CMT Research Institute (UPV)

H2-FCS Experimental Activities

CMT Presentation

June 2024

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CMT-Clean Mobility & Thermofluids

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CONTENTS

1. Introduction and motivation

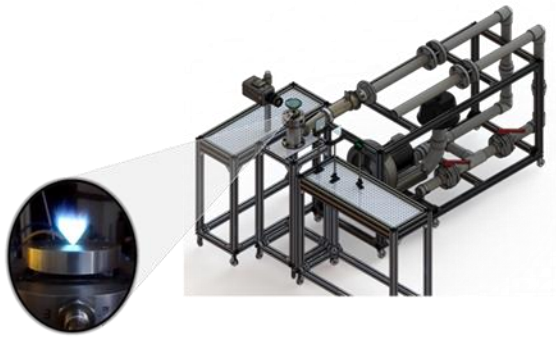
- Basic knowledge generation
- Systems analysis and evaluation
- Systems integration and optimization
- Final solution evaluation (LCA/TCO)
- Knowledge transfer to industry & society

KEY R & D & I TOPICS OF INTEREST:

- Hydrogen (FC / ICE / GT)
- Fuel cell systems (Propulsion / Energy Generation)
- Battery systems (Electrical-Thermal Performance)
- Internal combustion engines (ICE)
- Gas turbines (GT)
- Bio-fuels / e-fuels (ICE / GT)
- Oxy-combustion (ICE / GT)
- Powertrain hybridization / electrification
- Fluid Structure Interaction (FSI)
- Biotechnology

1. Introduction and motivation

H2 Research division at CMT

	ICE	GT	FC
Key experimental environment			
Target application	Transportation (road & marine) Power generation	Transportation (aero) Power generation	Transportation (road & aero) Power generation

1. Introduction and motivation

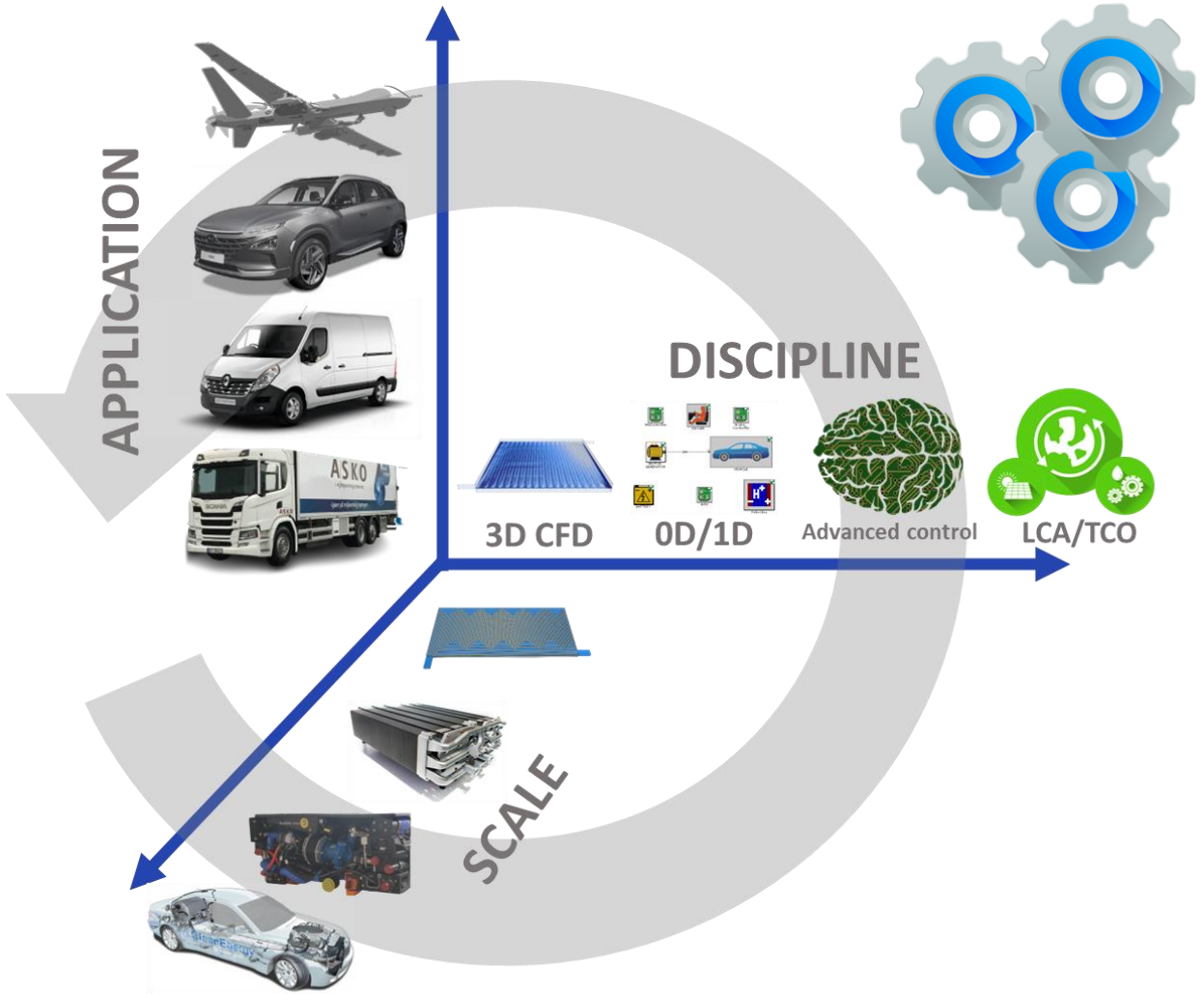
How can the **fuel cell** technology be **improved?**

How should **fuel cell powertrains** be **designed** and **controlled**?

What is the **actual performance** and **durability** of fuel cell vehicles?

What is the **environmental impact** and **cost** of fuel cell vehicles?

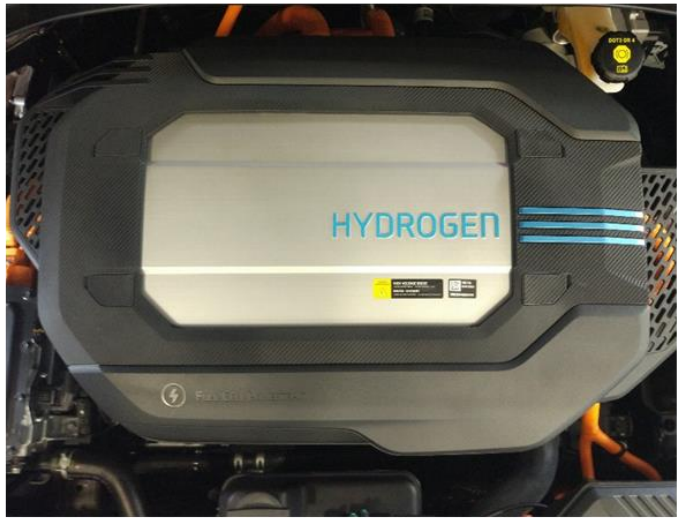
What are the **benefits** of fuel cell technology **compared to other propulsion systems**?



