

# Testing meets Simulation - Synergien für Innovation in der Wasserstofftechnologie

H2 als Gamechanger, Groß Siegharts, 26. November 2025

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## HyCentA Research Leading Hydrogen Innovation

- **120+ researchers** mechanical engineering, physics, chemistry, process engineering, electrical engineering
- **600+ projects** successfully completed
- **20+ years of R&D expertise**
- **State-of-the-art research**, testing and refueling infrastructure
- **International Cooperations**
- **COMET K1 Center**



Extra-university research organization at  
Graz University of Technology (TUG)



# Research Areas along the Entire Value Chain



Area 1 – ECT  
**Electrolysis  
and Power-to-X**



Material research, new **electrolysis technologies**, alternative processes (from materials to industrial applications)



Area 2 – INT  
**Green Energy  
and Industry**



Research on **generation, purification, compression, storage, distribution and delivery** technologies for the industry and the energy Sector



Area 3 – MOT  
**Green Mobility**



**Fuel cell** research on materials, cell, stack and system; optimisation of entire **powertrain** system including **hydrogen storage**



Area 4 – MET  
**Circularity and  
Sys. Optimization**

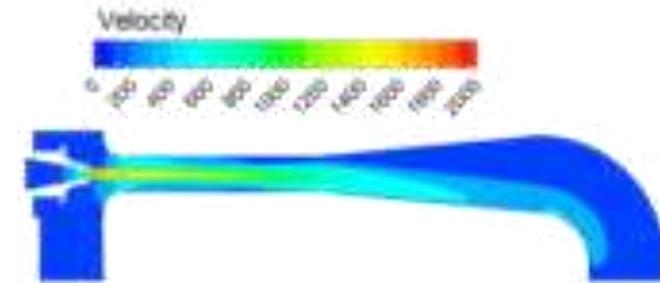
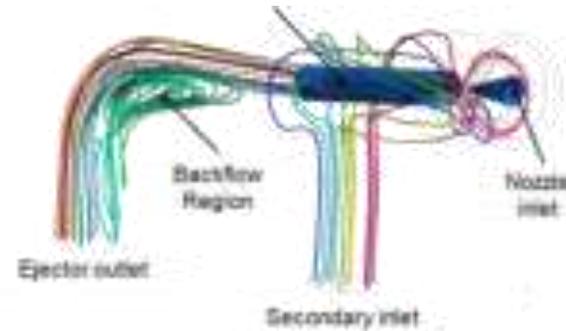
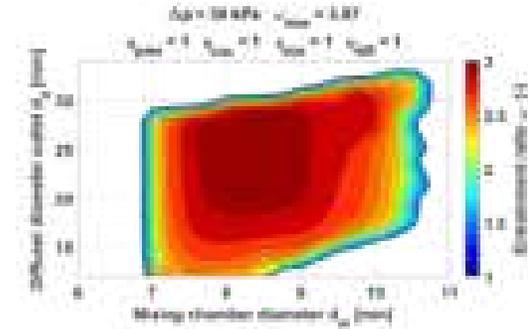
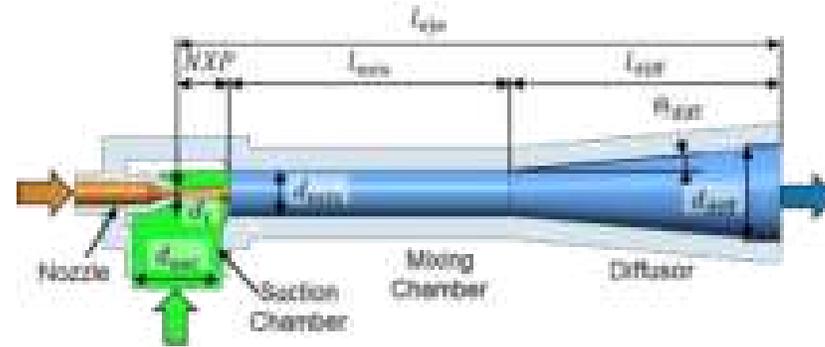
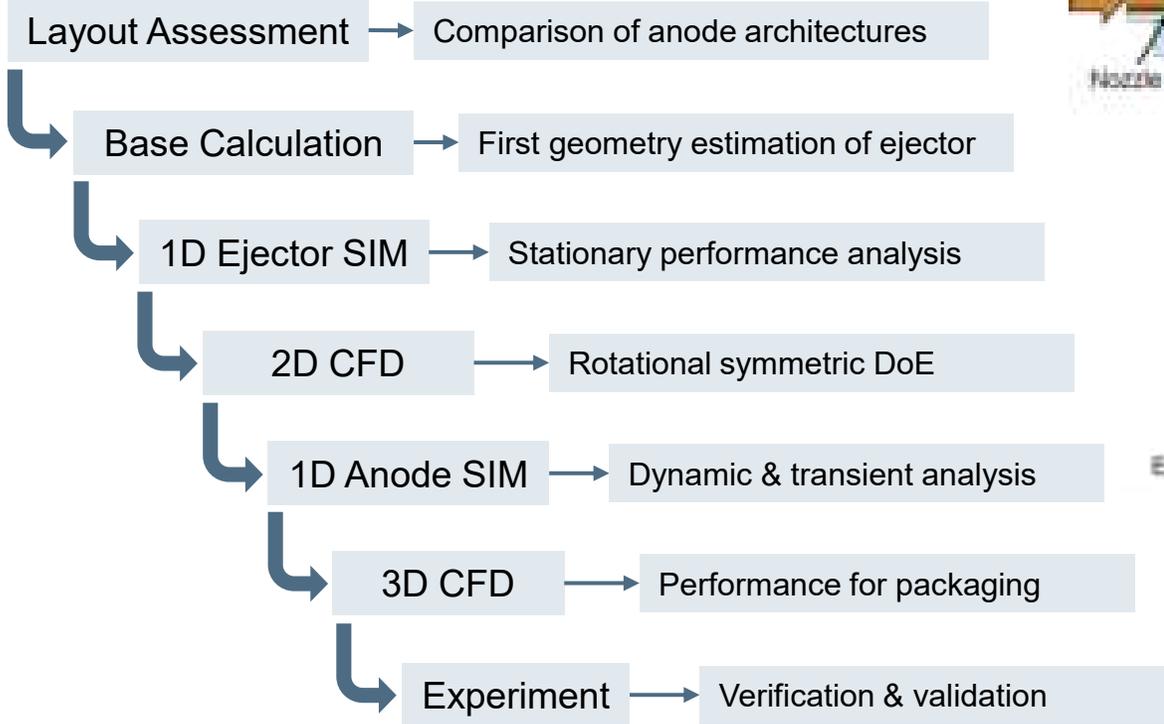


Measurement and **testing** technologies, **controls**, diagnostics, **modelling** and simulation “digital twin”



