EUROPEAN HYDROGEN ENERGY CONFERENCE

Fuel Cell Hybrid PowerPack for Rail Applications

ASOCIACIÓN ESPAÑOLA DEL HIDRÓGENO

Using Absorption Refrigerator and Metal Hydrides in Hydrogen Fuel Cell Trains: Draft Design Process and Feasibility

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Clean Hydrogen Partnership

Co-funded by the European Union

FCH2RAIL Project in Numbers

- Start date: 01 January 2021
- Duration: 48 Months
- Total budget: **13.3 Mio €**
- H2020 Innovation Action funded by Fuel Cells and Hydrogen 2 Joint Undertaking, now Clean Hydrogen Partnership
- 7 technical Work packages, 29 Milestones, 43 Deliverables
- **2 Demonstrators**: Fuel Cell Hybrid Power Pack and Bi-Mode Train
- 8 Beneficiaries from Belgium, Germany, Spain and Portugal

FCH2RAIL

Agenda

1. Motivation and Waste Energy Analysis
2. Absorption AC and Hydrogen Powered Air-Conditioning
3. Design Evaluation for Hydrogen Train
4. Summary and Outlook

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FCH2RAIL

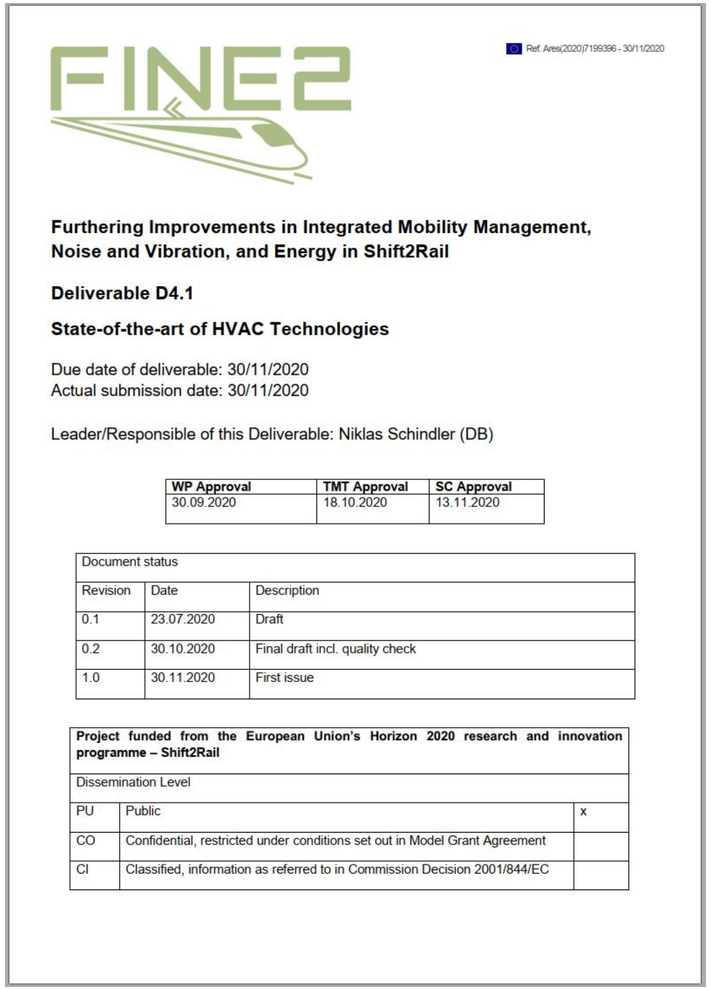
Motivation and Objective

Motivation

- SoA energy demand for cooling ca. 12,300 kWh/a in regional train coach (6,150 kWh electric)
- 370 kgH2/a ➔ 3,330 €/a (9 €/kgH2)

Objective

- How to reduce HVAC energy demand in hydrogen trains?
- Use waste energy for this reduction


Ref. Ares(2020)7199396 - 30/11/2020

FINE2

Furthering Improvements in Integrated Mobility Management, Noise and Vibration, and Energy in Shift2Rail

Deliverable D4.1

State-of-the-art of HVAC Technologies

Due date of deliverable: 30/11/2020
Actual submission date: 30/11/2020

Leader/Responsible of this Deliverable: Niklas Schindler (DB)

WP Approval	TMT Approval	SC Approval
30.09.2020	18.10.2020	13.11.2020

Document status		
Revision	Date	Description
0.1	23.07.2020	Draft
0.2	30.10.2020	Final draft incl. quality check
1.0	30.11.2020	First issue

Project funded from the European Union's Horizon 2020 research and innovation programme – Shift2Rail		
Dissemination Level		
PU	Public	x
CO	Confidential, restricted under conditions set out in Model Grant Agreement	
CI	Classified, information as referred to in Commission Decision 2001/844/EC	

[1]

HVAC: Heating Ventilation and Air-Conditioning
1) N. Schindler (2020) "Deliverable D4.1 State-of-the-art of HVAC Technologies", FINE2

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Waste Energy Analysis

- Hydrogen compression work and waste heat is currently unused in rolling stock

➔FC waste heat and hydrogen compression work can support auxiliaries

What is the amount of energy?
What is the quality of energy?

