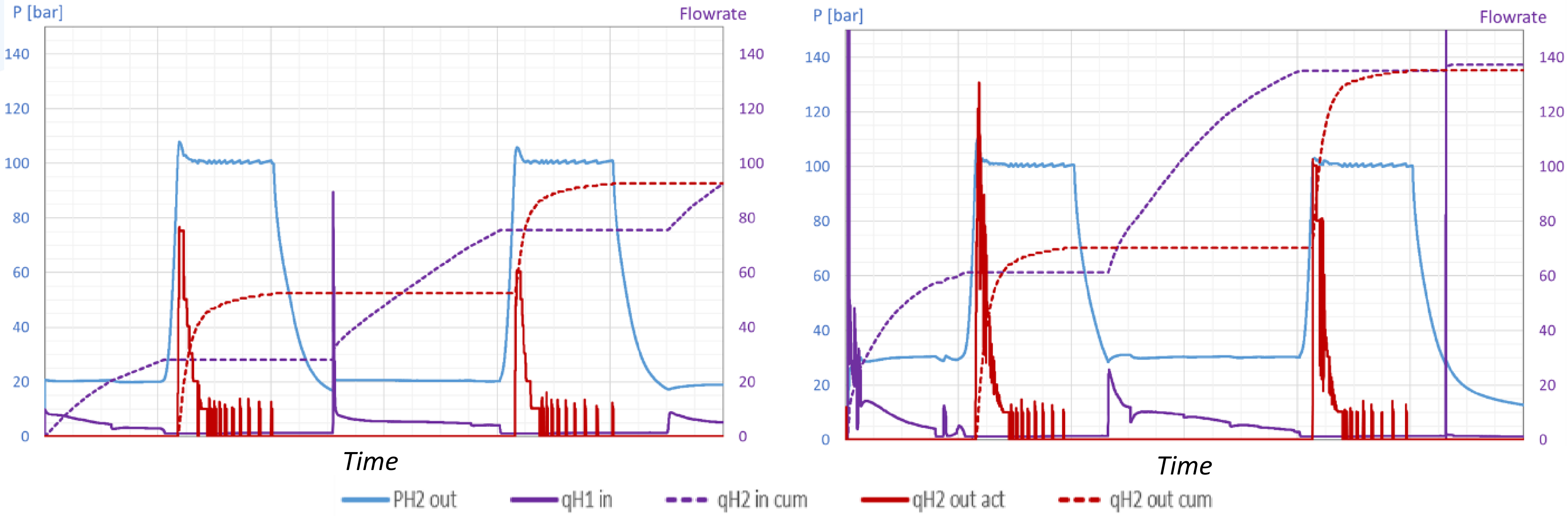
⇒ **Lessons learnt from tank behaviour**

- Significant impact of inlet pressure on desorption flow

⇒ Confirmation of the added value of pressurized H2 production

- Desorption profile strongly inhomogeneous : 70% of the hydrogen desorbed in 25% of the time

⇒ Important role of the control strategy : identifying the techno-economic optimal desorption time