# R&D Toolchain Ejector Systems

## Development toolchain for a injector-ejector units for PEM fuel cell systems



Tools: **ANSYS**



# Ejector System Simulation

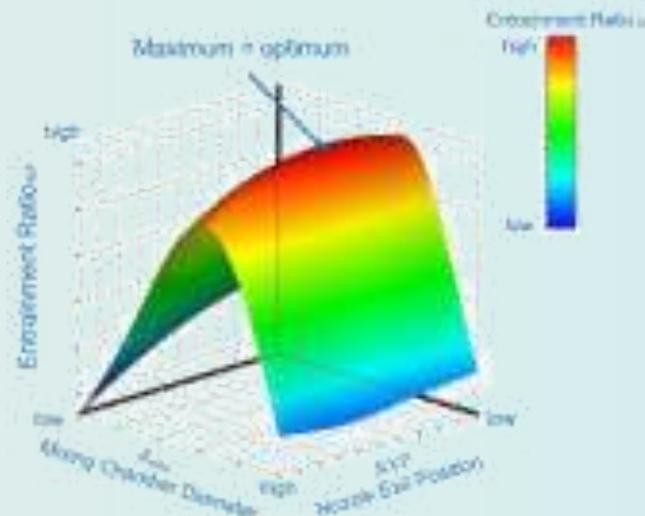
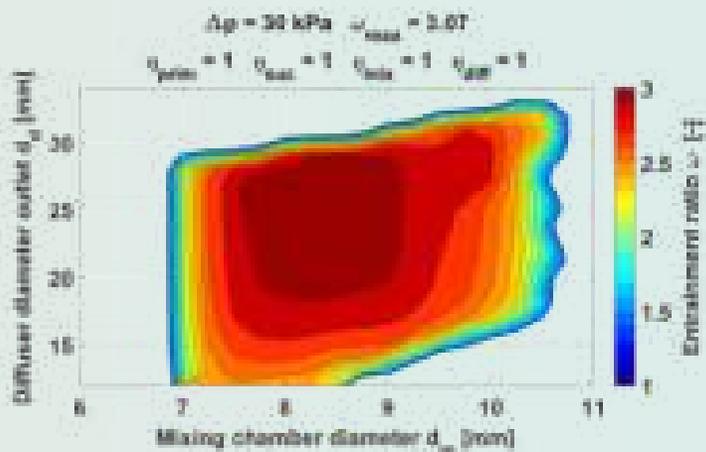
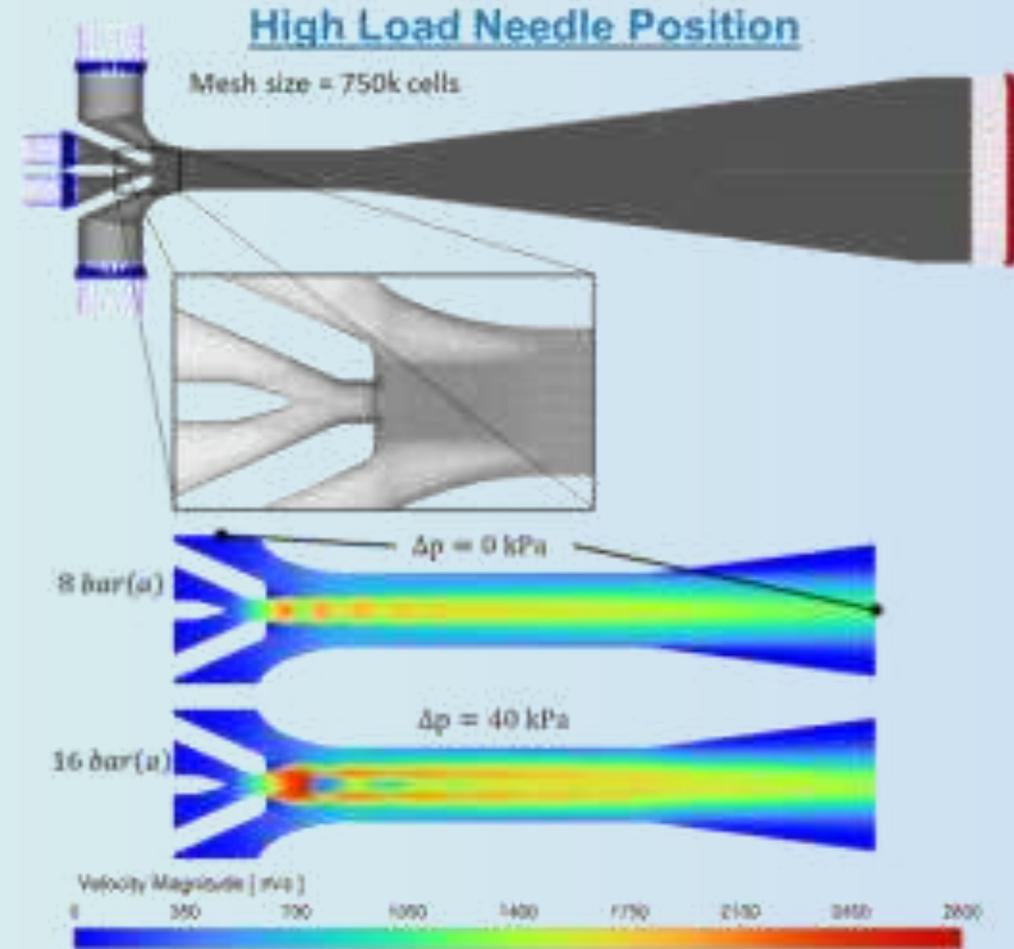
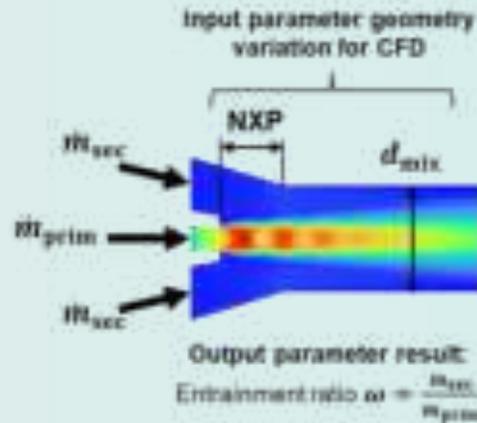
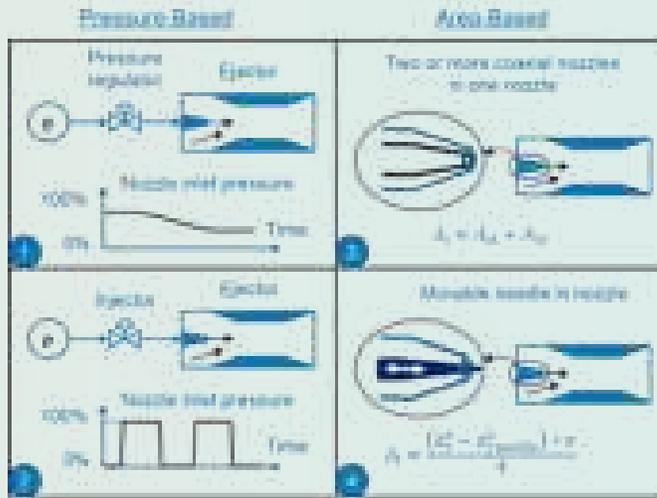
Base Calculation

1D Ejector SIM

1D Anode SIM

2D CFD

3D CFD



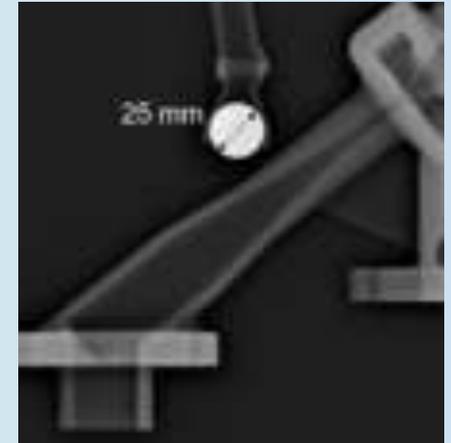
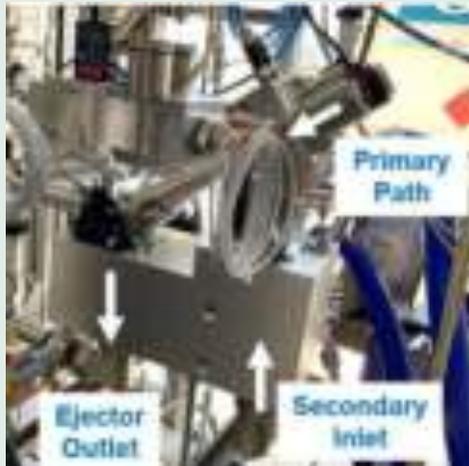