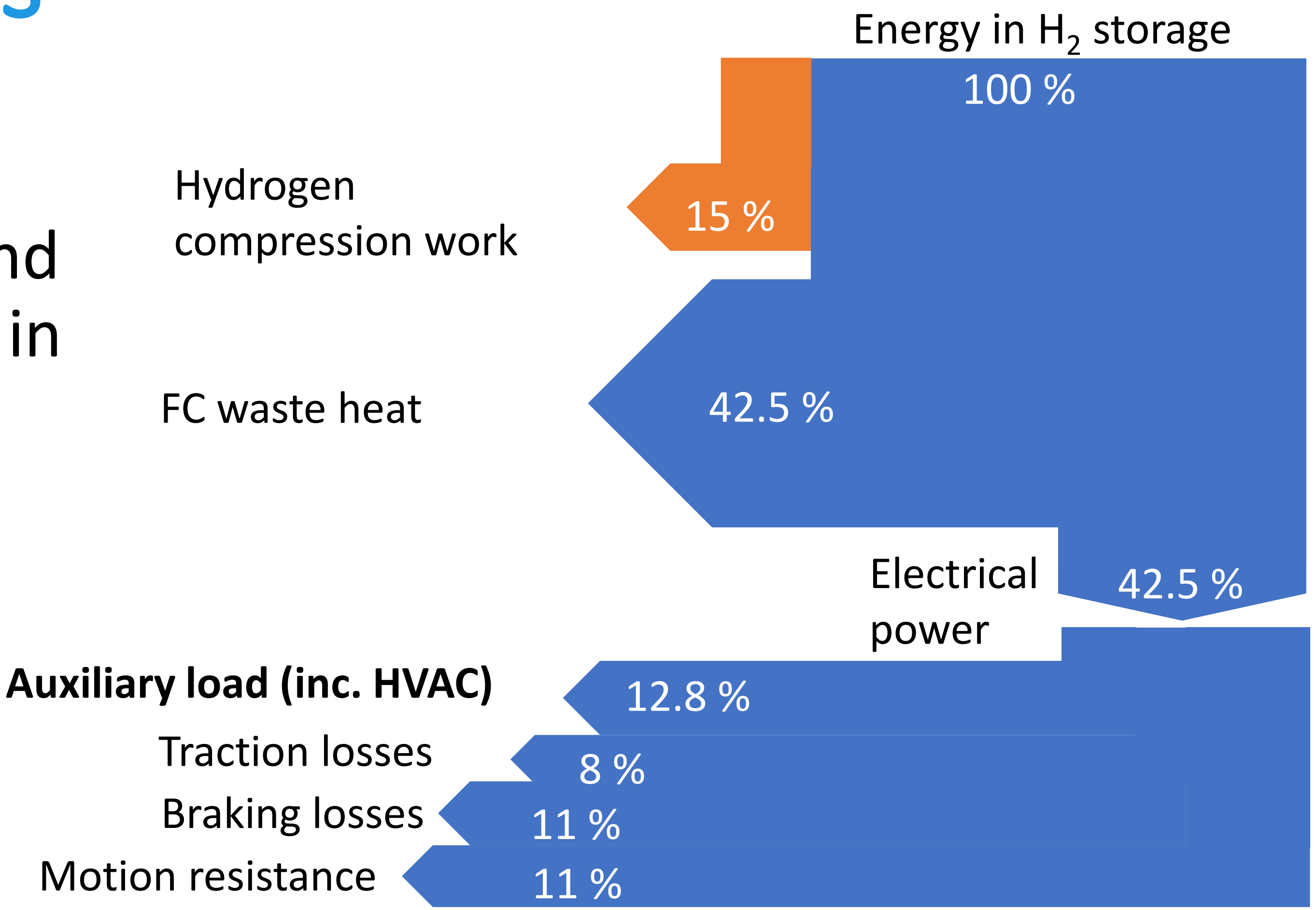

Fig. 2: Energy flow in urban FC rail systems (modified [2, 3])

2) Gonzáles-Gil et. al (2014) "A systems approach to reduce urban rail energy consumption", E. Conversion and Management
3) Cummins (2022) "Energy Efficiency of HD30 Systems", Homepage

Waste Energy - Amount and Quality

Waste heat flow

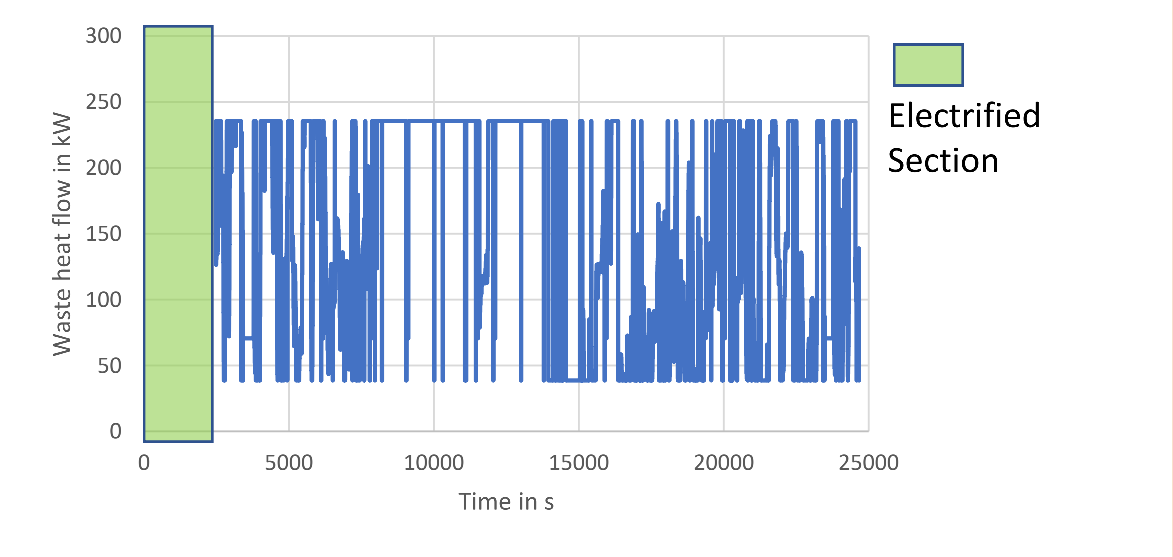

Fig. 3: Simulated fuel cell waste heat for part load use case [4]