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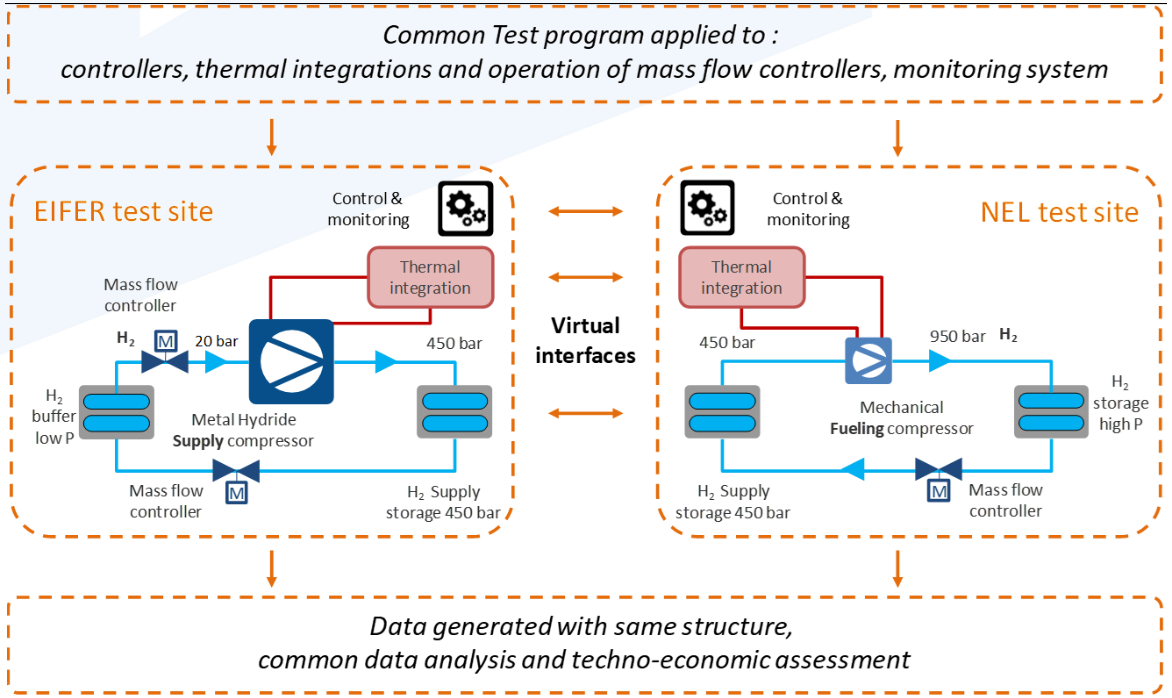
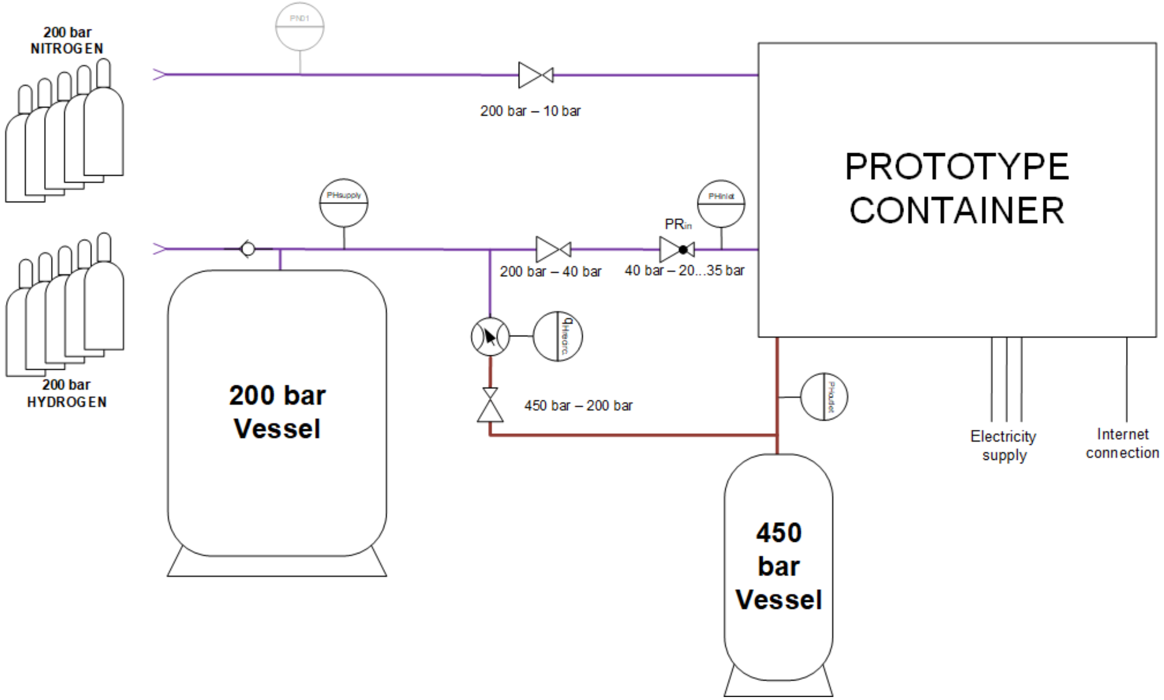
COSMHYC INNOVATIVE H2 COMPRESSION

Testing prototypes: testing concepts

⇒ **Both prototypes tested on separated sites to facilitate monitoring and maintenance**





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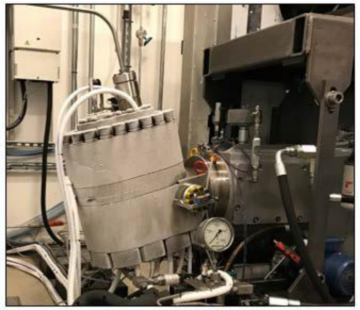
COSMHYC INNOVATIVE H2 COMPRESSION

Testing prototypes: the mechanical compressor

⇒ **The mechanical compressor prototype was tested in Denmark at NEL facility**

- More than 4000 h of tests were performed, including:
- Cold and hot tests : operation from -10° to +50°C successfully demonstrated
- Capacity tests : capacity of more than 60 kg/h demonstrated
- Pressure inlet/outlet well in phase with the capacity of the metal hydrde compressor
- Energy tests : consumption significantly improved compared to state-of-art
- Endurance tests : 10^{th} of millions of cycles demonstrated without failures, more than 5000 starts and stops



-10 °C compressor testing

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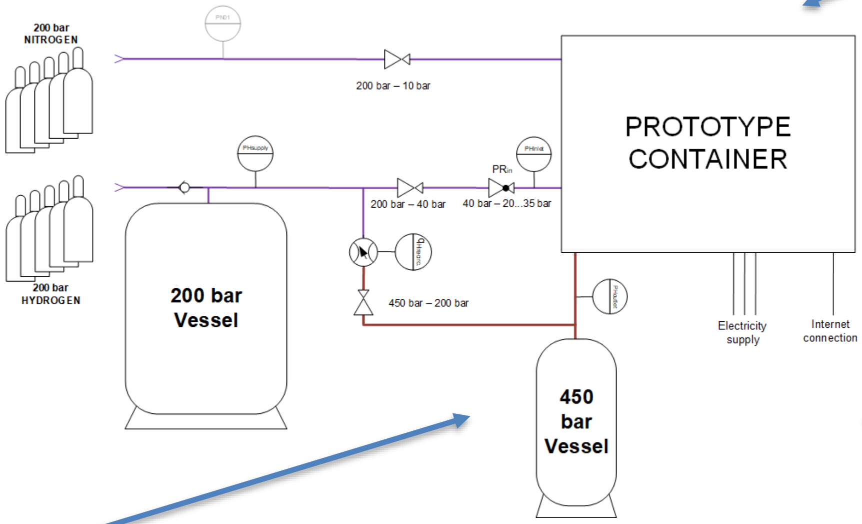
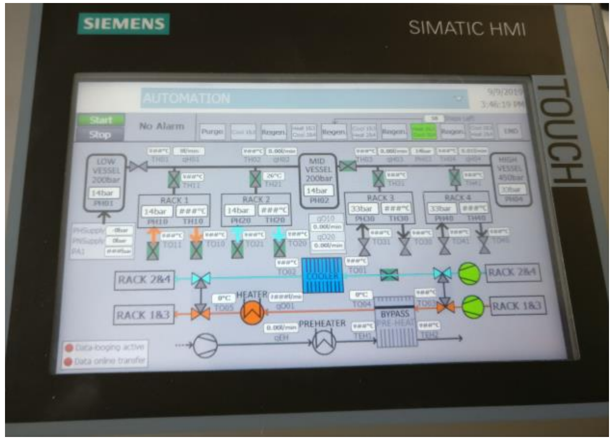
COSMHYC INNOVATIVE H2 COMPRESSION

