Ludwig Bölkow Systemtechnik

PRHYDE
Protocol for heavy-duty Hydrogen refuelling

CASE STUDY: PRHYDE PROJECT

Protocol for Heavy-Duty Hydrogen Refuelling

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World Hydrogen Mobility, 31 May 2023, Stuttgart

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- Cutting edge competence
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  - Interdisciplinary team of engineers and economists
  - Completely independent advice
- Bridging technology, markets, and policy
- Global and long-term perspective
- Rigorous system approach – thinking outside the box
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01

GENERAL NEED FOR A NEW STANDARD FOR HD H2 REFUELLING

Current SAE J2601 fuelling protocol principle considers most conservative values on vehicle side

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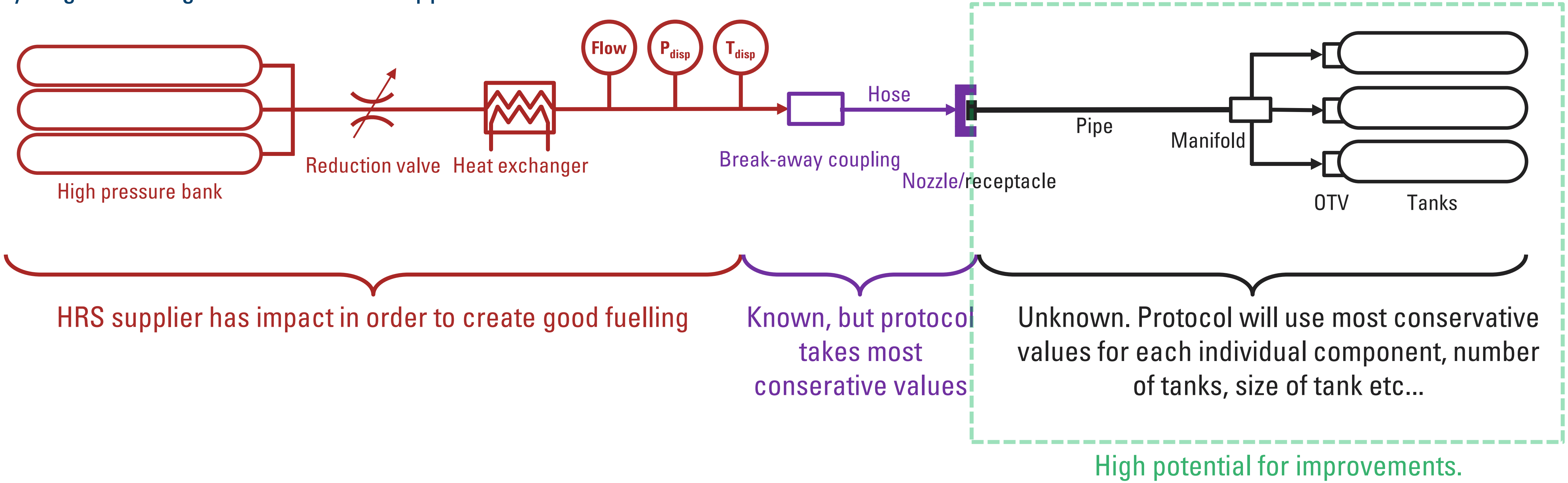
Hydrogen fuelling based on current approach in SAE J2601:



Station must account for a broad range of potential vehicle characteristics.

→ Fuelling speed is negatively affected by stacking of conservative assumptions.

Use of worst-case assumptions limits performance of existing hydrogen fuelling, esp. for HD vehicles

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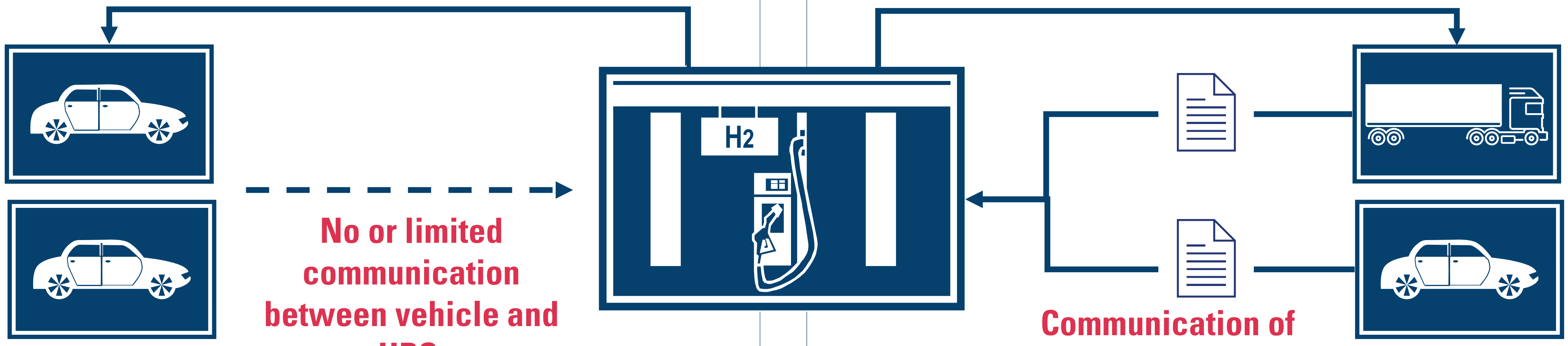
Current approach (SAE J2601)	PRHYDE approach
Fuelling based on “worst-case” assumptions	Vehicle optimized fuelling