Hydrogen mass flow

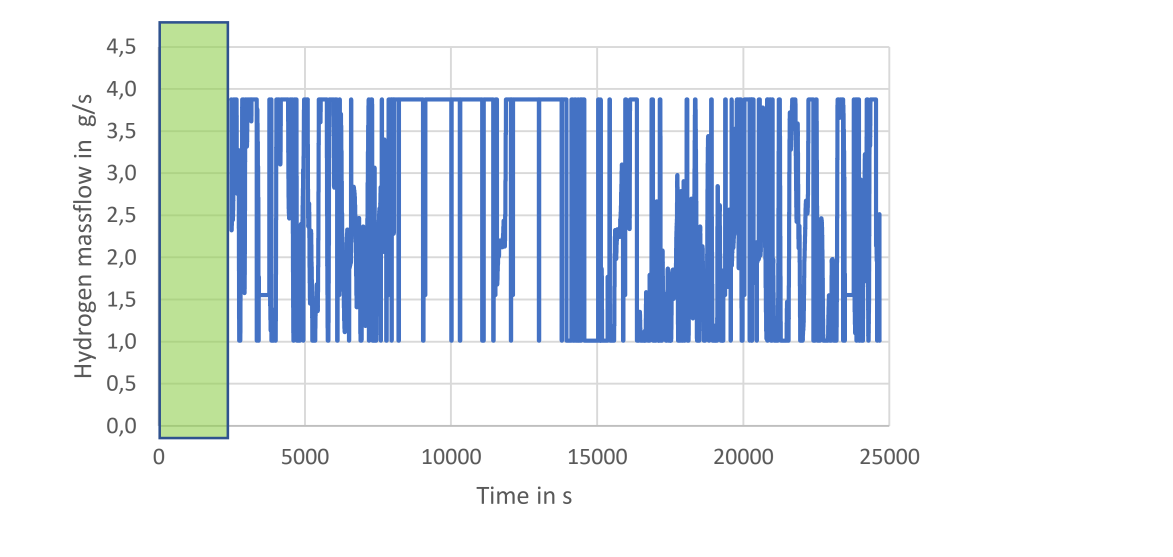

Fig. 4: Simulated hydrogen consumption for part load use case [4]

➔Up to 75 °C fuel cell coolant temperature

➔ Waste heat availability is track dependent

➔50 bar is considered as an empty tank and 8.5 bar is the FC inlet pressure (pressure regulator)

➔Compression work is track dependent

4) M. Kordel (2022) „D1.6 - Report on concept, draft design and preliminary simulation requirements", FCH2Rail

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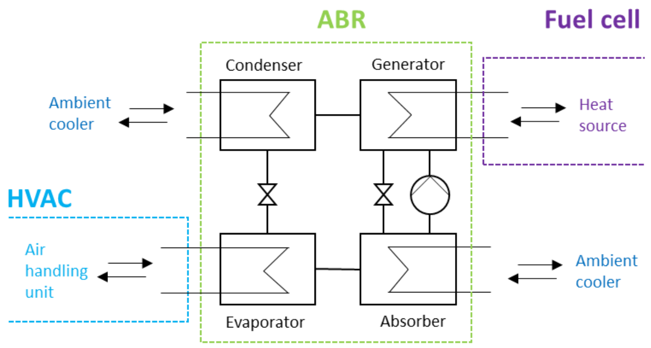
Technologies for Waste Energy Usage

Absorption refrigerator (Waste heat)



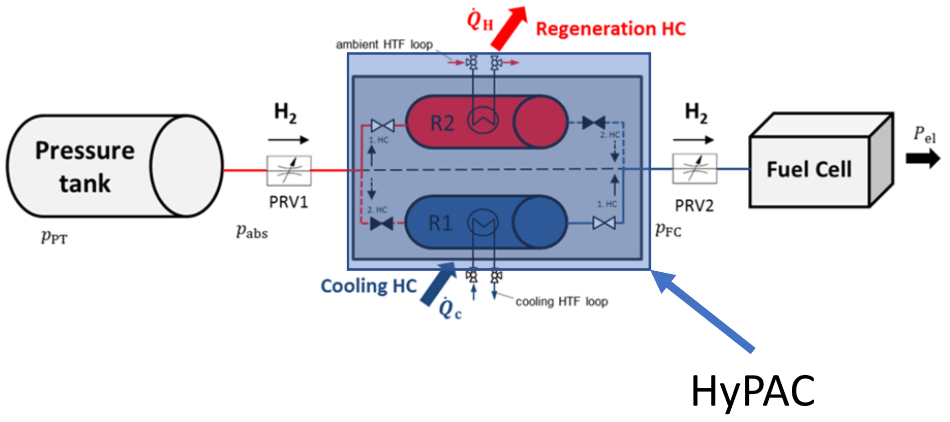
- Pair of refrigerant (water) and absorbent (LiBr) drives refrigerant cycle and thermal compressor
- Thermal compressor uses a heat flow to increase pressure of the refrigerant
- Only liquid pumps and no compressors are needed

➔ Fuel Cell's waste heat will be used to provide cooling capacity

Constraints:

- Waste heat temperature
- Ambient Temperature
- Waste heat amount

Hydrogen Powered Air-Conditioning (H2 Compression work)