Testing prototypes: the metal hydride compressor





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Testing prototypes: the metal hydride compressor

⇒ **Operation and maintenance issues**

- Surprisingly few problems encountered with the core technology as long as the purity level of hydrogen matches the requirement
- Most issues encountered with the BOP, including**:**
    - Reliability of H2 components
    - Reliability of thermal BOP
    - Tightness of heating integration
    - Material compatibility of heating fluid with components

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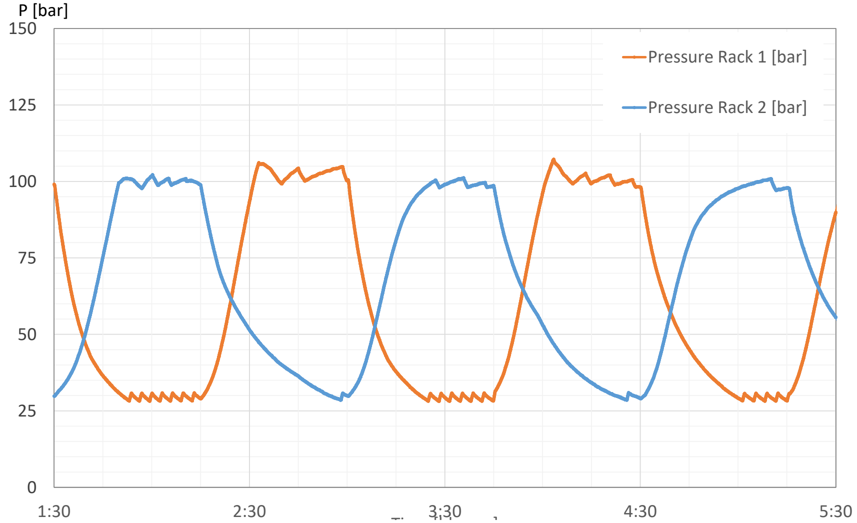
Testing prototypes: the metal hydride compressor

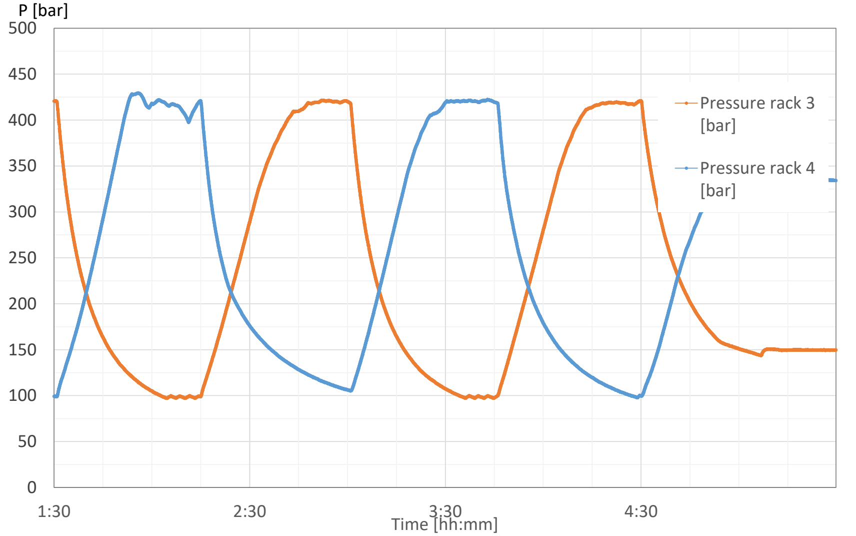
⇒ **Pressure level reached stage 1: 28 bar -> 112 bar**
⇒ **Pressure level reached stage 2: 97 bar -> 429 bar**

- Significantly higher pressures possible >450 bar, but not implemented in automatic mode for safety reasons
- A compression ratio of > 15 achieved
- < 50% useful time in the process: a strong potential for further optimization remains
- Further optimization needed in well-defining optimal intermediate pressure

⇒ **Prototype as a stand-alone solution already today meets the requirements of several end users needs**