1. Introduction and motivation

Experimental framework

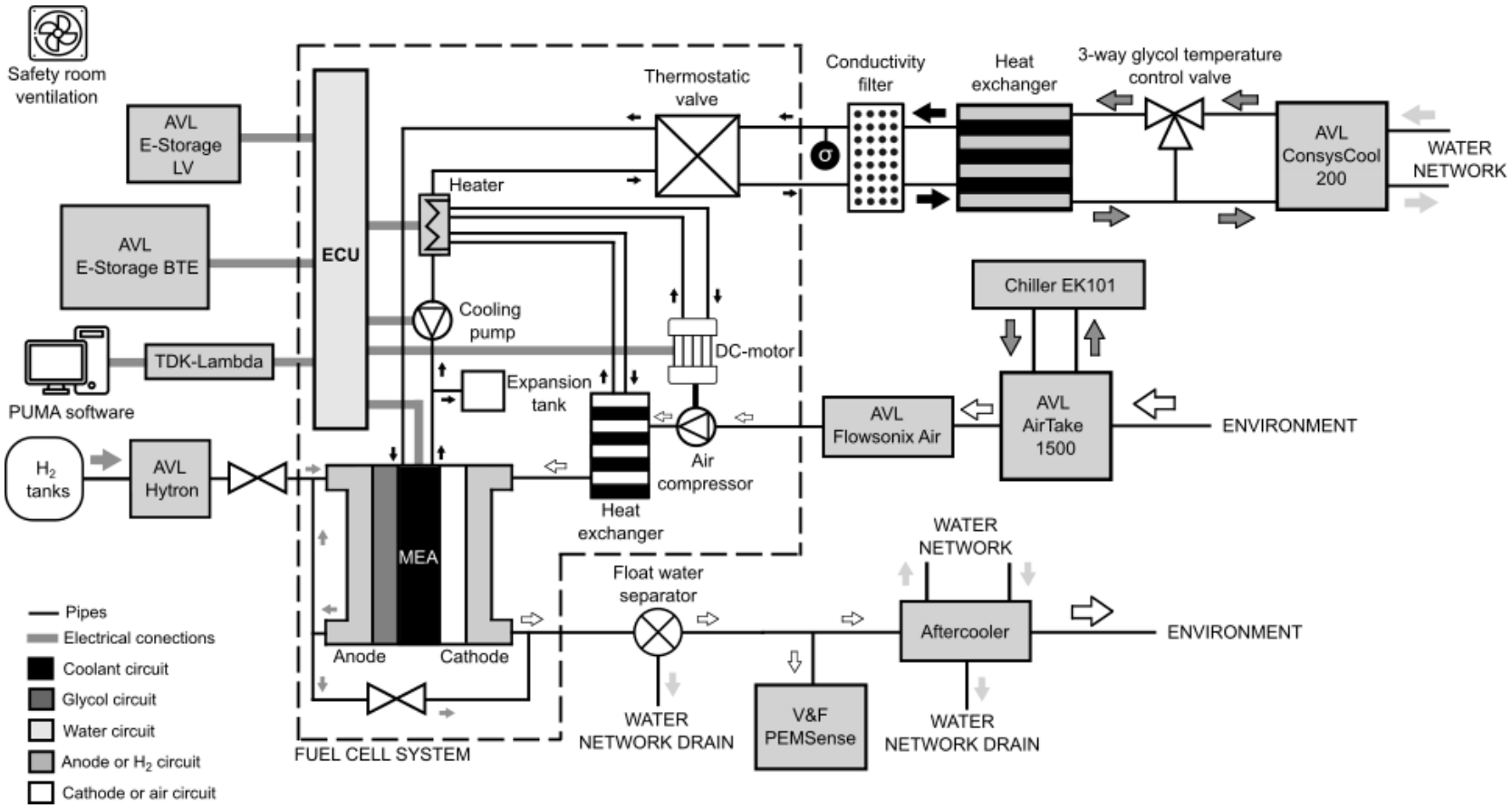
- Hybrid power plant test bench.
- H_2 generation hydrolyser.
- Fuel cell test bench.
- Fuel cell automotive platform.
- Battery thermal issues / runaway test facilities.
- Oxy-fuel combustion single cylinder engine.
- H_2 combustion single cylinder engines.
- Pressurized continuous burner (multi-fuel).
- Large wind tunnel.



2. Experimental research framework

Advanced testing equipment

- **Performance tracking**
- Ambient **T** and **RH** control
- Coolant **conductivity** control
- Tracking of **inlet** and **outlet species**



2. Experimental research framework

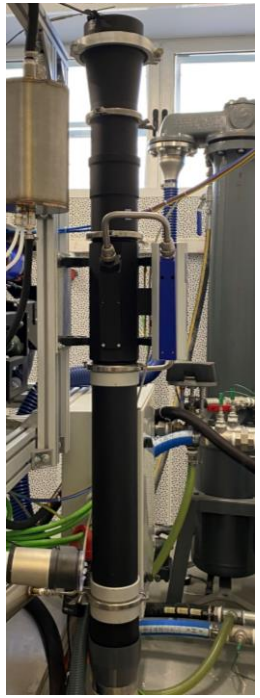
Control of the inlet species

Anode

HyTron

Cathode

Flowsonix



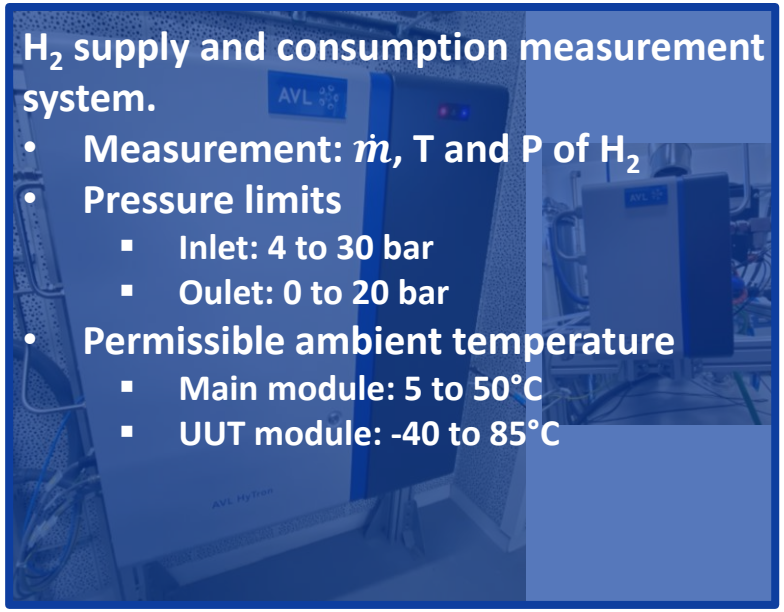
Air Take (AT1500)

2. Experimental research framework

Control of the inlet species

Anode

HyTron

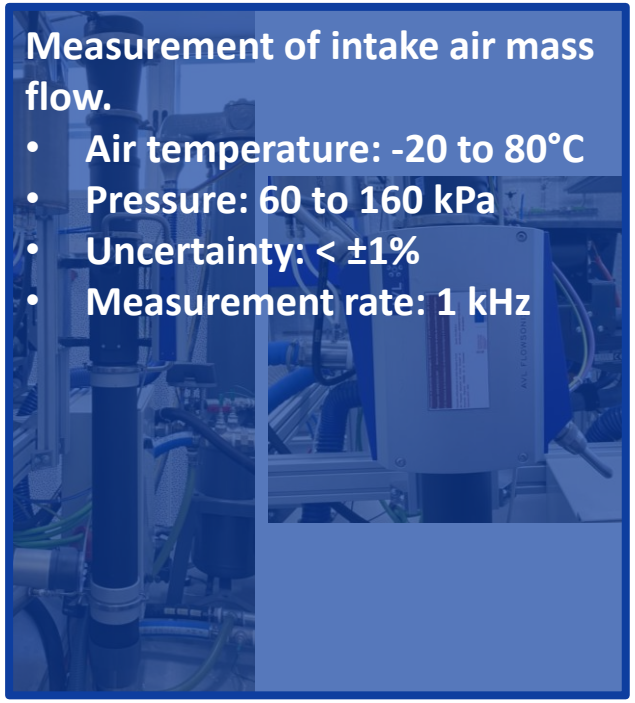


H_2 supply and consumption measurement system.

- Measurement: $\dot{m}$, T and P of H_2
- Pressure limits
  - Inlet: 4 to 30 bar
  - Oulet: 0 to 20 bar
- Permissible ambient temperature
  - Main module: 5 to 50°C
  - UUT module: -40 to 85°C

Cathode

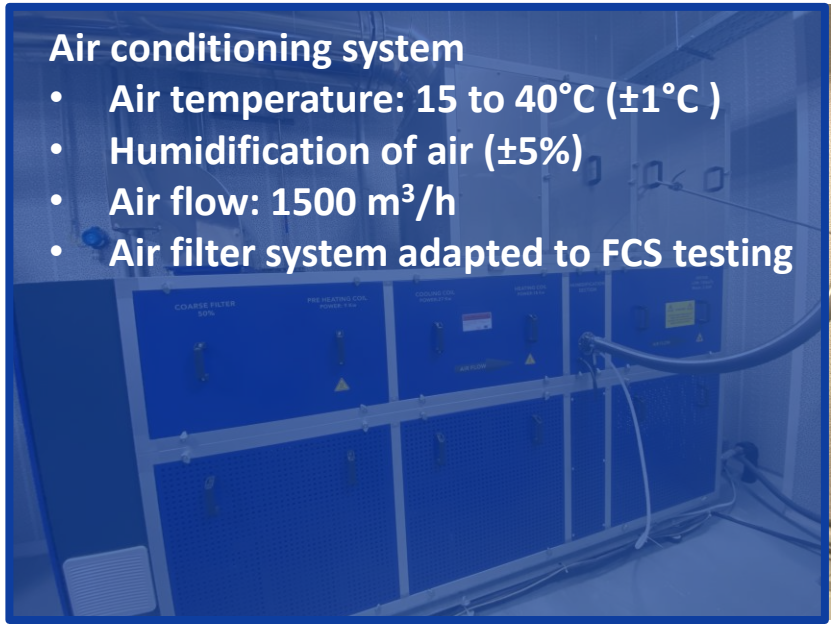
Flowsonix



Measurement of intake air mass flow.