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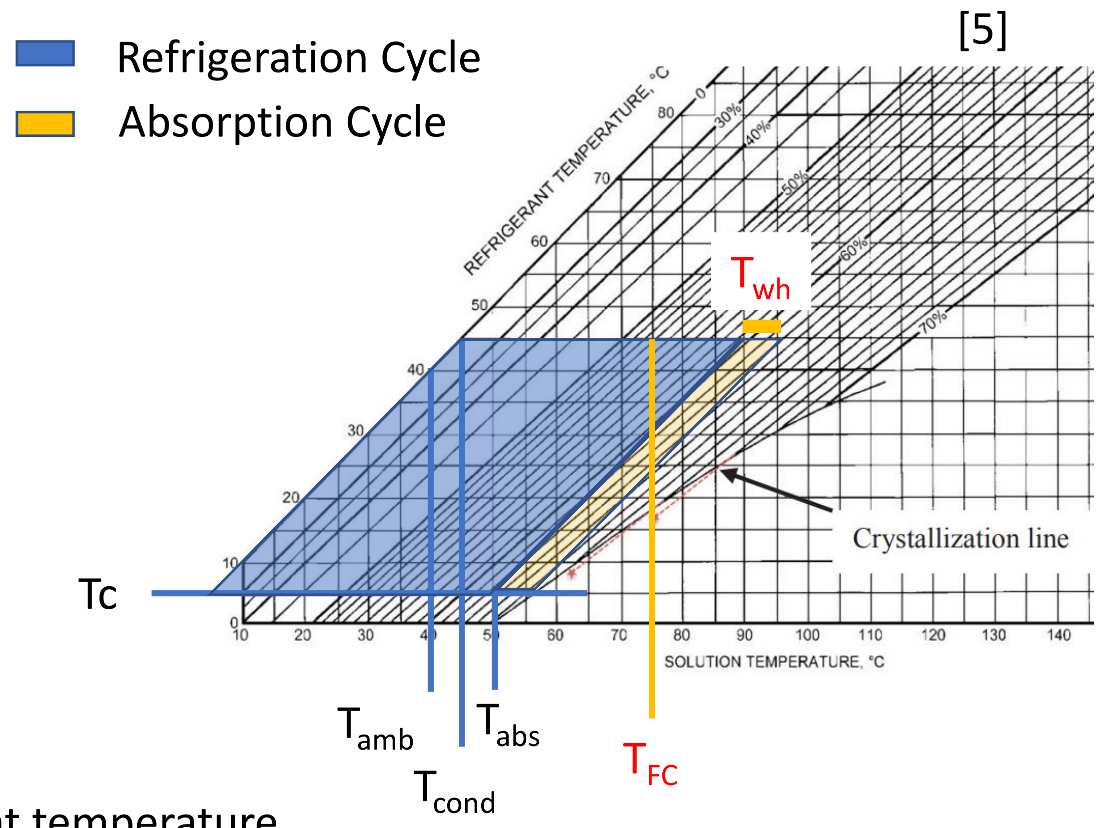
Absorption Refrigerator

standard cycle - LiBr

Process / Material constraints	
Cooling temperature	T_c = 5°C
Maximum ambient temperature	T_{amb} = 40 °C
Minimum condenser temperature	T_{cond} = 45°C
Minimum absorber temperature	T_{abs} = 50° C
Waste heat temperature range	T_{wh} = 97 °C – 105 °C
Fuel cell waste heat temperature	T_{FC} = 75 °C



Fuel cell temperature is below minimum waste heat temperature
Standard cycle is not feasible with fuel cell waste heat temperature

4) M. Kordel (2022) „D1.6 - Report on concept, draft design and preliminary simulation requirements", FCH2Rail

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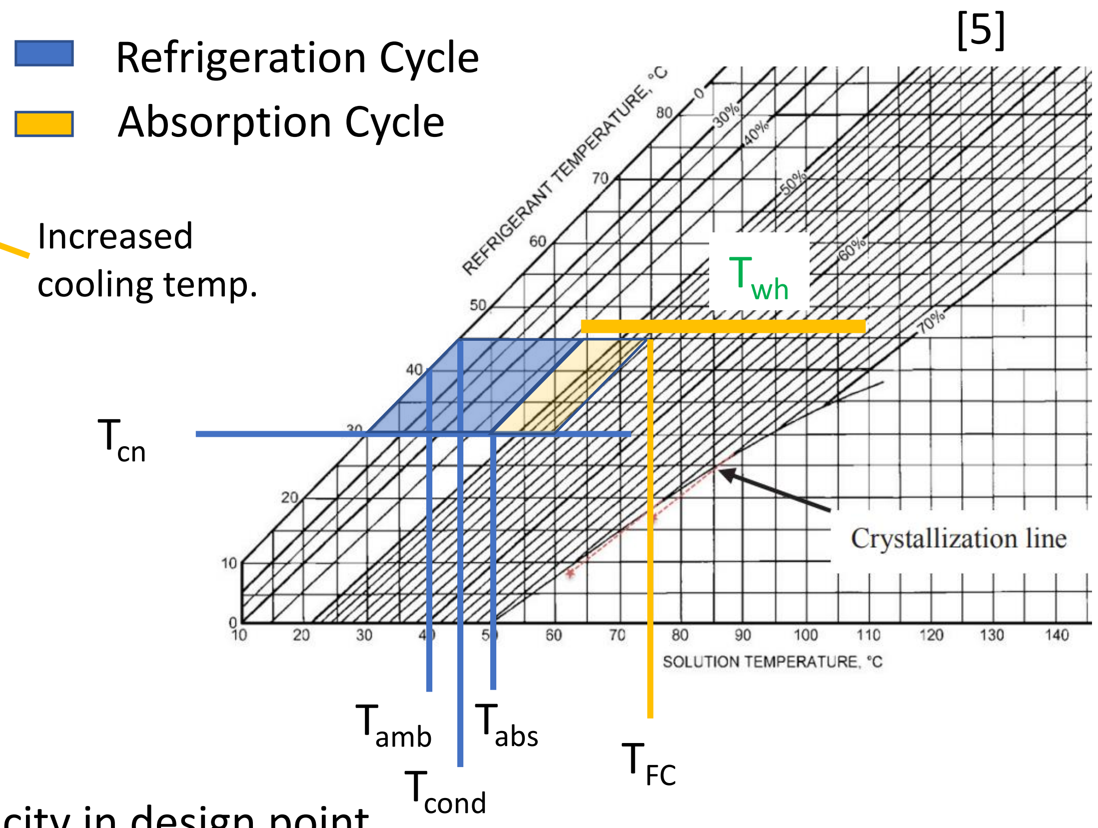
Absorption Refrigerator

improved cycle - LiBr

Process / Material constraints	
Cooling temperature new	T_{cn} = 30°C
Maximum ambient temperature	T_{amb} = 40 °C
Minimum condenser temperature	T_{cond} = 45°C
Minimum absorber temperature	T_{abs} = 50° C
Waste heat temperature range	T_{wh} = 65°C – 105°C
Fuel cell waste heat temperature	T_{FC} = 75 °C