Sources: Hydrogen Europe & NEL





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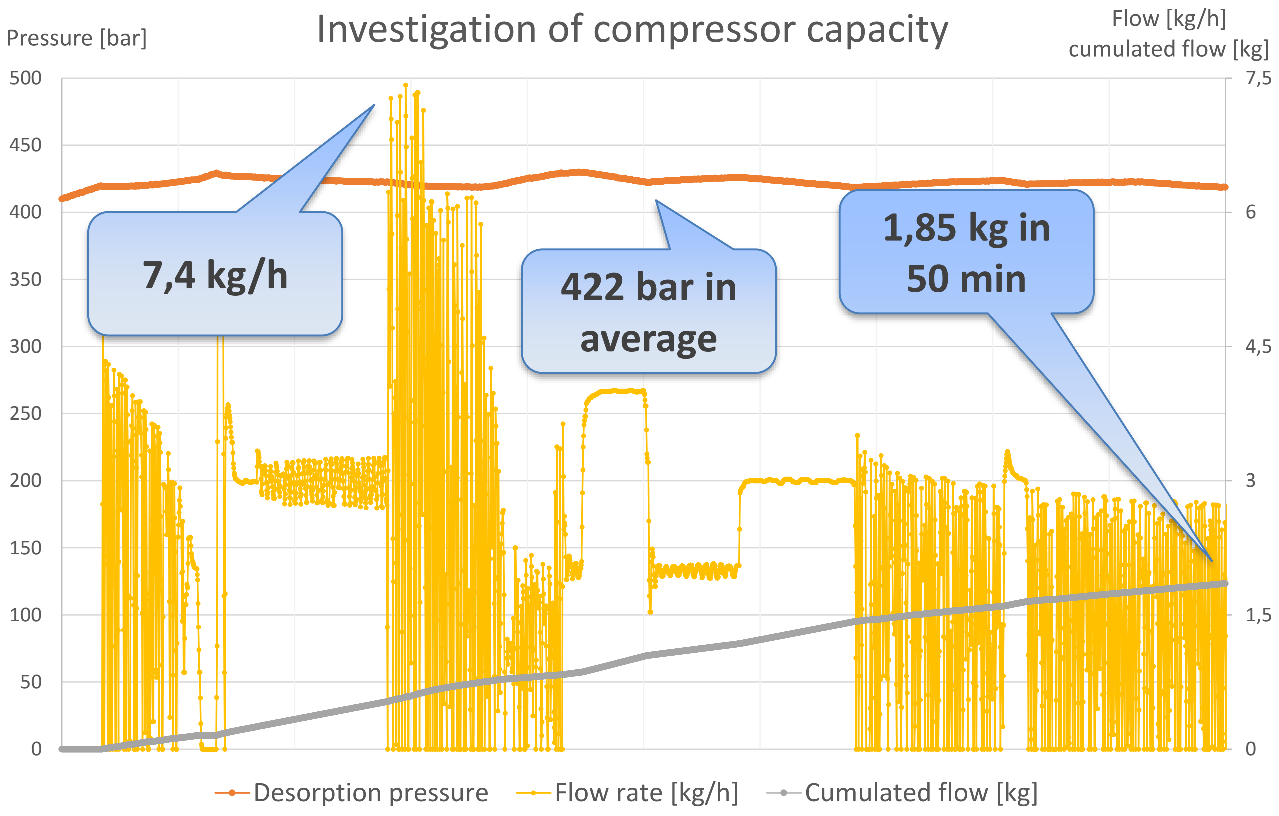
Testing prototypes: the metal hydride compressor

⇒ **Capacity: target = 2 kg/h**

- Peak flow rate observed : up to > 7 kg/h
- Flow rate over ~1h : 2,2 kg/h
- Average flow rate depending on:
    - Setting cycling time
    - Heat power profile
    - Set-up temperature
    - Outlet pressure
    - Climatic conditions
    - User profile

- Values observed currently vary between a few 100 g/h to several kg/h
- Further investigations still ongoing

⇒ **More than 10 X the state-of-art reached !**



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COSMHYC INNOVATIVE H2 COMPRESSION

Testing prototypes: the metal hydride compressor

⇒ **Energy consumption**

- Only preliminary analysis so far as additional tests still ongoing
- Energy consumption consists of :
  - Heating energy for absorption/desorption
  - Inertia of hydrides, tanks, thermal circuit
  - Electricity for auxiliaries
  - Electricity for cooling fans
- Preliminary values show a consumption significantly better than the state-of-art of hydride compression but higher than comparable mechanical compressors (> 9 kWh)
- However, if a waste heat source is available, electricity consumption can be lower than 1 kWh/kg
- Significant improvement potential : auxiliaries, thermal insulation, inertia of tanks etc.

⇒ **Strong potential for using the technology where waste heat (industry, H2 production) is available**

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Testing prototypes: the metal hydride compressor