# Ejector System Testing

Component

Anode System

Post Analysis

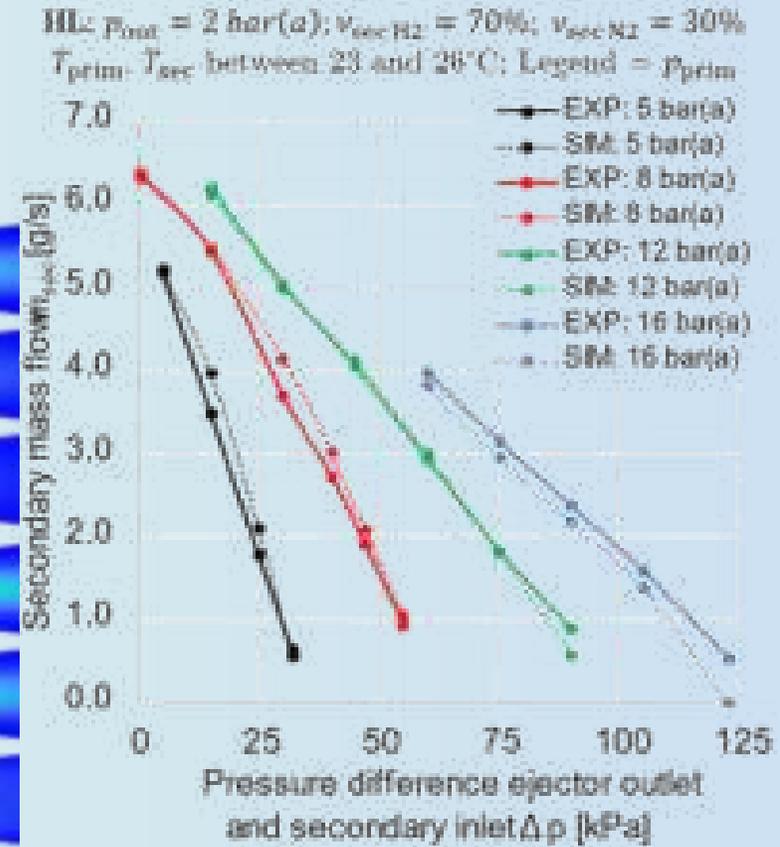
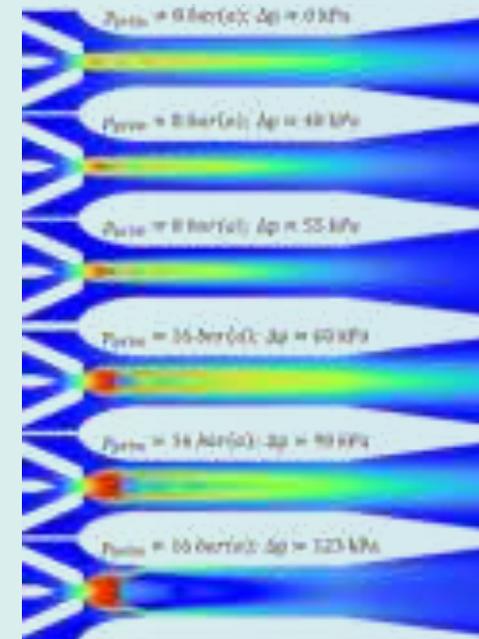
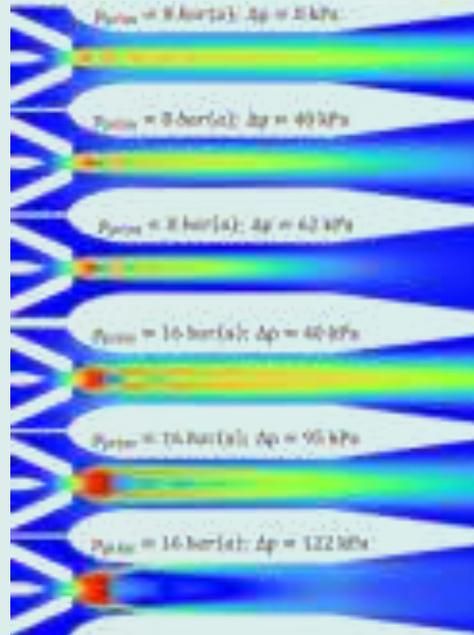
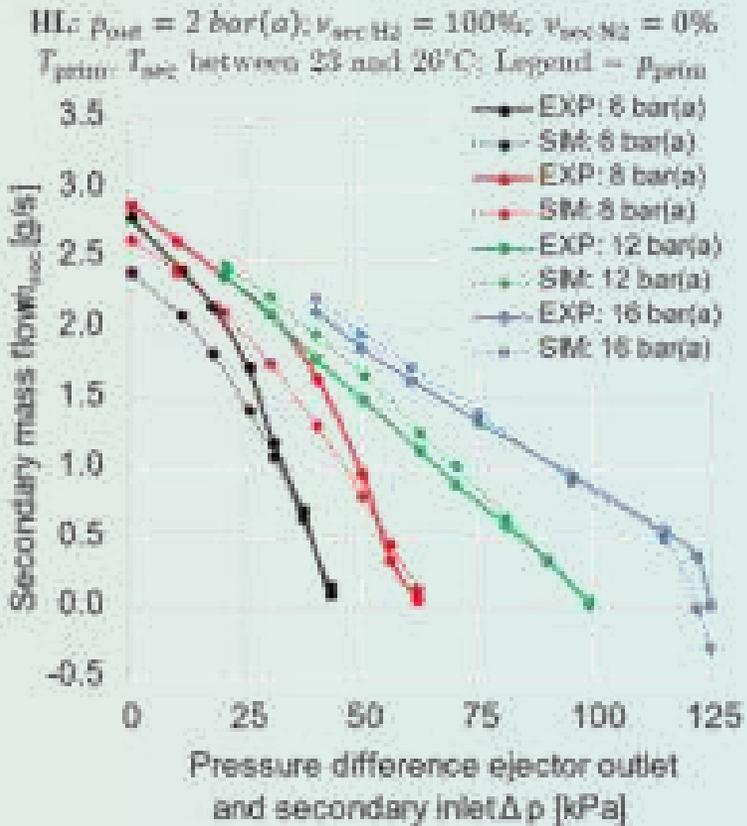