- Air temperature: -20 to 80°C
- Pressure: 60 to 160 kPa
- Uncertainty: < ±1%
- Measurement rate: 1 kHz

Air Take (AT1500)



Air conditioning system

- Air temperature: 15 to 40°C (±1°C)
- Humidification of air (±5%)
- Air flow: 1500 m^3/h
- Air filter system adapted to FCS testing

2. Experimental research framework

Control of the operating parameters

Consyscool 200

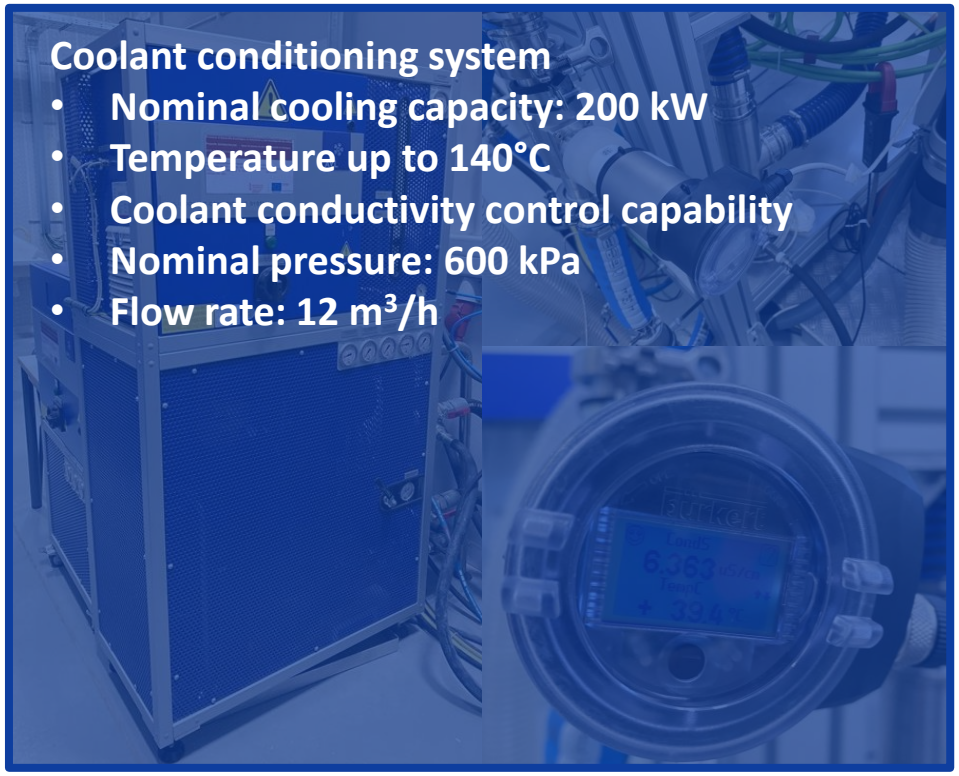
eStorage BTE

eStorage LV

2. Experimental research framework

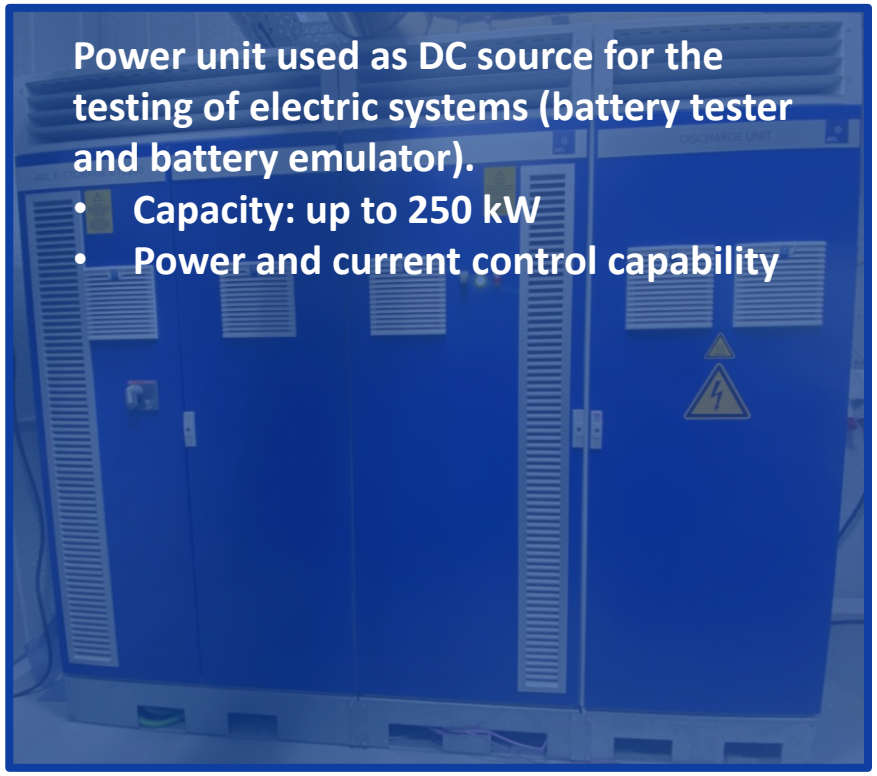
Control of the operating parameters

Consyscool 200



Coolant conditioning system
- Nominal cooling capacity: 200 kW
- Temperature up to 140°C
- Coolant conductivity control capability
- Nominal pressure: 600 kPa
- Flow rate: 12 m^3/h

eStorage BTE



Power unit used as DC source for the testing of electric systems (battery tester and battery emulator).
- Capacity: up to 250 kW
- Power and current control capability

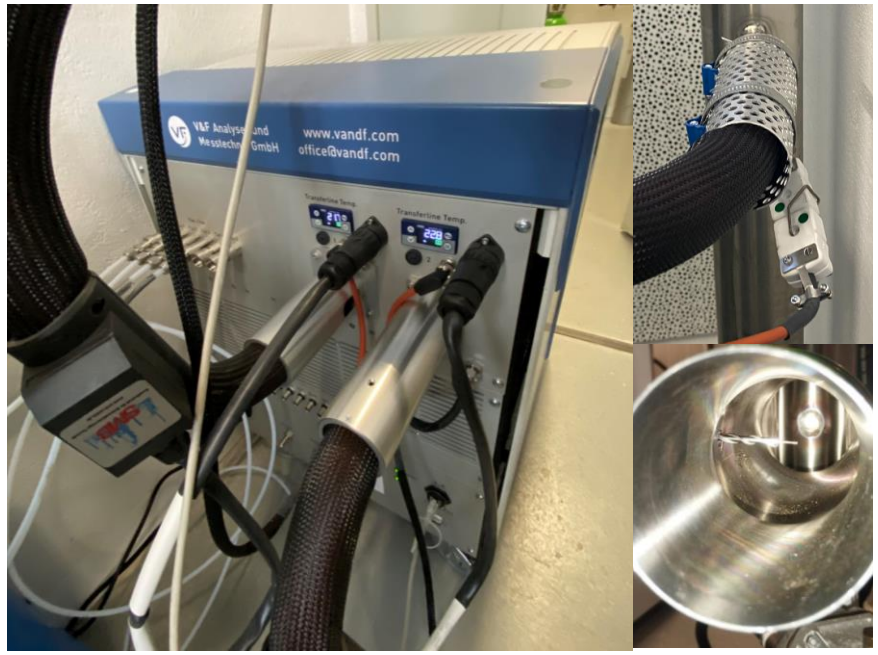
eStorage LV

Power unit used to supply the power required by the BoP systems.
- Supply voltage: 500 V
- Frequency: 500 Hz