⇒ **Noise disturbance were investigated around the compressor (5m)**

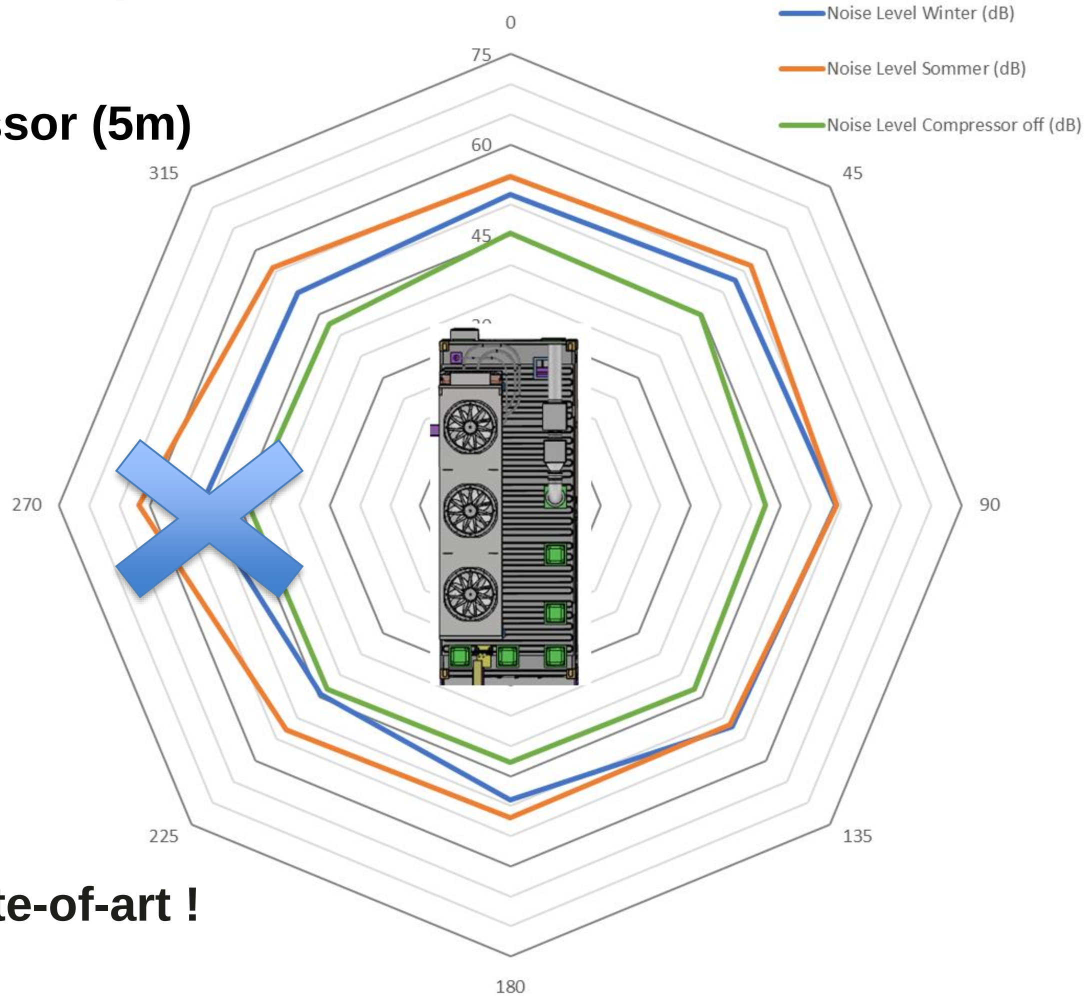
- **2 typical operation modes were assessed:**

- Summer / day mode, with the cooler at maximal working power.
- Winter / night mode, with the cooler at a lower speed.

- **In average, the following noise source was measured:**

- 53,9 dB in summer / day mode
- 50,6 dB in winter / night mode

- **The main noise source is the ventilation,**
- **This could be mutualised with other HRS equipment**
- **This noise source is qualitatively less disturbing than a piston**



⇒ **The overall noise disturbance is much lower than the state-of-art !**

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COSMHYC
INNOVATIVE H2 COMPRESSION

Overall conclusions

⇒ **2 technologies developed and prove their complementarities**

⇒ **Scale-up successfully achieved**

⇒ **TRL level successfully increased**

⇒ **Pressure targets achieved**

⇒ **Strong potential for noise reduction demonstrated**

⇒ **Further optimization is still needed, especially regarding energy consumption (when no waste heat is available), reliability of BOP, flow rate management**

⇒ **Activities continue within COSMHYC XL & COSMHYC DEMO, towards demonstration and commercialization**

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Thank you for your attention !

Contact: colomar@eifer.org

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COSMHYC Final Event

24th of February 2021

Techno-economic assessment

Speaker Jan Zerhusen

LBST

ludwig bölkow systemtechnik

Innovative compression solutions

for efficient hydrogen mobility

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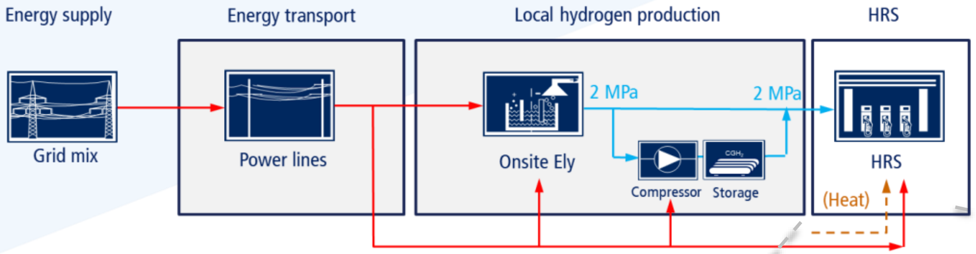
COSMHYC INNOVATIVE H2 COMPRESSION