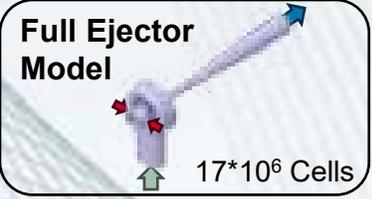


# Validation Simulation – Testing

100 % H<sub>2</sub>

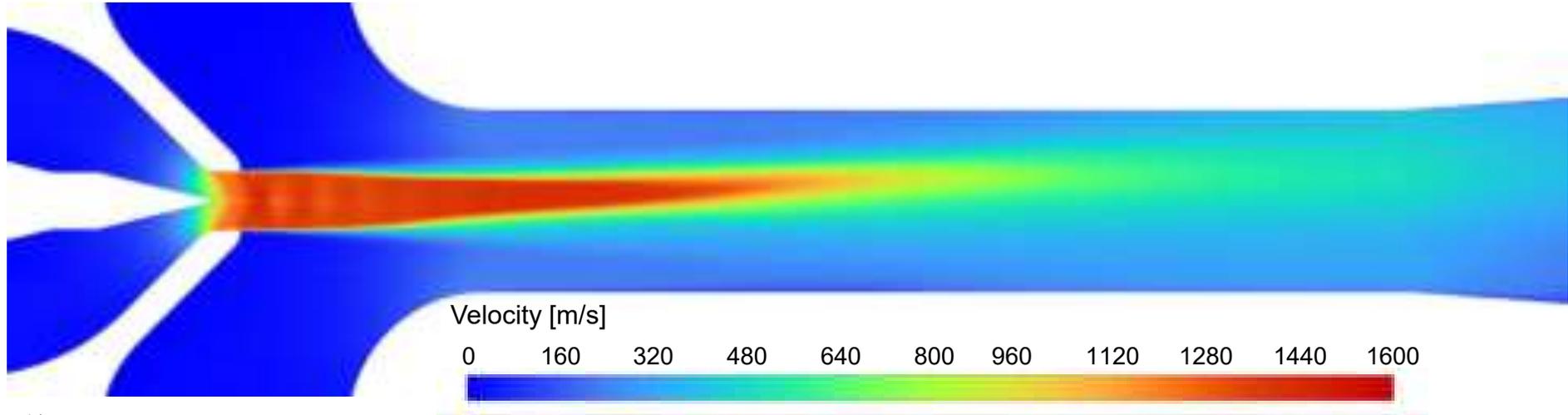
70% H<sub>2</sub>, 30% N<sub>2</sub>



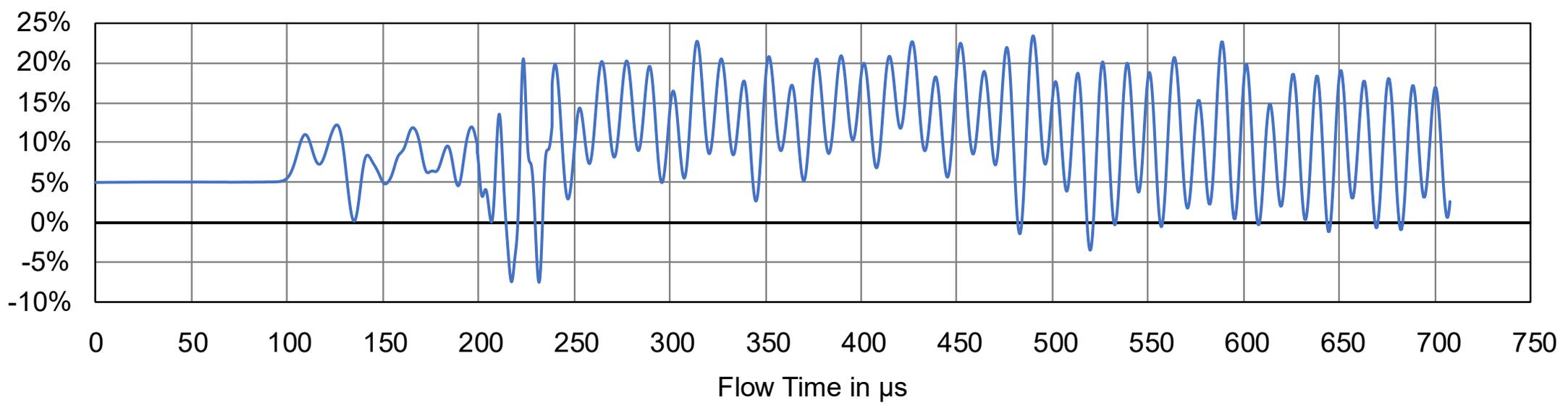