Improved absorption AC cycle provide cooling capacity in design point
Combination with Vapor Compression Refrigerator System is necessary

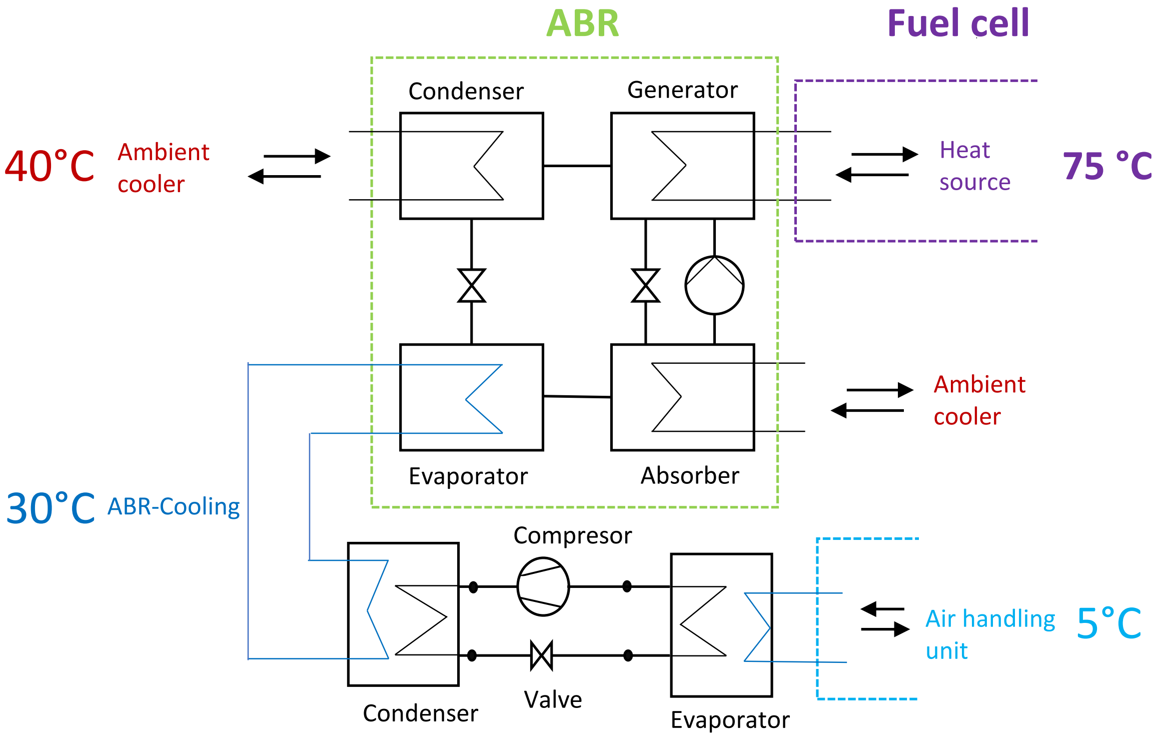
4) M. Kordel (2022) „D1.6 - Report on concept, draft design and preliminary simulation requirements", FCH2Rail

Absorption Refrigerator

new concept

- With this fuel cell system, the absorption refrigerator can operate in a cascade with a VCRS
- 77 % of the time, the waste heat is above 58 kW and the absorption refrigerator can provide the cooling capacity in design point

- Concept in design point is defined
- Next Steps: Annual energy savings in different climate zones



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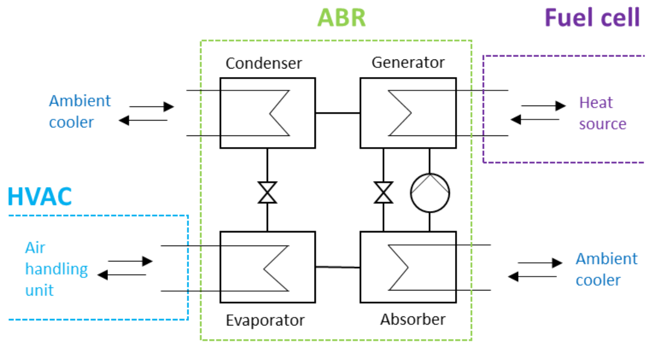
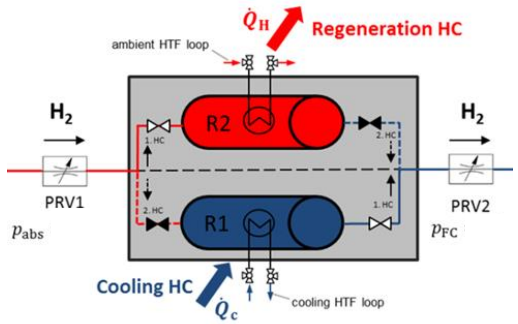
Technologies for Waste Energy Usage

Absorption Refrigerator



HyPAC (H2 Compression work)



- 2 Metal-Hydride reactors
- Absorption of high pressure H2 from hydrogen tank ➔ Heat
- Desorption at low pressure towards fuel cell ➔ Cold
- Switching between absorption and desorption when desorption pressure is below threshold (8.5 bar)

➔ Pressure difference between tank and fuel cell will be used to provide cooling capacity