2. Experimental research framework

Analysis of the outlet species

PEMSense



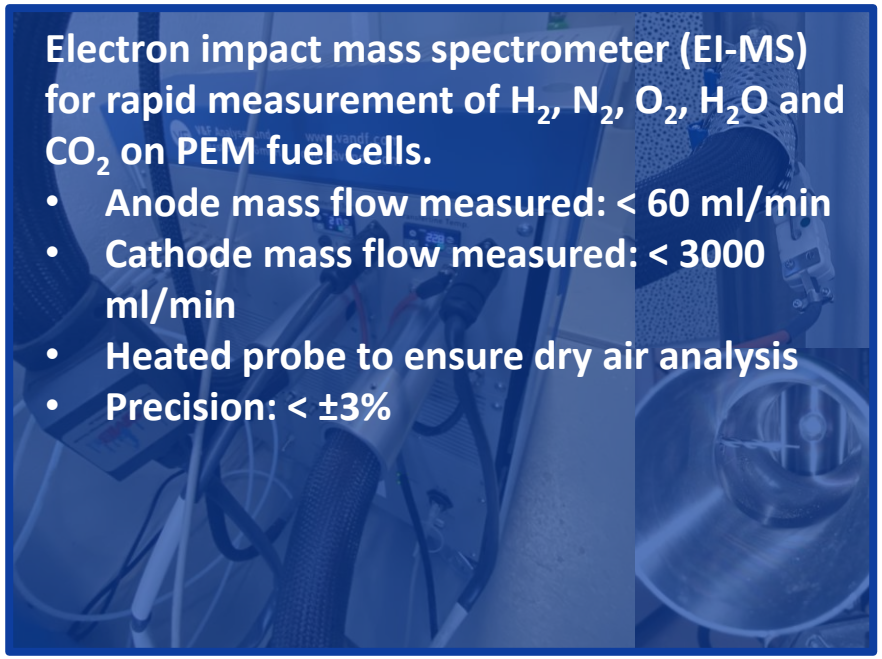
Research capabilities

- ***Steady*** analysis of consumption and system efficiency
- Advanced ***dynamic tracking*** of the outlet cathode species
- Understanding of ***crossover*** phenomena in the cell
- Evaluation of passive ***humectation/purge strategies*** and safety compliance analysis (H_2 conc. At the cathode exhaust)
- Optimization of the ***cathode stoichiometry*** for performance improvement
- Analysis of specific ***key procedures*** as start-up and shutdown
- Study of the ***H_2*** mass flow ***recirculation*** to the anode

2. Experimental research framework

Analysis of the outlet species

PEMSense



Research capabilities

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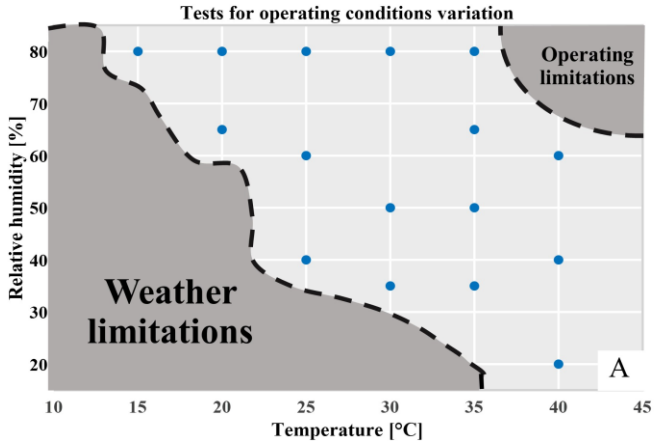
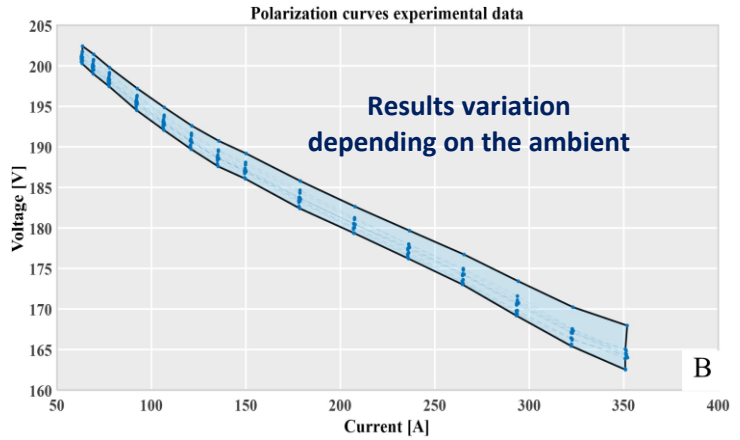
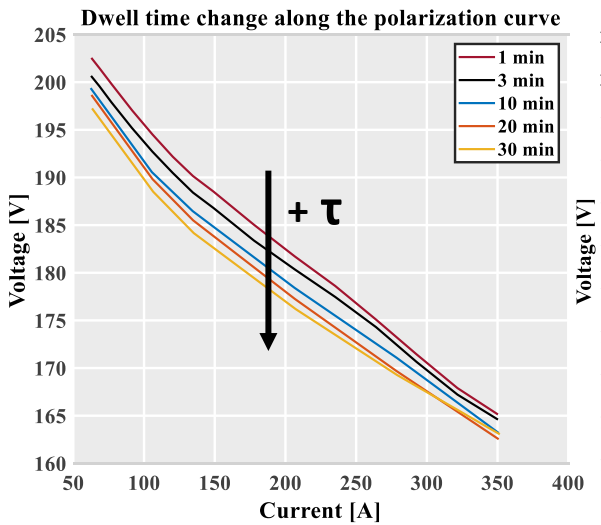
3. Testbench performance

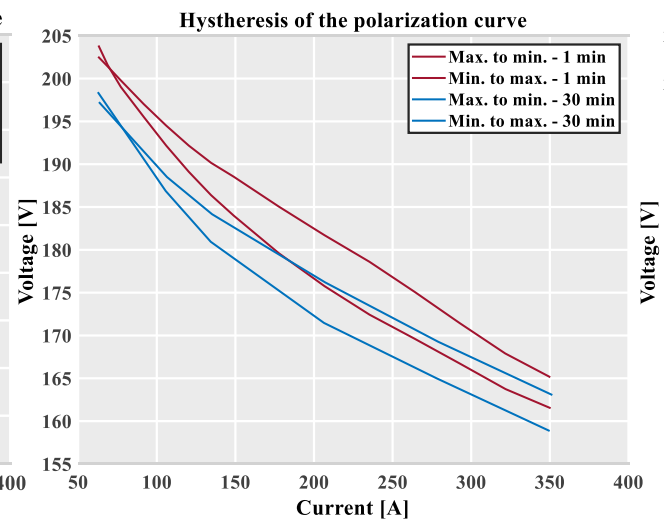
Steady-state research activities

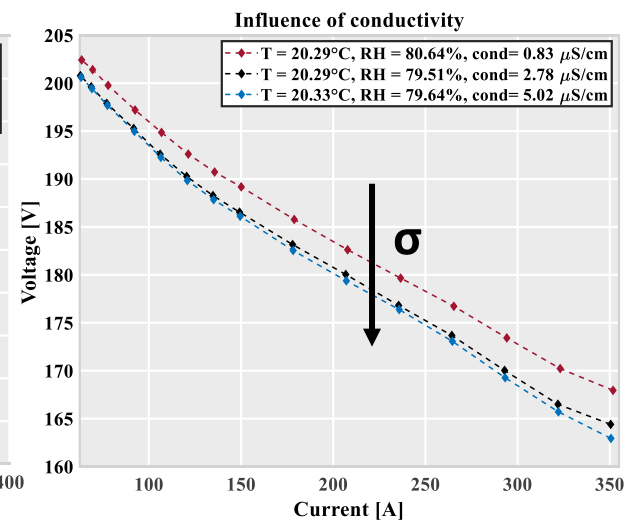
- Analysis of the influence of ambient conditions
  → Air ***temperature*** and ***humidity***
- Steady-state performance study
  → ***Dwell time*** variations
- ***Hysteresis*** study of the polarization curve
- Influence of the ***coolant conductivity*** on the performance of the system
- Study of the ***FCS decay with the operating time*** (start-up and shutdowns)