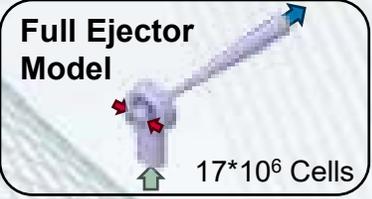
# LES Results

## Instantaneous Velocity Magnitude

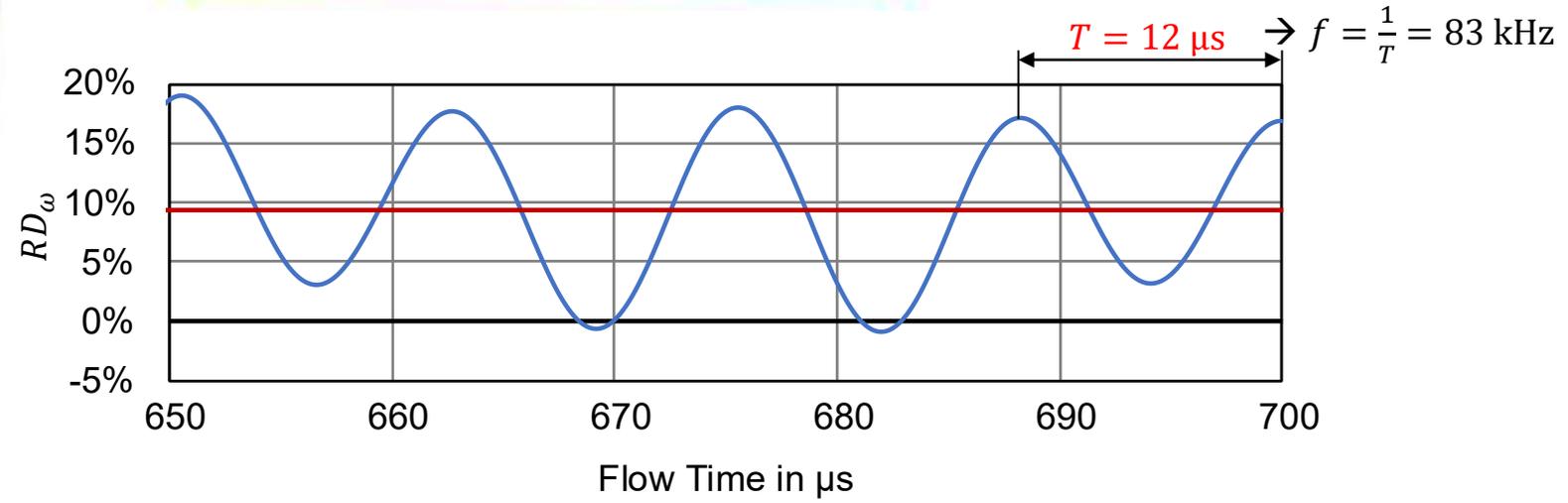
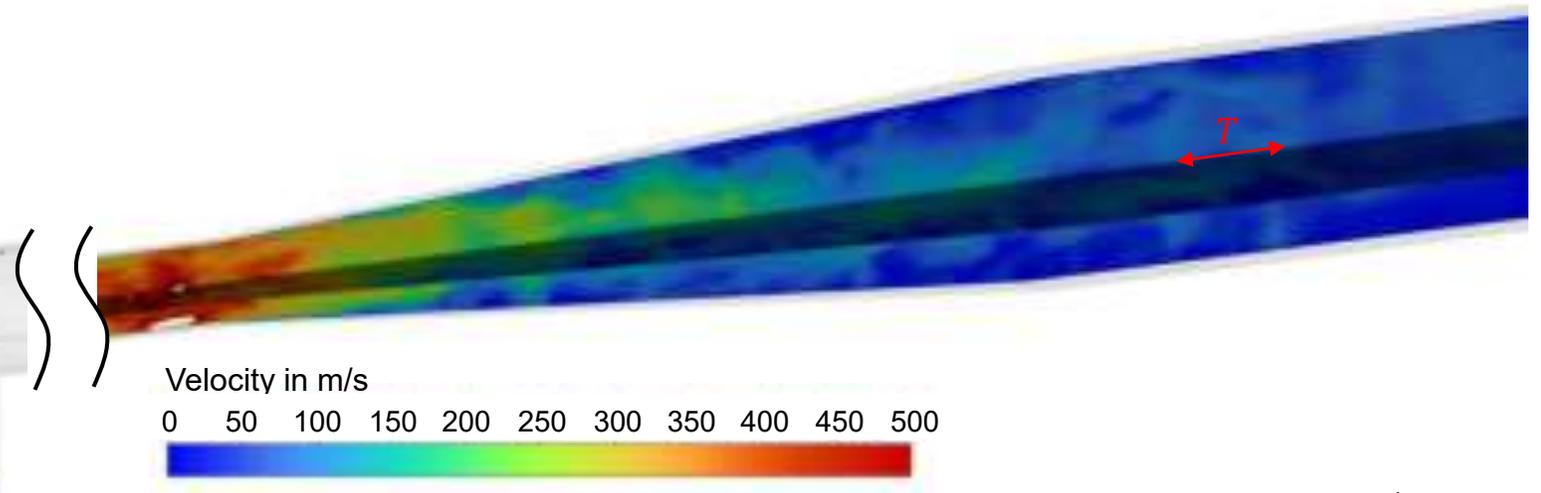
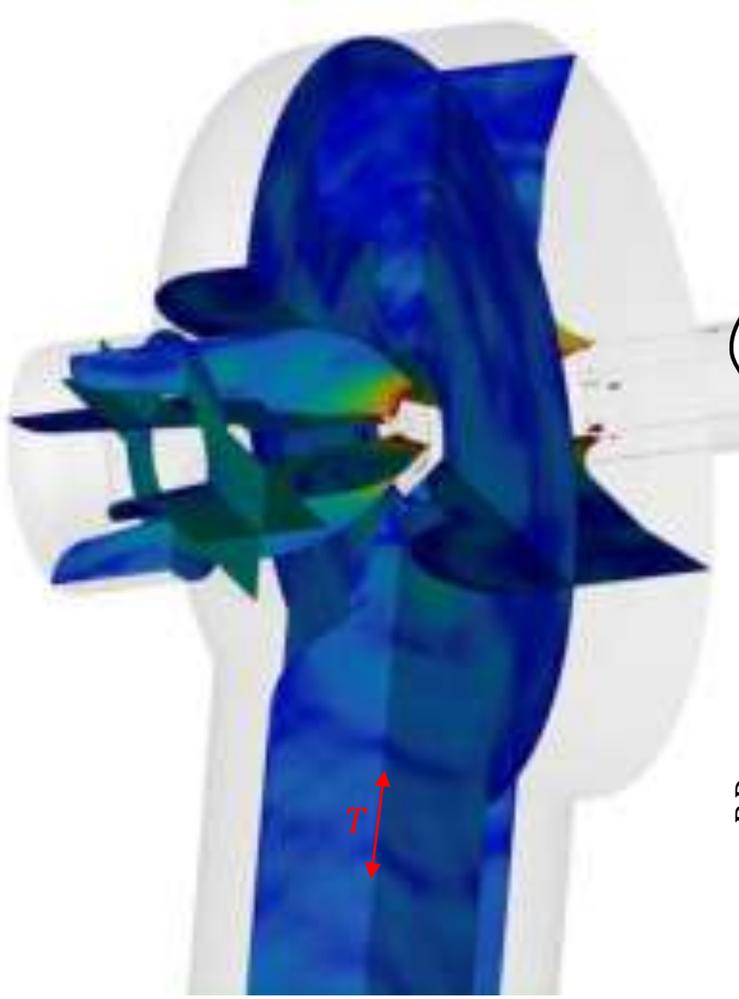
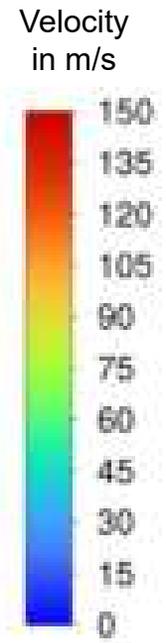