Constraints:

- Tank pressure and fuel cell pressure
- Ambient temperature
- Hydrogen mass flow and dynamics

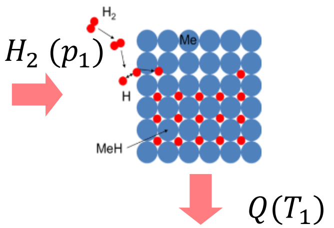
HyPAC
state of the art

Material Characteristics

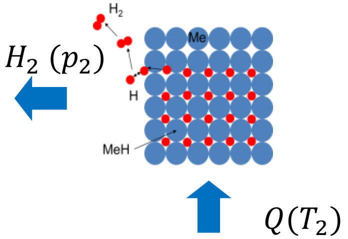
$$\ln\left(\frac{p_{eq}}{p_0}\right) = \frac{\Delta H_{abs/des}}{R \cdot T_{EQ}} + \frac{\Delta S_{abs/des}}{R}$$

$$\dot{Q}_{abs/des} = \frac{\dot{m}_{H_2}}{M_{H_2}} \cdot \Delta H_{abs/des}$$

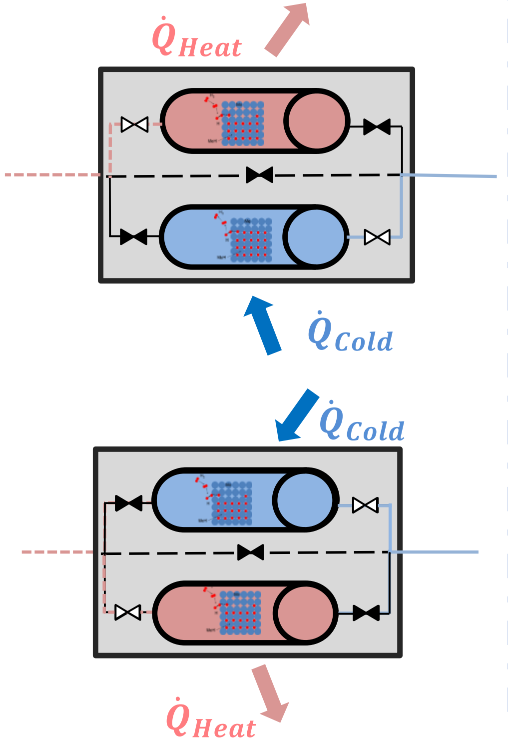
Absorption:



Desorption:

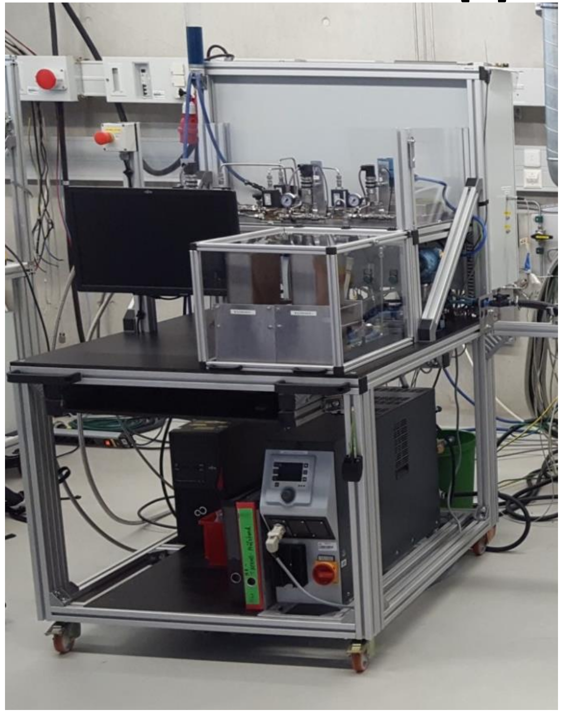


Operating Principle



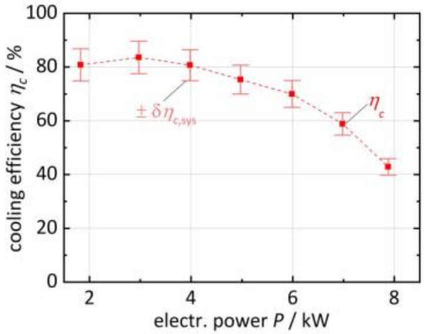
Test Bench

[5]



Test Bench – Efficiency

[5]



5) C. Weckerle (2020) *"A metal hydride air-conditioning system for fuel cell vehicles."*

Capability is temperature and pressure dependent
An established material was selected for FCH2Rail

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HyPAC

standard cycle

Process / Material constraints	
Cooling Temperature requirement	$T_c = 5°C$
Optimal Fuel Cell Inlet Pressure	$p_{FC0} = 6$ bar
Maximum ambient temperature	$T_{amb} = 40°C$
Minimum recool temperature	$T_{rec} = 45°C$
Minimum tank pressure	$p_{abs} = 50$ bar
Actual Fuel Cell Inlet Pressure in FCH2RAIL	$p_{FC} = 8.5$ bar