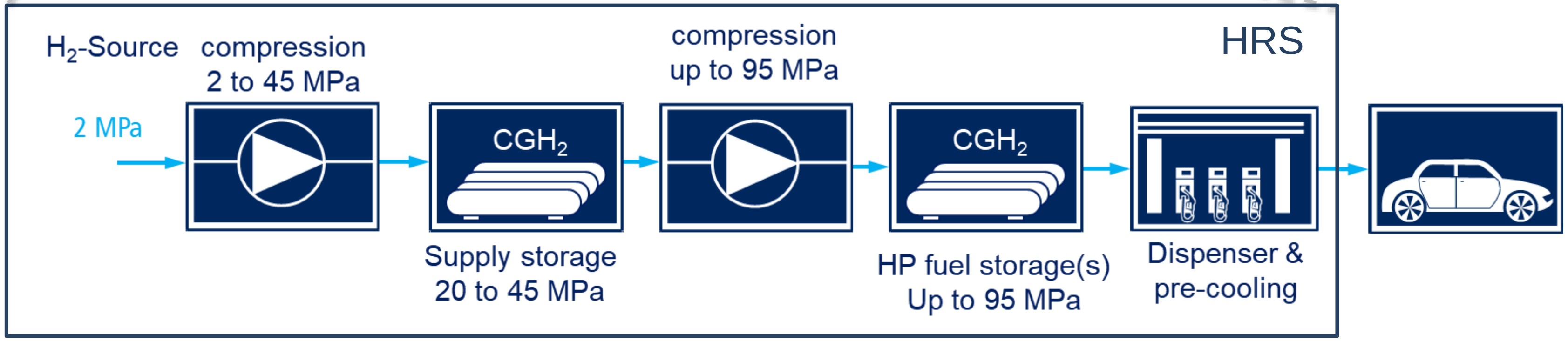
Cost assessment 70 MPa hydrogen refuelling station (HRS)

Hydrogen supply scenario: Lowest input pressure 2 MPa (e.g. from local LP-storage)
Hybrid compressor concept: Continuous operation of metal hydride compressor and peak operation of mechanical compressor



Metal Hydride Compressor
Continuous operation

Mechanical Compressor
Peak refuelling



HRS based on H_2-Mobility specs.

Capacity:	~ 200 kg/day
Peak dispensing:	33 kg/h
Back-to-Back:	1
Vehicles per day:	30

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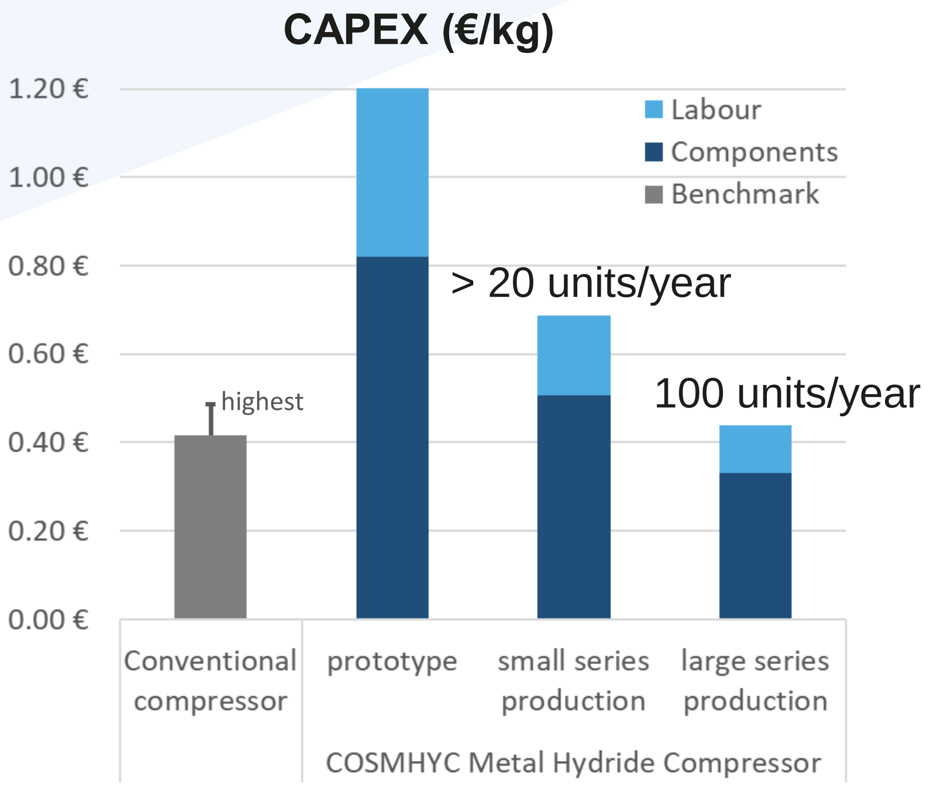
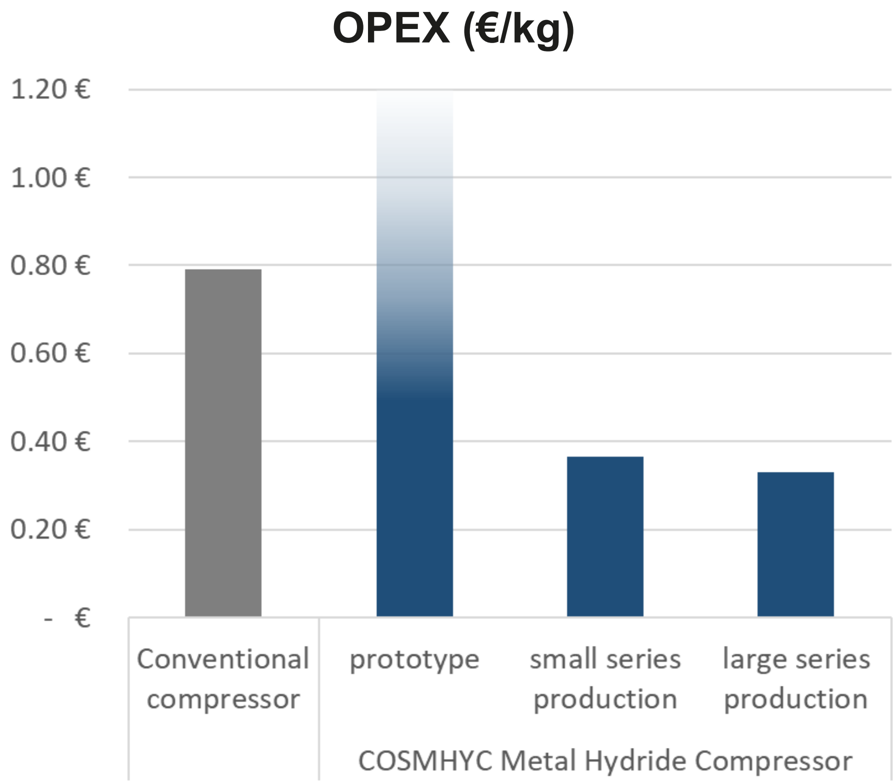
Cost assessment Metal Hydride Compressor