No or limited communication between vehicle and HRS.

Communication of vehicle specific fuelling tables to the HRS.

Gaseous H_2 fuelling today: LDV (2 – 10 kg) and MDV (10 – 30 kg) in 3-10 minutes with fuelling speed of max. 60 g/s. HDV (30+ kg) require faster approach to achieve fuelling times <10 minutes (→ i.e. 90 – 300 g/s).

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02 OVERVIEW OF PRHYDE PROJECT

Acknowledgement:

Clean Hydrogen Partnership

Co-funded by the European Union

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) under Grant Agreement No 874997. This Joint Undertaking receives support from the European Union's Horizon 2020 Research and Innovation programme, Hydrogen Europe and Hydrogen Europe Research.

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PRHYDE at a glance: Protocol for heavy-duty hydrogen refuelling

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PRHYDE:

- **Project:** January 2020 - September 2022
- **Budget:** 3.2 million EUR (Funding: 1.5 million EU)
- **Partners:** 11 international partners + 14 additional stakeholders ("external expert group")
- **Goal**: recommendations for new HD fuelling protocols for compressed (gaseous) H_2 fuelling:
  - for large tank systems / HD vehicles with 35, 50, and 70 MPa nominal working pressures
  - results as basis for further standardization process (see activities in ISO TC197 WG24 SG3B)
- **Website**: https://prhyde.eu

Members of the PRHYDE consortium:

LBST Ludwig Bölkow Systemtechnik

Air Liquide creative oxygen

cea LE RIPAULT

engie Lab CRIGEN

ITM POWER Energy Storage | Clean Fuel

nel

NIKOLA

ZBT

Please note: Further linked third partner to the project are MAN and Toyota North America.
We also thank the following companies and institutions for their contribution to the project (in alphabetical order): Bennet Pump, Daimler, **FirstElement Fuel**, Hexagon Purus, Honda, LifteH2, Luxfer, **National Renewable Energy Laboratory (NREL)**, National Technology & Engineering Solutions of Sandia, LLC (NESS), NPROXX, Risktec, Savannah River National Laboratory (SRNL) and TÜV SÜD Rail.

The PRHYDE project consists of 5 key work packages that were conducted between 01/2020 and 09/2022

2020

WP2: SoA and target definition

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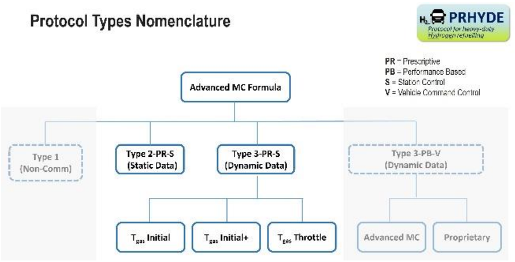
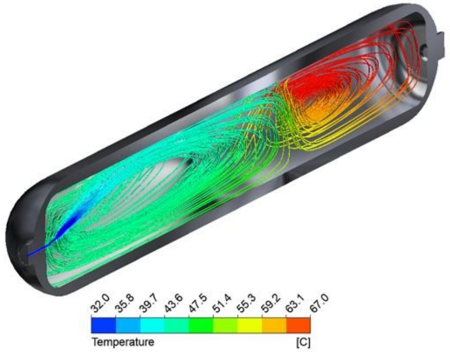
WP6: Dissemination & stakeholder webinars / workshops (2020-2022)

12/2020 – 09/2022

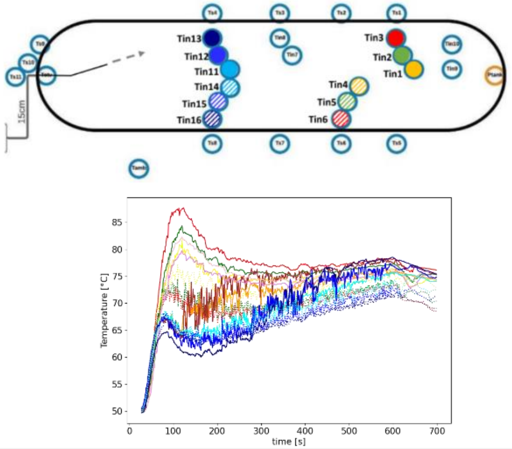
WP3: Protocol development



WP4: Modelling



WP5: Experimental validation



12/2022

Final publications as input for standardisation organisations (D6.7 PRHYDE results)