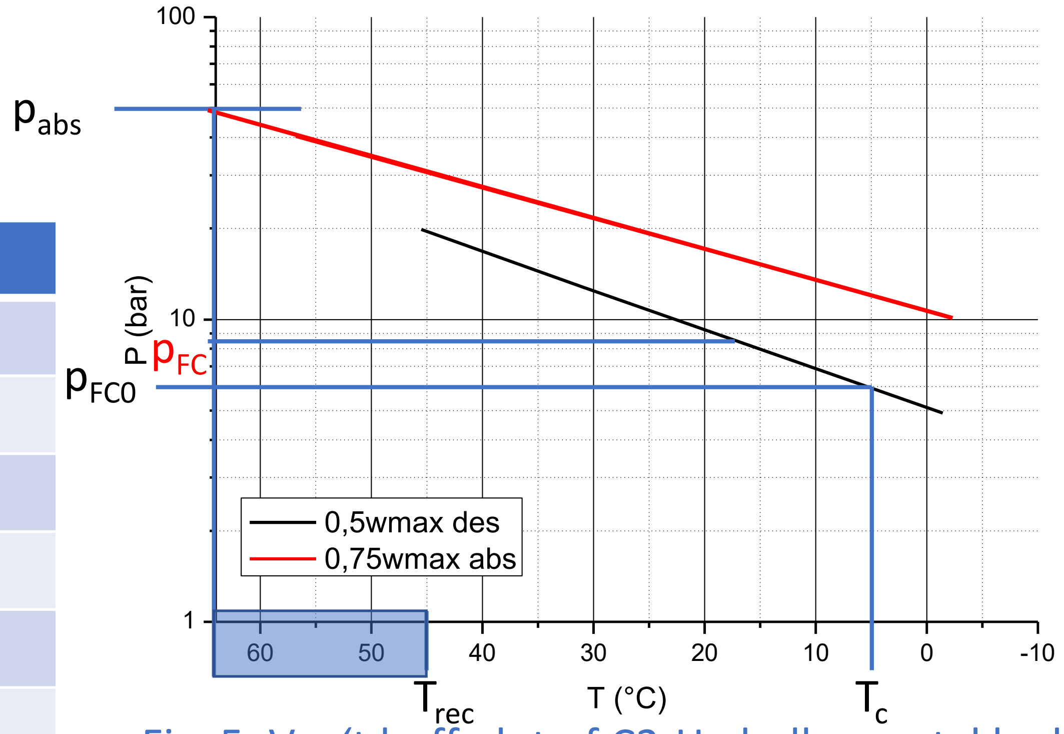


Fig. 5: Van't hoff plot of C2-Hydralloy metal hydride [5]

Fuel cell pressure is above optimal fuel cell inlet pressure
Standard cycle is not feasible with fuel cell pressure

$$\ln\left(\frac{p_{GG}}{p_0}\right) = \frac{\Delta H_{abs/des}}{R \cdot T_{GG}} + \frac{\Delta S_{abs/des}}{R}$$

5) C. Weckerle (2020) *"A metal hydride air-conditioning system for fuel cell vehicles."*

HyPAC

improved cycle

Process / Material constraints	
Cooling Temperature new	T_{cn} = 18.5°C
New Fuel Cell Inlet Pressure	p_{FC}= 8.5 bar
Maximum ambient temperature	T_{amb} = 40°C
Minimum recool temperature	T_{rec} = 45°C
Minimum tank pressure	p_{abs} = 50 bar
Actual Fuel Cell Inlet Pressure in FCH2RAIL	p_{FC} = 8.5 bar

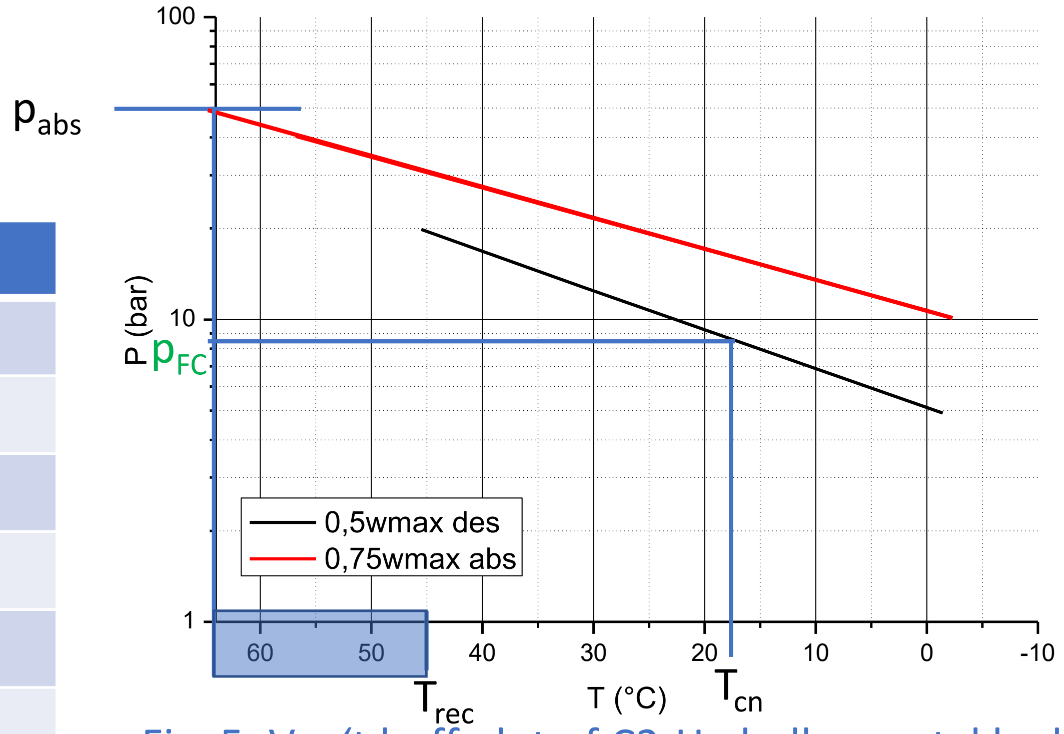


Fig. 5: Van't hoff plot of C2-Hydralloy metal hydride [5]