CAPEX: reduction due to series production → reduced complexity, improved assembly, higher purchase volume, etc.
CAPEX: metal hydride compressor on par with benchmark → metal hydride advantage in some cases
OPEX: cost advantage for metal hydride → heat usually less expensive than electricity





Electricity: 0.15 €/kWh
Heat: 0.03 €/kWh

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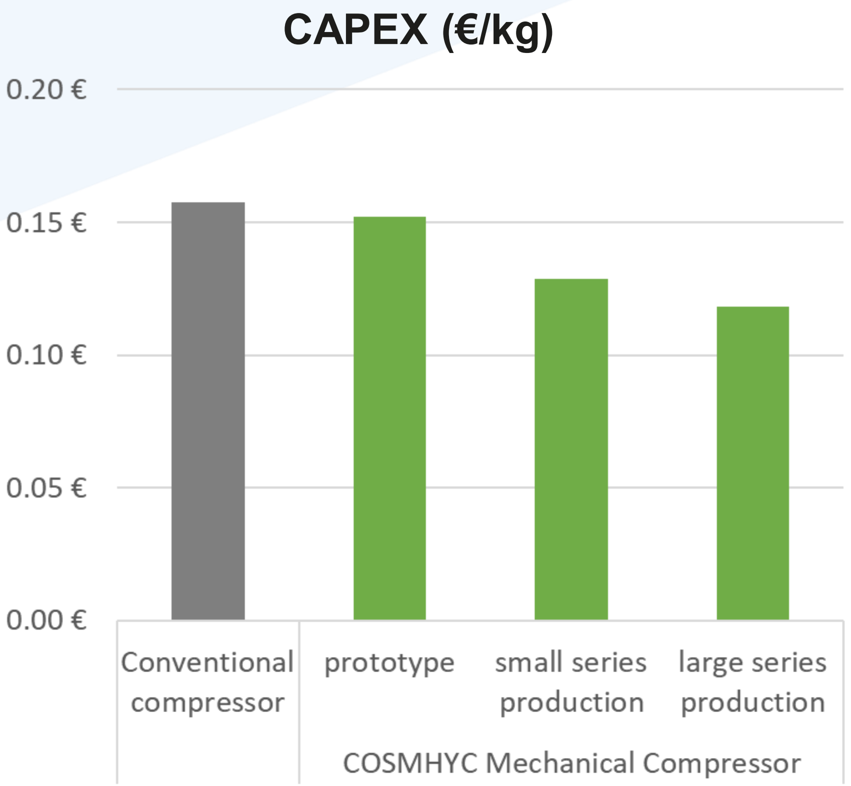
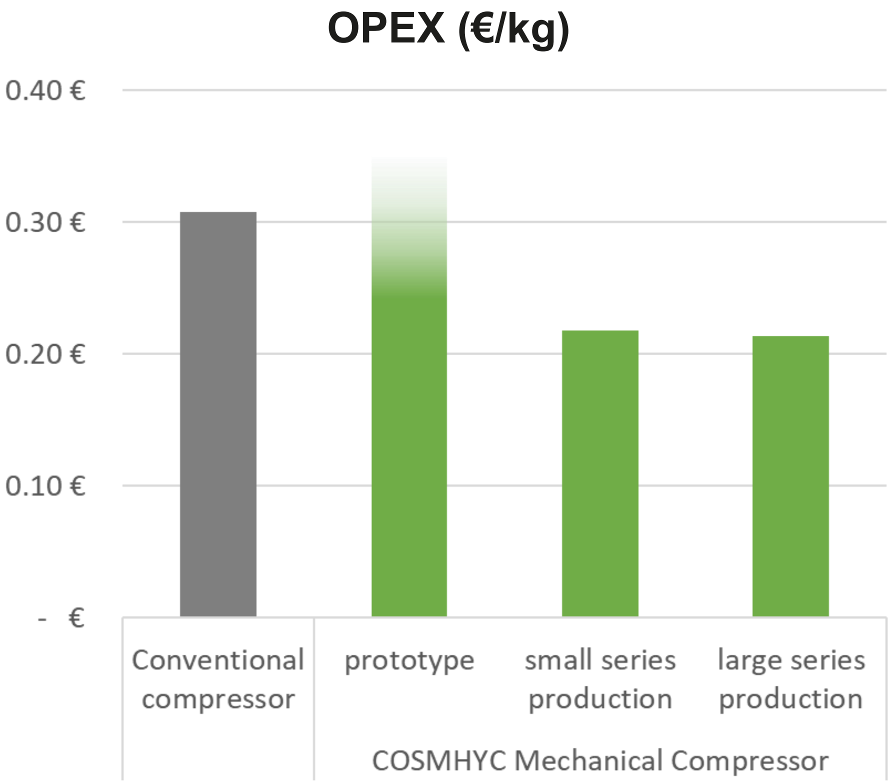
Cost assessment Mechanical Compressor