Relative deviation in simulated entrainment ratio from the experiment

$$RD_{\omega} = \frac{\omega_{SIM} - \omega_{EXP}}{\omega_{EXP}}$$




# LES Results Instantaneous Velocity Magnitude

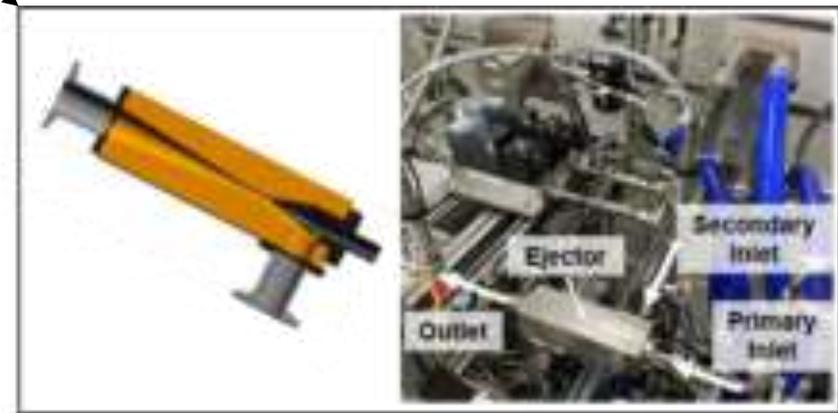
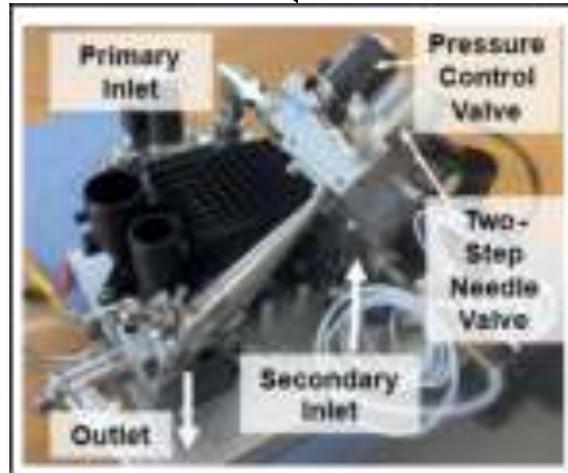
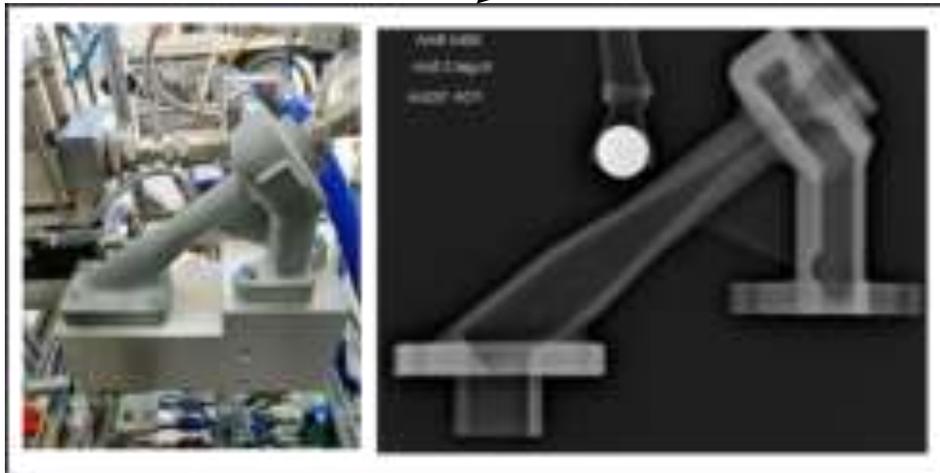
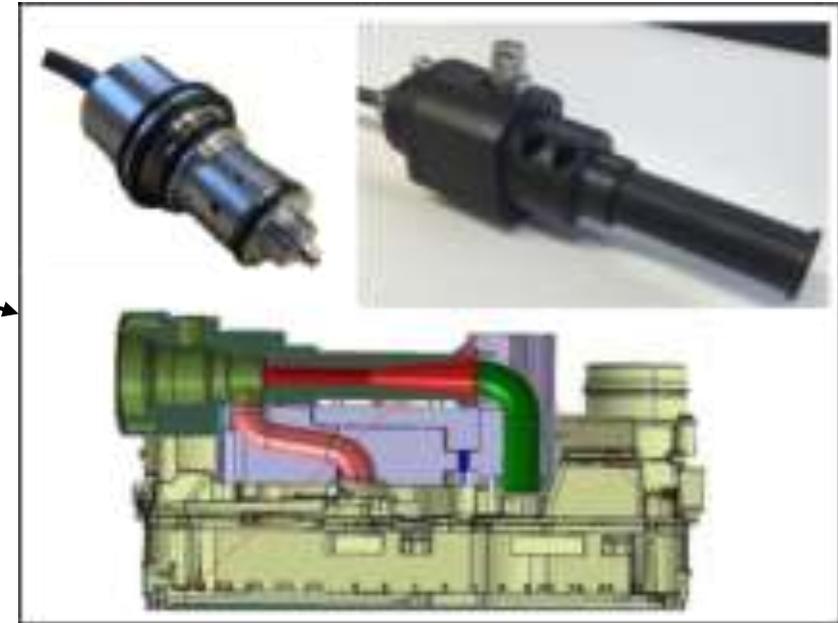




# Applied Ejector Systems

Project	Ejector System
KeyTech4EV	Pulsed injector-ejector
HyFficient	Single ejector
HyFleet	Two-step needle ejector
HyFleet	3D printed ejector

Focus



# LH<sub>2</sub> Experience at HyCentA

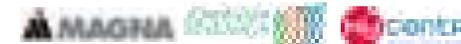
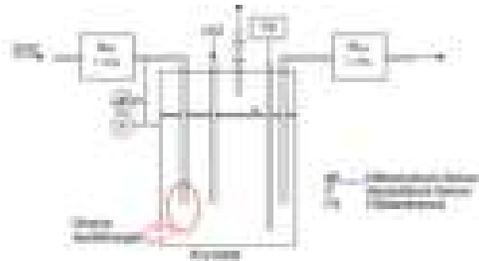
2006 - 2007:  
LH<sub>2</sub> - Periphery  
Pressure build-up system  
with individually developed  
system components

2006 - 2008:  
LH<sub>2</sub> - liquid hydrogen tank  
system  
(made by MAGNA)  
BMW Hydrogen 7

2007:  
Sensorcluster LH<sub>2</sub> -  
automotive measuring  
system (complete  
monitoring of a liquid  
hydrogen tank)

2006 - 2007:  
CryoSens - robust LH<sub>2</sub>  
flow measurement for  
automotive applications  
cryogenic and gaseous  
hydrogen for pressures  
up to 350 bar

2010 - 2013:  
Slush - mixture of liquid  
and solid hydrogen at  
extremely low  
temperatures.  
Advantage: higher  
density than LH<sub>2</sub>



# Need for LH2

- **Aviation:** Roughly **two-thirds of today's kerosene consumption** – which directly correlates with CO<sub>2</sub> emissions – comes from **flights operated with short- and medium-range aircraft** (flights with fewer than 165 PAX and flights with fewer than 250 PAX, respectively).
  - These aircraft account for **70 percent of the global fleet**
- **Heavy-duty:** Prototype fleet already on public roads
- **Shipping:** for shorter range ships and cruisers



Source: Airbus, <https://www.airbus.com/en/innovation/low-carbon-aviation/hydrogen/zeroe>

Source: Hydrogen-powered aviation A fact-based study of hydrogen technology, economics, and climate impact by 2050



Source: Hydrogen Europe, "Hydrogen," in Riviera Marine Fuels webinar week, 2020



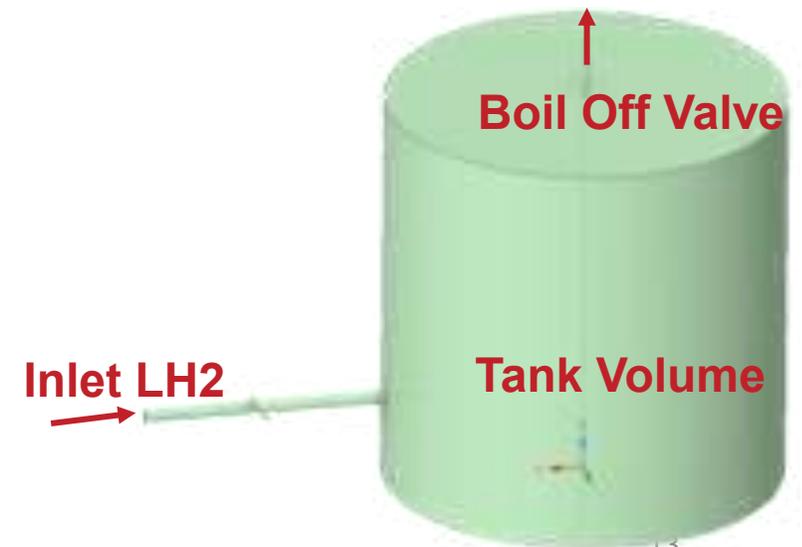
Source: 'MF Hydra': World's first liquid hydrogen-powered ferry gets operational (interestingengineering.com)



Source: Daimler Trucks, Mercedes-Benz Trucks provides outlook on hydrogen-based GenH2 Truck at IAA Transportation 2022 in Hanover

- **Development of 3D CFD model** for calculating **spatial temperature distribution** in tank during filling
- **Geometry** of HyCentA's cryo-tank as basis with experimental filling data available for **semi-validation**
- Combination of various **advanced CFD methods**:
  - **Volume-of-Fluid phase model**
  - Domain **initialization with temperature gradient**
  - Dynamic **adaptive mesh refinement** based on location of phase boundary
  - **Custom code** for **dynamic activation and deactivation of boil-off outlet boundary condition**
- The **methodology** developed **enables** in the future: **optimization of filling**, investigations of **dormancy times** and **thermal stratification**, **boil-off behaviour**, **sloshing**, etc.