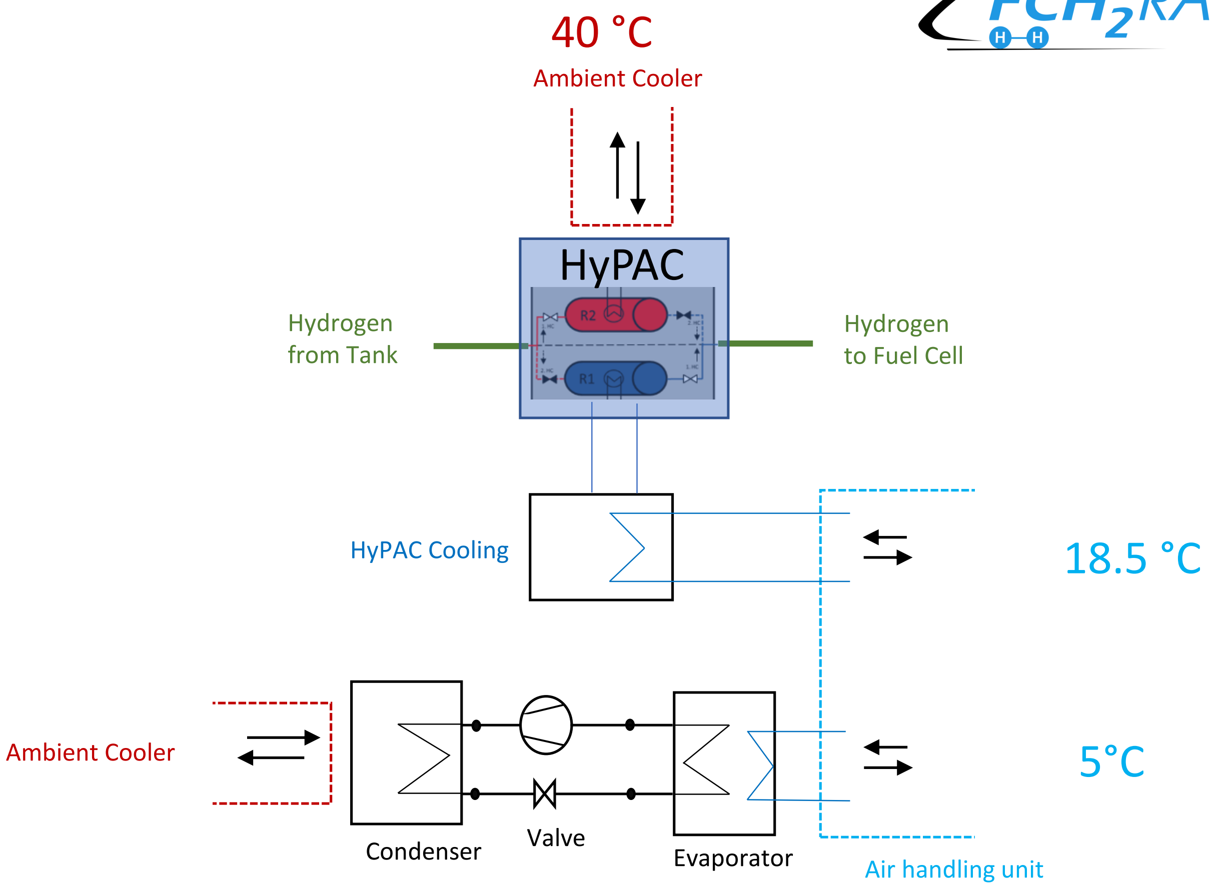
Improved HyPAC cycle can provide cooling capacity in design point
Combination with VCRS is necessary

5) C. Weckerle (2020) *"A metal hydride air-conditioning system for fuel cell vehicles."*

HyPAC
new concept

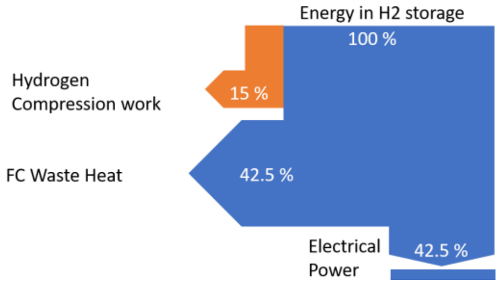
- Combination with VCRS is necessary to cover all operating points
- With 3.9 g/s (H_2) 32 kW cooling capacity can be provided
- 32 % of the time the Hydrogen massflow is above 3.9 g/s

- Concept in design point is defined
- Next Steps: Annual energy savings in different climate zones and for part load operating

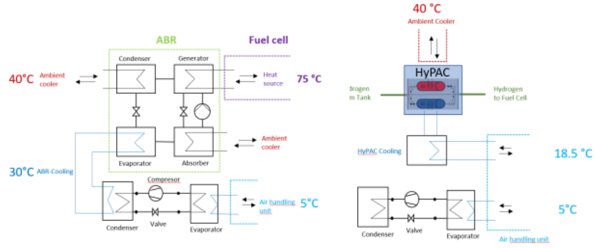


→ 32 % of the time, cooling capacity can be reduced by up to 32 kW
For the FCH2Rail scenario, 70.7 kWh cooling energy can be saved (35.6 kWh electrical)

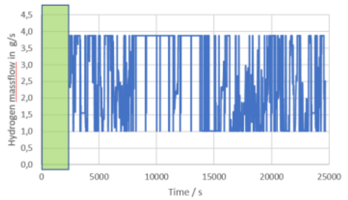
Summary and Outlook

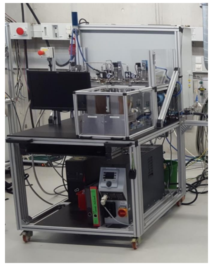


- Waste heat and pressure energy is currently unused on rolling stock



- Design concept for Absorption AC and HyPAC in FCH2Rail FC train has been developed
- Absorption AC (LiBr) can support VCRS 77 % of the time in selected use case





- HyPAC can reduce up to 32 % cooling capacity in design point

Outlook

- Detailed simulations in different climate zones
- Calculation of potential annual energy reduction for both technologies
  - ➔ Part load

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Thank you for your attention

www.fch2rail.eu

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