CAPEX: Material costs of prototype already below benchmark; further reduction when optimizing for series prod.
OPEX: Reduced electricity consumption and increased lifetime compared to benchmark





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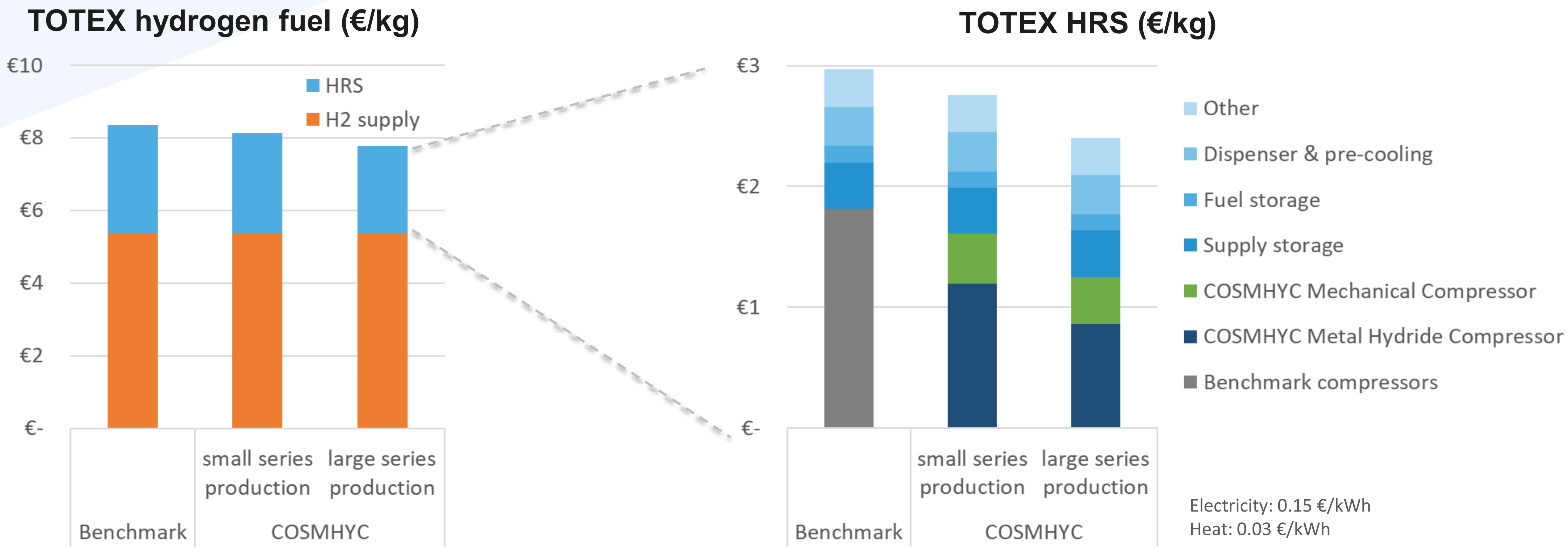
Cost assessment Total hydrogen costs

Overall cost savings at HRS of about 0.2 to 0.6 €/kg depending on mass production status
Cost advantage also depends on electricity and heat costs



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COSMHYC
INNOVATIVE H2 COMPRESSION

Cost assessment Impact of energy prices

Cost advantage of hybrid concept at small-series production
Large-scale production extends “green area” to bottom left

Cost advantage (€/kg)

Heat costs (€/kWhth)	Electricity costs (€/kWhel) 0.05	0.10	0.15	0.20	0.25
0.00	0.1	0.2	0.4	0.6	0.8
0.01	0.0	0.2	0.4	0.5	0.7
0.02	-0.1	0.1	0.3	0.5	0.6
0.03	-0.1	0.0	0.2	0.4	0.6
0.04	-0.2	-0.0	0.1	0.3	0.5
0.05	-0.3	-0.1	0.1	0.2	0.4
0.06	-0.3	-0.2	0.0	0.2	0.3
0.07	-0.4	-0.2	-0.1	0.1	0.3
0.08	-0.5	-0.3	-0.1	0.0	0.2

Advantage COSMHYC concept “green area”

Result from previous slide

Disadvantage COSMHYC concept

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Cost assessment Conclusion

Cost advantage of COSMHYC compression concept expected based on project results and learnings

- Further development towards mass production required (End of project: TRL 5)
- Identified system simplifications etc. enable significant reduction of CAPEX compared to prototype
- At mass production, hybrid concept will be on par in CAPEX but will show lower OPEX compared to benchmark technology
- Cost advantage over benchmark technology at moderate energy prices and HRS utilization

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Thank you for your attention!

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