Conditioning tank – 60 kg LH2

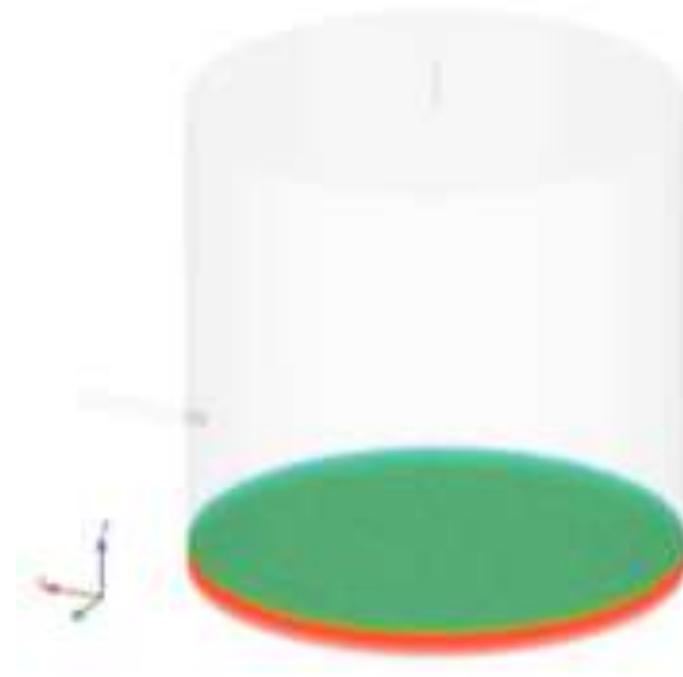


# LH2 Filling – Results

Iso-Surface with liquid phase mass fraction greater than 0.5



Phase volume fraction

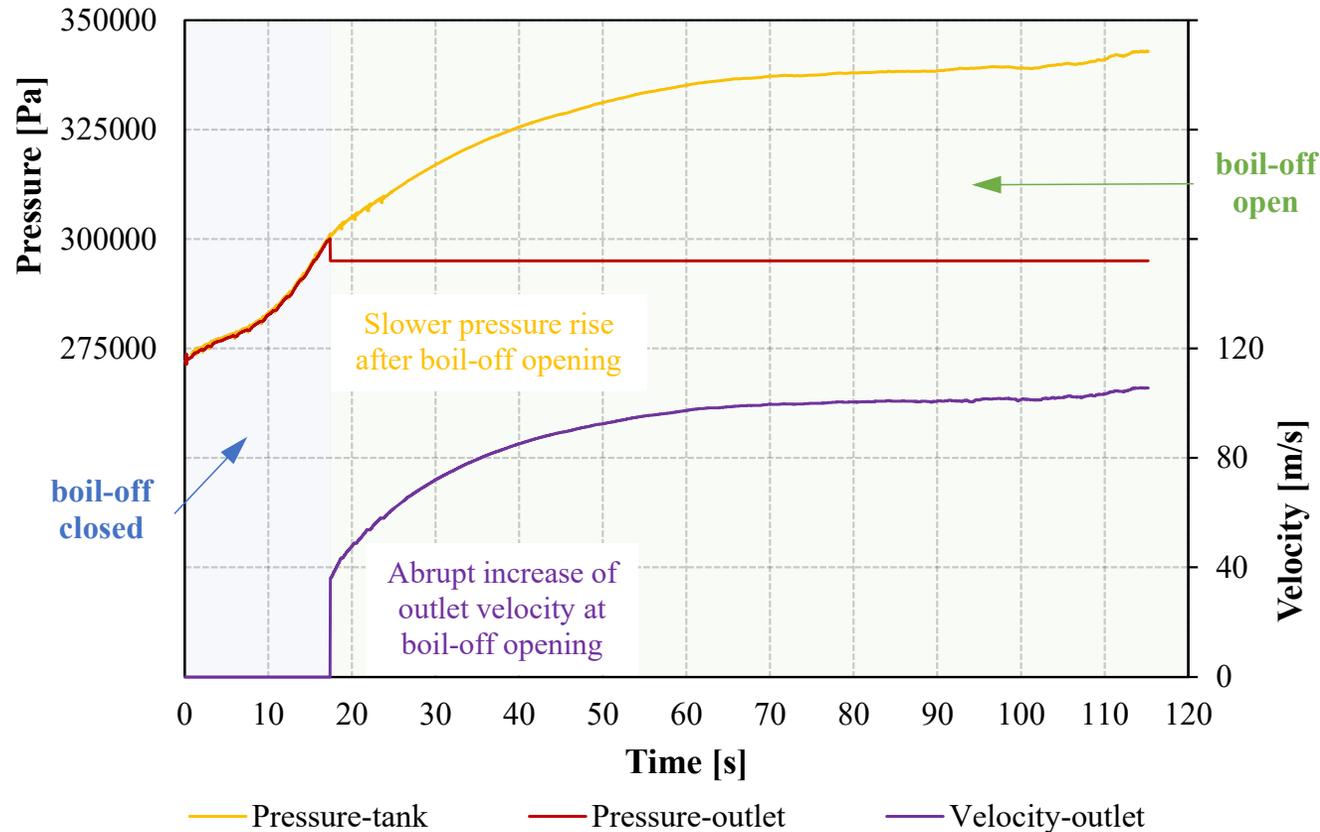


Phase mass transfer



# LH2 Filling – Boil-Off

- Boil-off valve ensures **no tank overpressure during filling and dormancy period**
- **Boil-off valve opens:  $p > 3 \text{ bar(g)}$**
- **Gaseous hydrogen released represents a loss**
- **Slower tank-pressure rise after boil-off opening (17 sec)**
- **Abrupt increase of outlet velocity after boil-off opening**
- **Outlet velocity depends on pressure difference between tank and outlet**
- Increase outlet mass flow:
  - Improve **pressure outlet boundary condition**
  - **Increase outlet diameter**