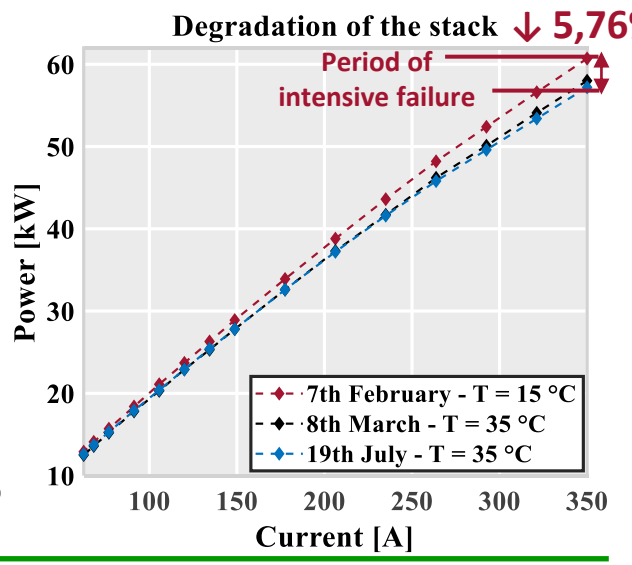










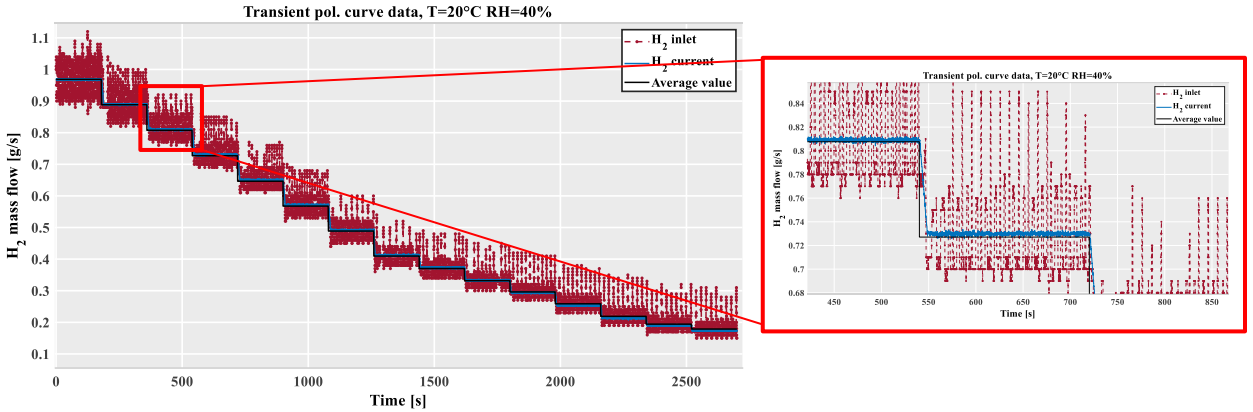


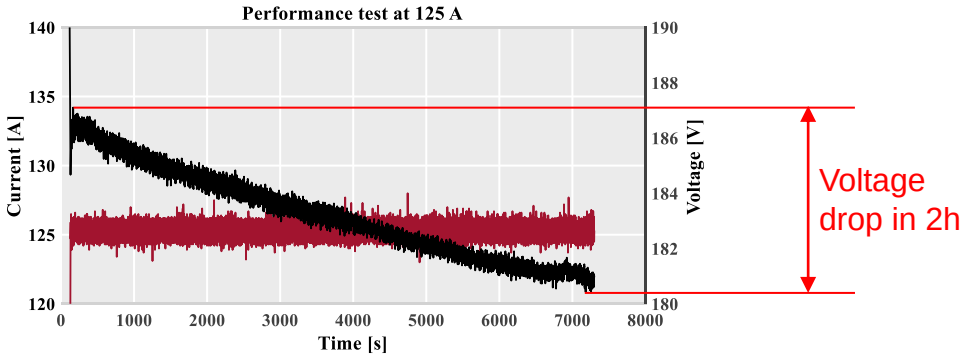
3. Testbench performance

Study of the dynamic performance

Transient analysis of steady-state measurements (**pol. curve**)

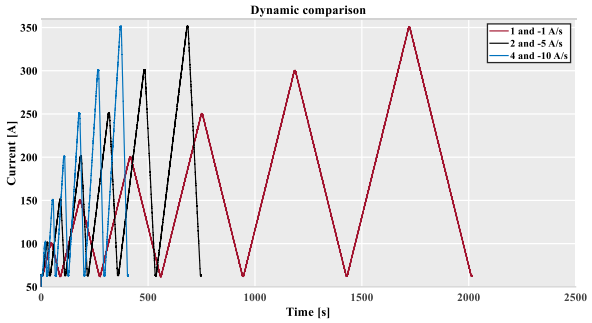
- → Optimization of the purging strategy
- → Analysis of the loss of performance along time

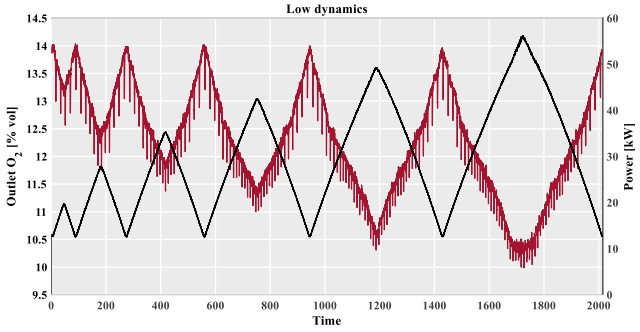


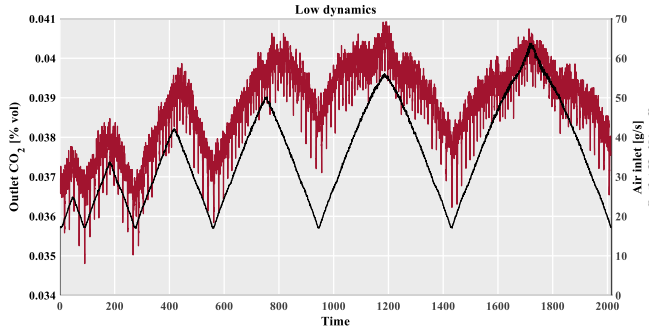


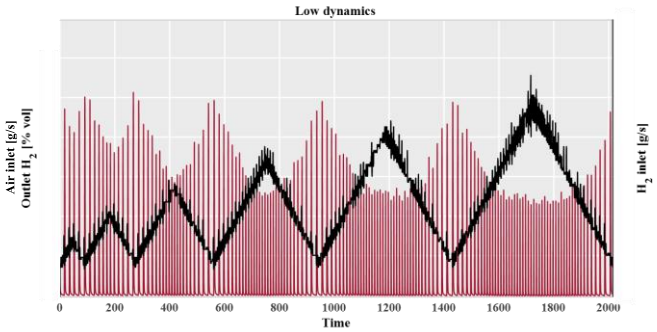
Comparison of **different dynamic levels**

- → Impact on the overall performance (efficiency and consumption)
- → Capability of the FCS key parameters to follow the required performance (T_{stack}, $\dot{m}$, P_{FCS}…)
- → **Influence on the cathode species**
  - % CO_2: degradation
  - % H_2: safety (regulation) compliance



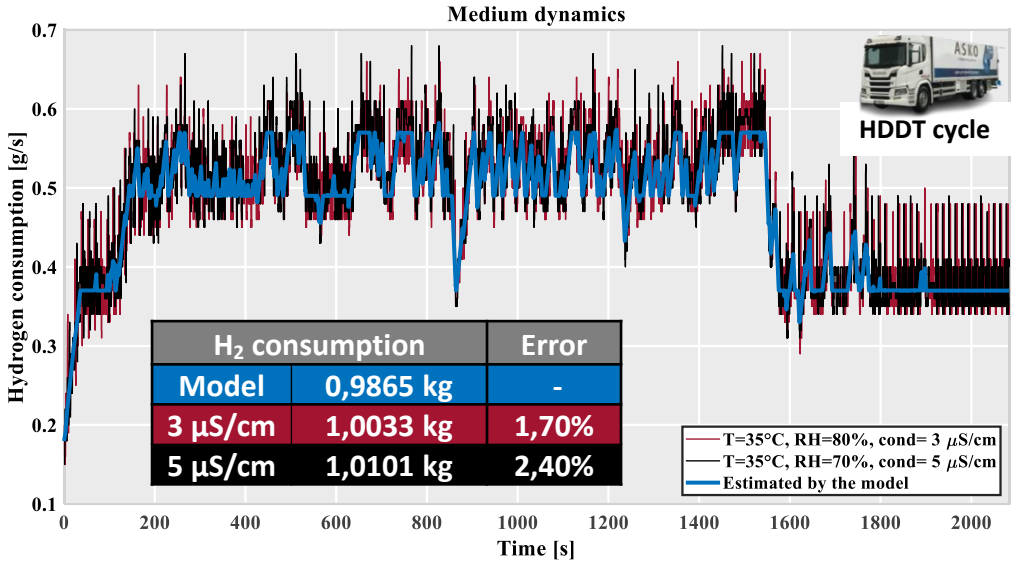






3. Testbench performance

Driving conditions testing

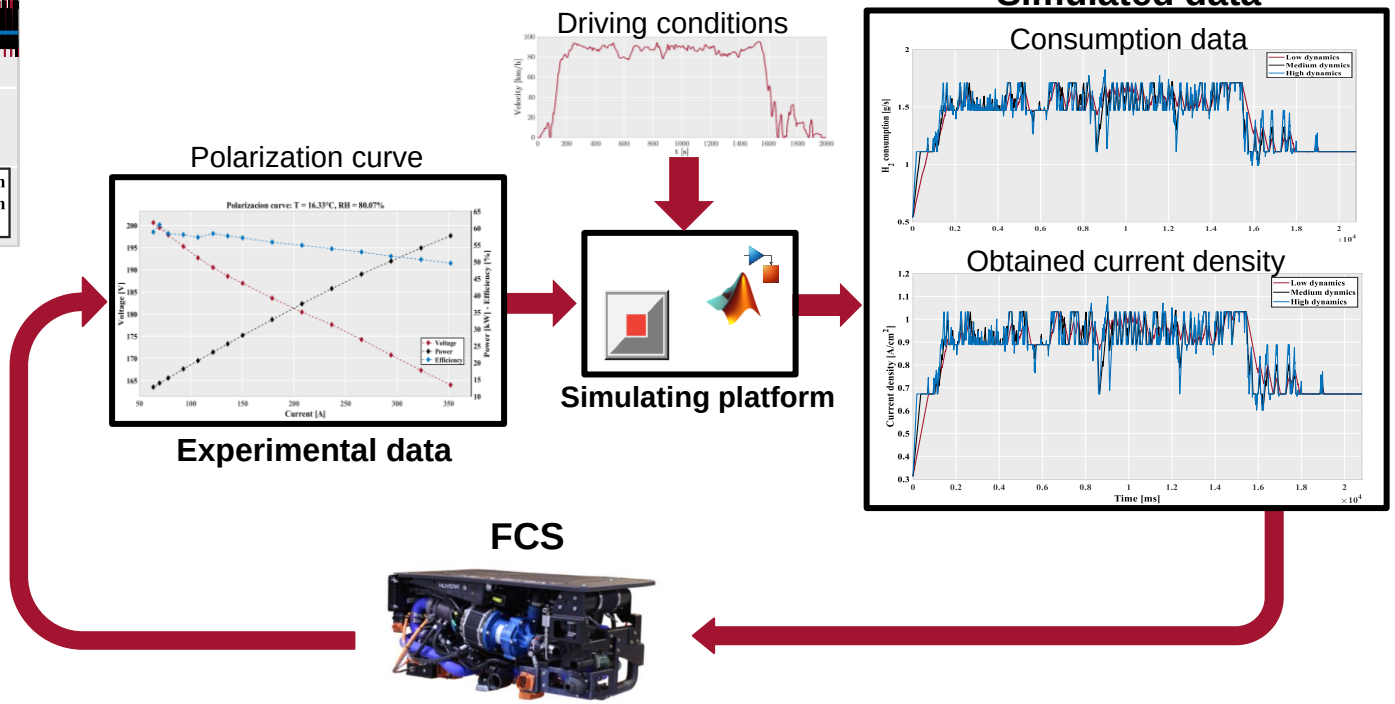


H_2 consumption		Error
Model	0,9865 kg	-
3 µS/cm	1,0033 kg	1,70%
5 µS/cm	1,0101 kg	2,40%

Testing of the FCS performance

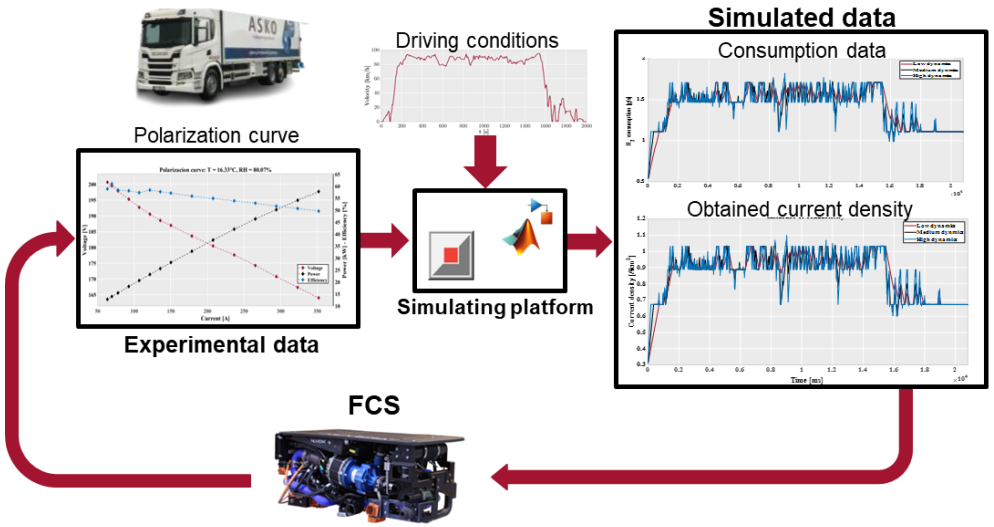
- Standarized driving cycles (HDDT, WLTC…)
- Real driving routes (i.e. TEN-T routes)

Results validation → MATLAB-Simulink tool



4. H_2 losses estimation

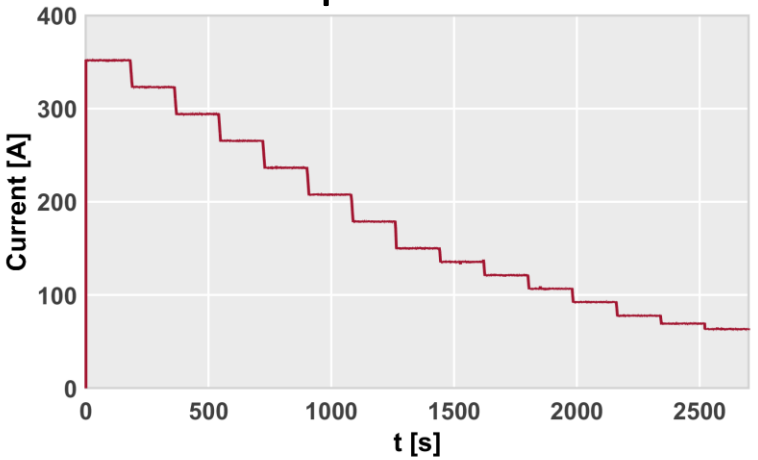
Methodology: realistic driving testing



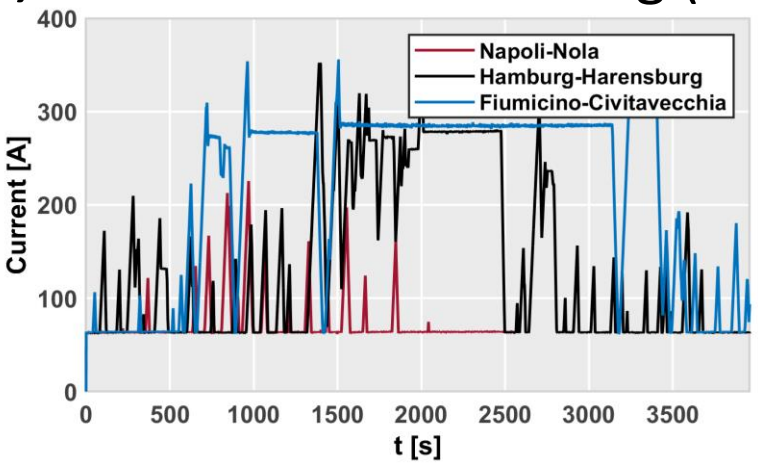
FCS: 4x60 kW; **Batt.:** 73,2 kWh; **HDV**: 4LH;