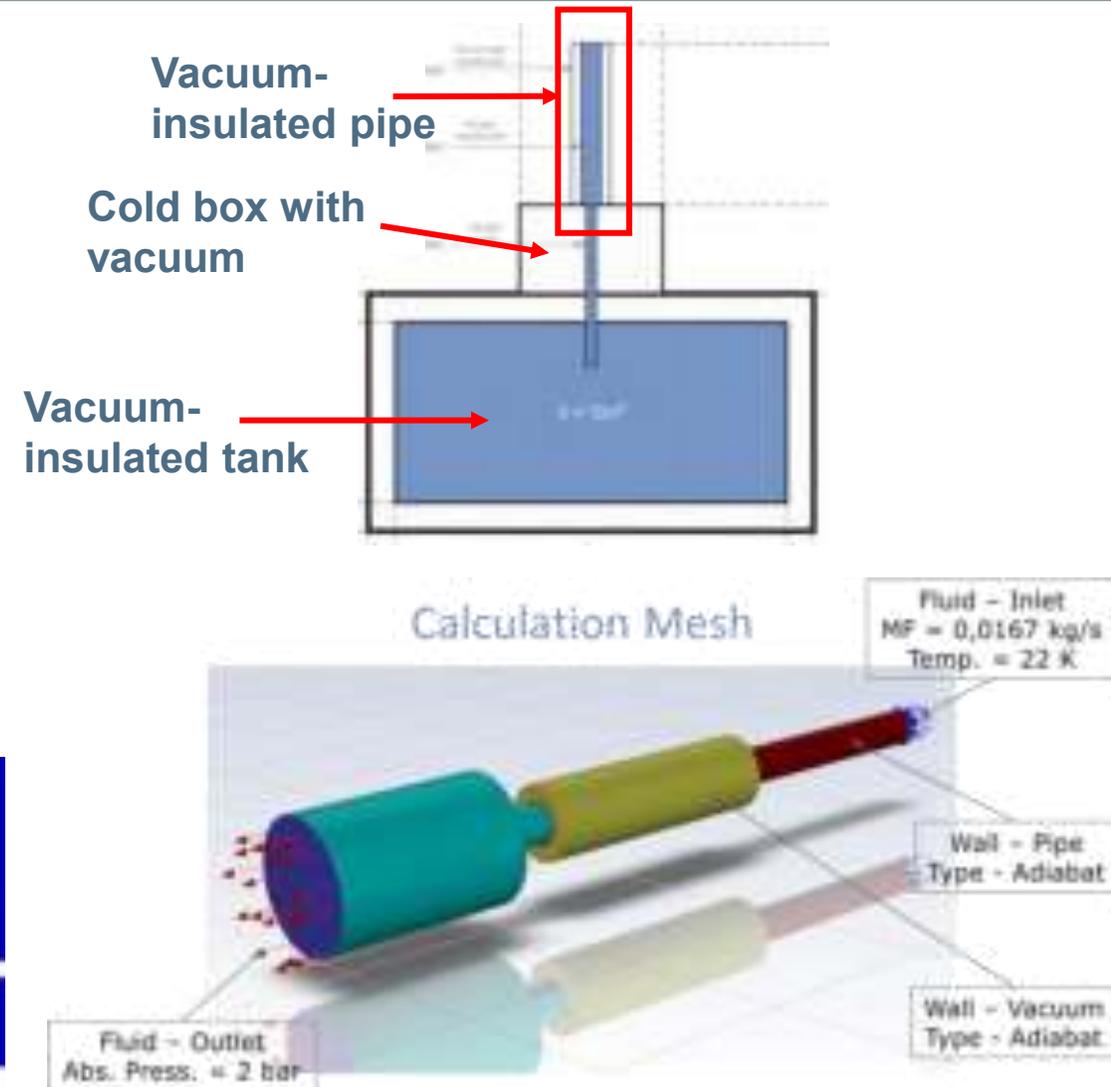
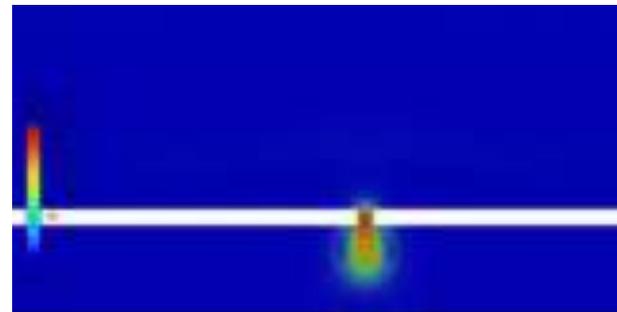
- Simulation of rapid venting of LH2 tank in case of safety-relevant events
- **First step:** assumption of gaseous hydrogen exiting tank and simplified venting line



- Local zone with explosive mixture after valve
- Next step: derivation of worst case scenarios due to geometry design
- Implementation of dynamic boundary incl. LH2 droplets
- Further options: bringing solver to the limit with air liquefaction, icing, change of flow direction due to pressure change in flight etc.

# LH2 Safety - Cryogenic Leakage

- To minimize evaporation of LH2 due to heat intake vacuum-insulation is required
- Sudden loss of vacuum due could lead to higher filling losses or even uncontrolled pressure increase in system due to phase change
- CFD simulation to investigate thermodynamic behavior of LH2 entering vacuum-insulated pipe
- Simplified geometry and boundary conditions defined with Magna
- Assumption of a hole in the wall
- Numerically challenging





- 4000 kg LH<sub>2</sub> stationary tank
- Multiple testing stations
- Outdoor space for testing larger tanks for aviation
- Helium station for inertisation
- LH<sub>2</sub> conditioning container and optional cryogenic pump
  - Up to 860 kg/h and 36 bar LH<sub>2</sub> supply
- 4000 kg LN<sub>2</sub> stationary tank
- State-of-the-art CAx infrastructure for 3D CFD simulations and digital-twins

# AUTARK - Austrian liquid hydrogen tank system technologies

- **AUTARK - first research project for the Liquid Hydrogen Lab approved for funding**
- **Main focus:**
  - **Decreasing weight** of LH2 storage systems for aviation
  - **Increased hydrogen safety** of the storage system (e.g. venting)
  - **Development of novel valve components**
- **Role of HyCentA:**
  - **In-depth 3D CFD simulations of venting phenomena**
  - **Experimental validation of valves, the cold box and the tank**
  - **Experimental assessment of venting and detonations/deflagrations**

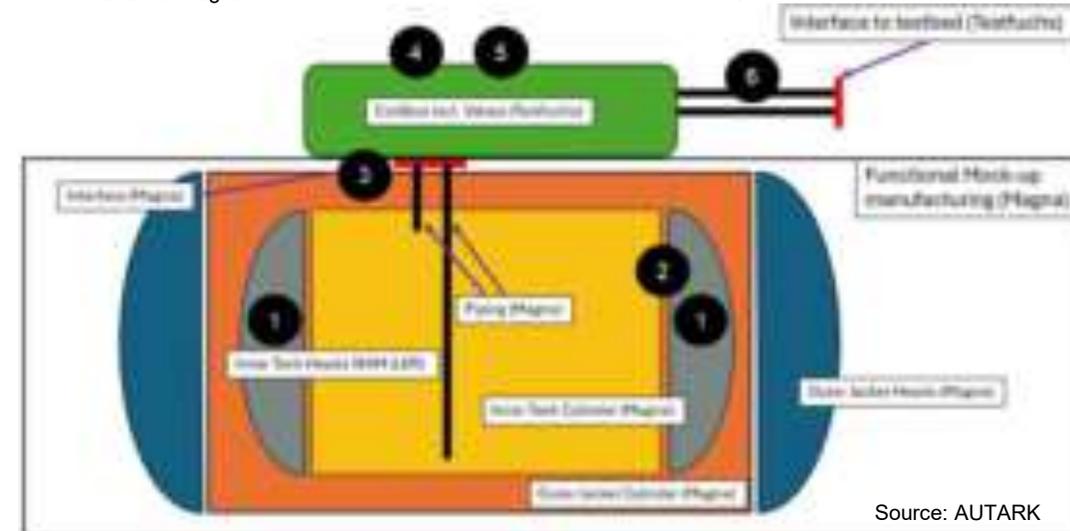


Source: Magna

### Physical test articles

- 1 Inner tank (IT) dome (heads) incl. HEX
- 2 Inner tank (IT) welded assembly
- 3 Tank / Coldbox interface
- 4 Cold Box built in aluminium
- 5 Aluminium SOV+PRV in aluminium
- 6 Venting pipes with CV

HEX: heat exchanger  
 CV: check valve  
 SOV: shut of valve  
 PRV: pressure relief valve  
 OJ: Outer jacket



Source: AUTARK

### Consortium:



## Contact

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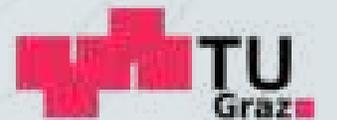
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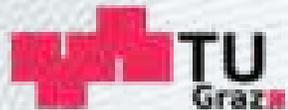
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