	Scenario 2	Scenario 3	Scenario 4
Route	Napoli-Nola	Hamburg-Harensburg	Fiumicino-Civitavecchia

Scenario 1: polarization curve



Scenario 2, 3 and 4: realistic driving (TEN-T routes)

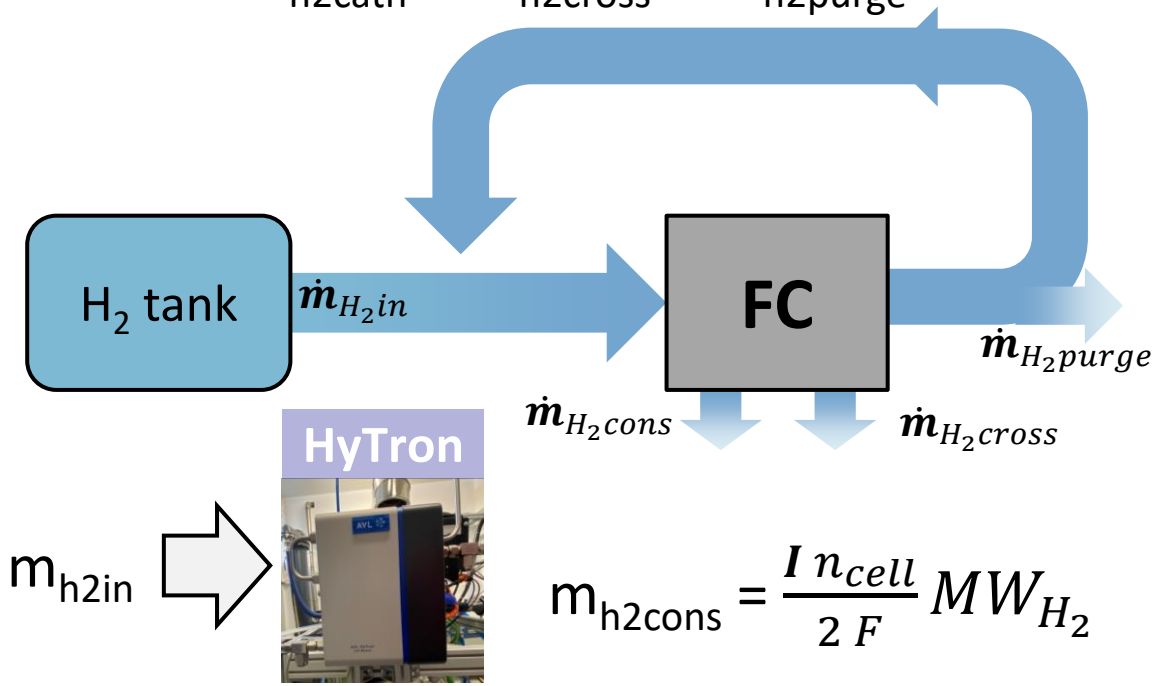


4. H_2 losses estimation

Approach 1: mass balance

$$m_{h2in} - m_{h2cons} = m_{h2cath}$$

$$m_{h2cath} = m_{h2cross} + m_{h2purge}$$



$$m_{h2cons} = \frac{I\, n_{cell}}{2\, F} MW_{H_2}$$

Disadvantage: accuracy of devices

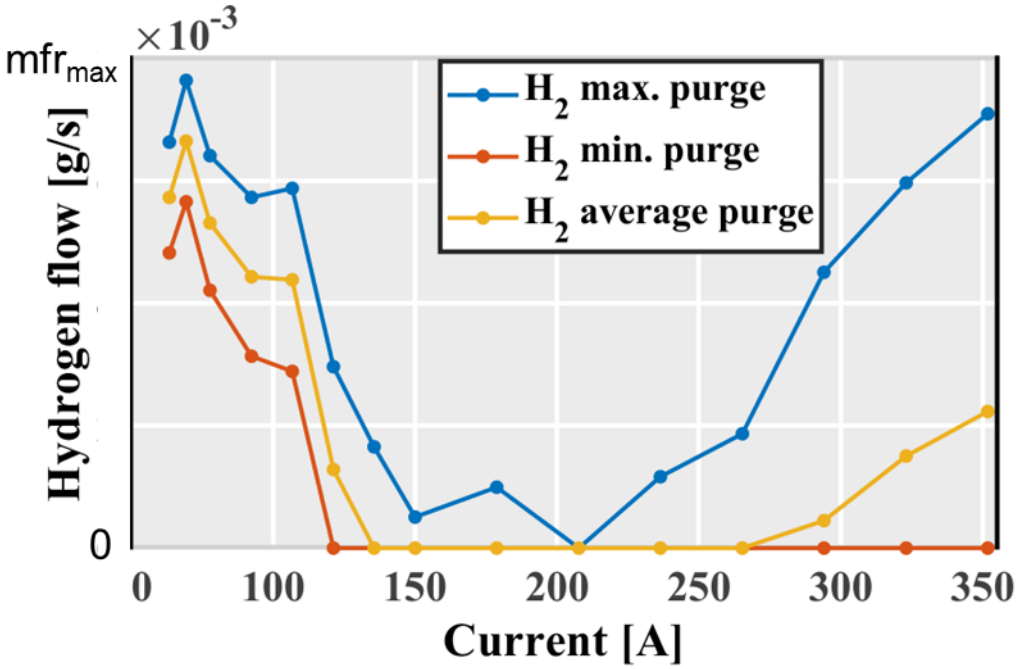
Approach 2: cathode outlet species measurement

PEMSense: high-frequency concentration analyzer

Disadvantage: outlet MFR is estimated

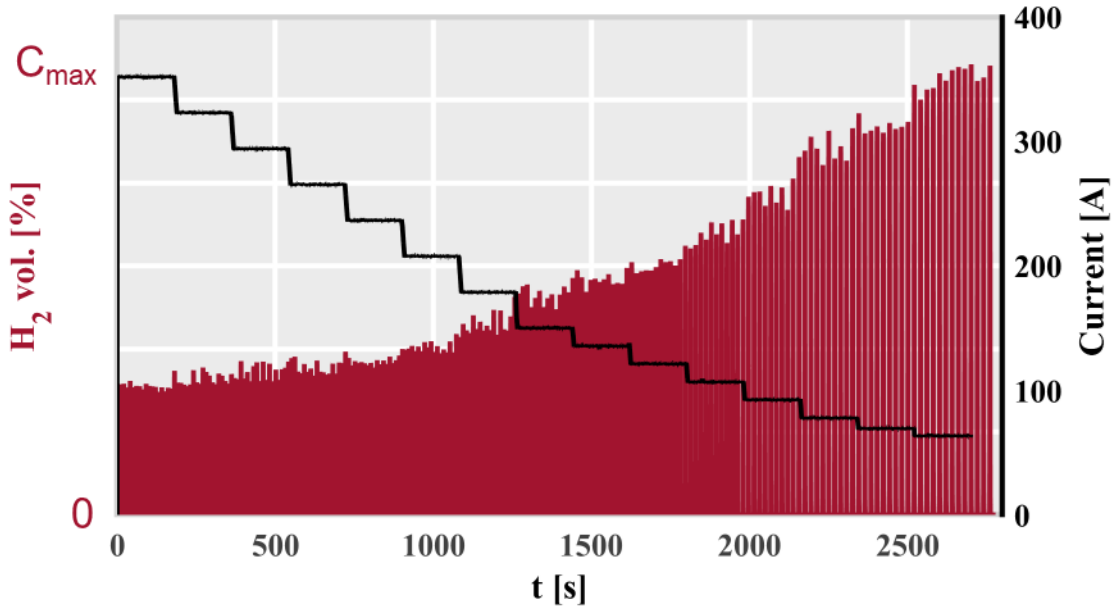
4. H_2 losses estimation

Approach 1: mass balance



Outcome: range

Approach 2: cathode outlet species measurement



Outcome: single value

4. H_2 losses estimation

Results:

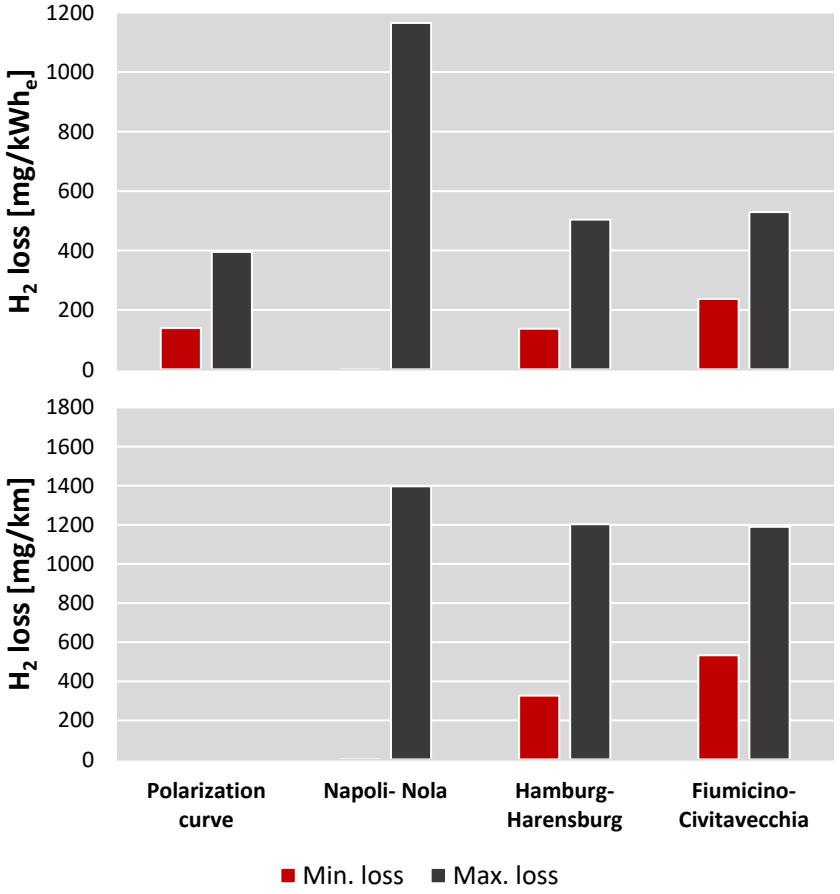
Energy-based

1-1165 mg/kWh

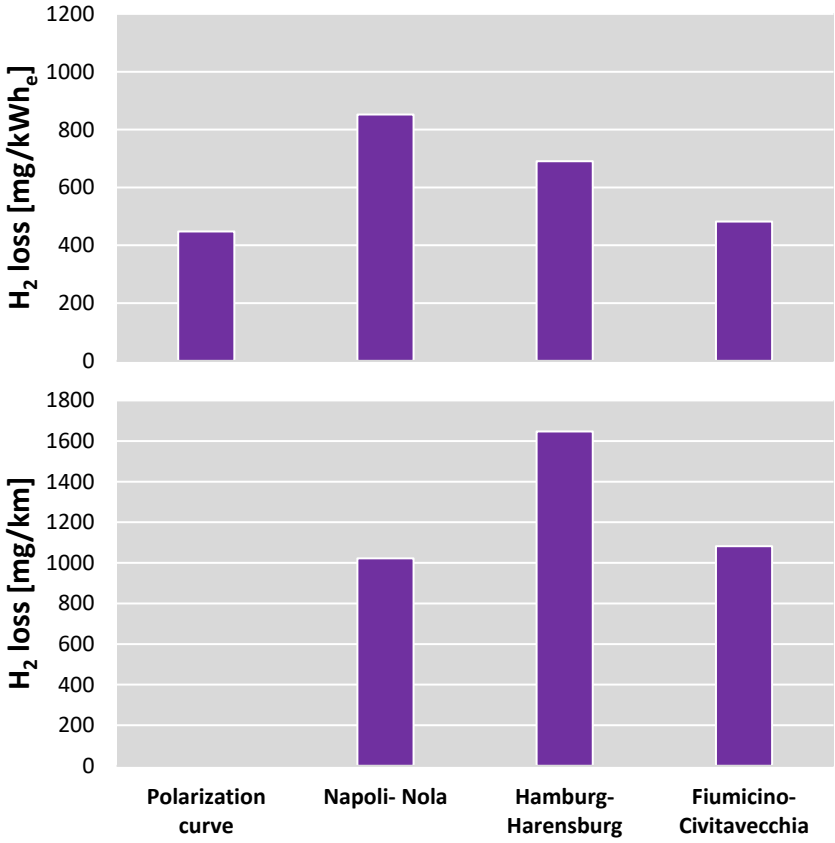
Distance-based

1-1647 mg/km

Approach 1



Approach 2



4. H_2 losses estimation

Conclusions

- There is not currently a standardized method to quantify H2 emissions in FCS
- H_2 loss (emissions) are highly dependent on how the FCS is operated, thus it depends on:
  - **Application** → Defines the load demand
  - **Control strategy** → Defines the FCS current evolution
  - **FC technology** → Defines the purge strategy and H2 crossover
- With the current results, the H_2 emissions in realistic driving for a group 4 HDV are:

	Approach 1	Approach 2
H_2 loss [mg/kWh]	1-1165	448-852
H2 loss [mg/km]	1-1397	1022-1647

- Results of mg/kWh_e could be used for other applications
- Approach 2 seems more accurate but needs refinement (MFR measurement at cathode outlet)

5. Potential collaboration activities

- Optimization of the balance of plant control and components design for maximum efficiency
- Support in the design of humectation strategies for anode and cathode circuits
- Development and evaluation of high-power FCS concepts up to 200 kW
- Analysis of the actual FCS performance in realistic and standardized driving cycles (HDDT/VECTO) with software-in-the-loop heavy-duty vehicles and different powertrain architectures
- Identification and improvement of the FCS dynamic limitations by means of component and cathode exhaust species tracking analysis
- Support in developing anode purge strategies in steady-state and dynamic operation, including start-up, to comply with safety regulations (H_2 concentration at cathode exhaust)
- Identify FCS compatibility with different applications (rail, maritime, aerospace…) and powertrain architectures
- FCS altitude testing (mid-term)
- **Other… CMT always considers the necessities of the client and is flexible to adapt the facilities/activities**

Clean Mobility & Thermofluids

Research activities support

Expertise and background transfer

COMPANY

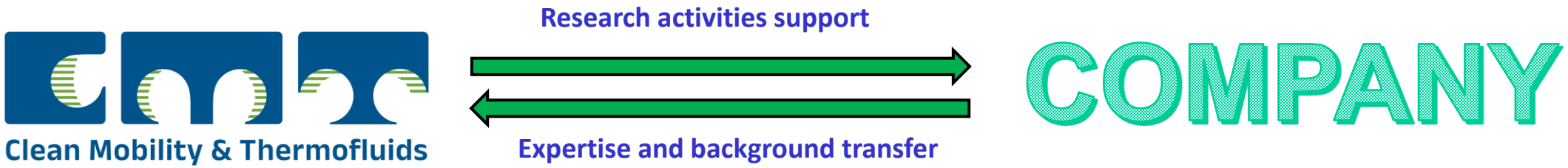
5. Potential collaboration activities

KEY IDEAS

- CMT considers the use of H2 as a **high-priority research line** for the mid and long-term future

  Significant recent investments in terms of **human and material resources**

- CMT provides a **top-level research framework** with proven capabilities and skills to collaborate in H2-ICE R&D activities
- The basic idea is to reach a **win/win situation** where both parts take advantage of the common research activities



COLLABORATION OPPORTUNITIES

- Public funded frameworks: Horizon Europe, Clean Hydrogen JU, Clean Aviation JU…
- Direct contracting → Faster & more flexible alternative

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Thank you for your kind attention