Nikola Tre FCEV with Trailer Attached (Source: Nikola)

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03 PRHYDE PROTOCOL CONCEPTS

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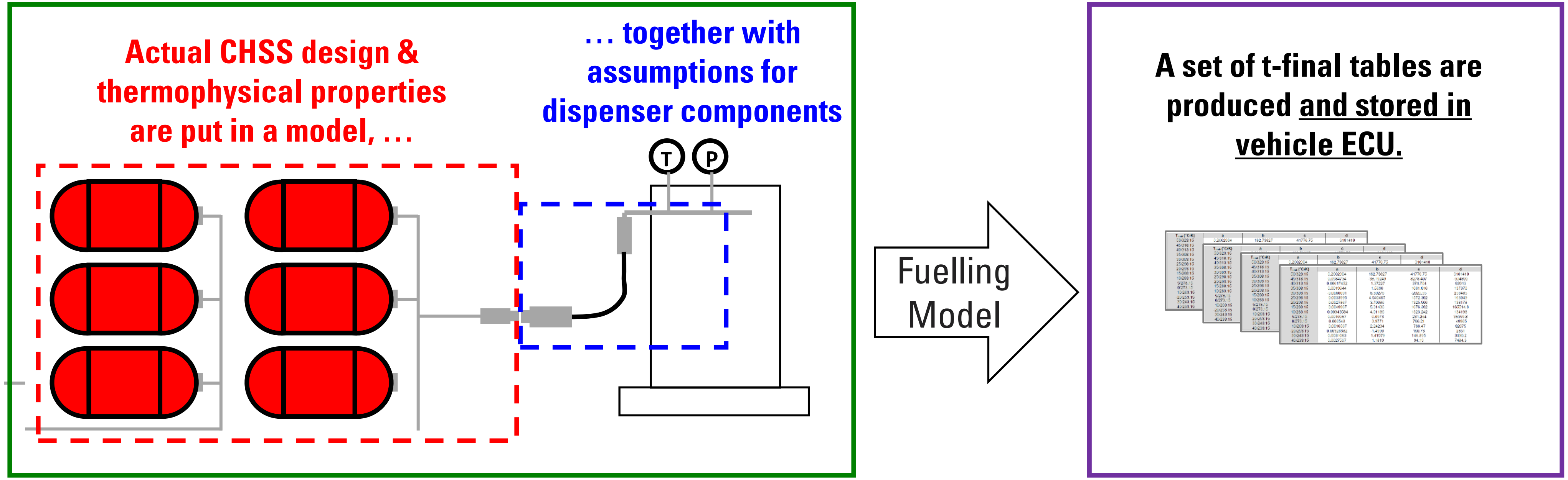
Vehicle selects suitable t_{final} table based on vehicle characteristics (e.g. tank pressure and temperature)

PRHYDE approach (1/2):

Step 1: **OEM develops set of t_{final} tables** based on thermophysical properties for each vehicle / tank configuration **with a fuelling model**:

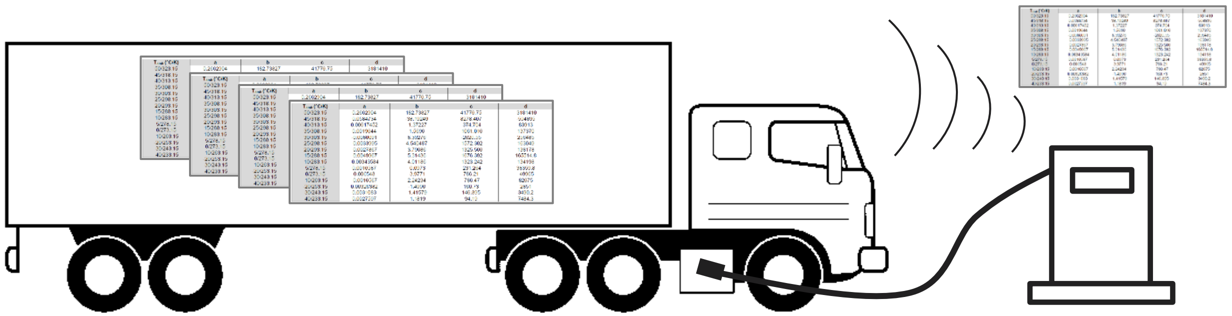


Vehicle selects suitable t_{final} table based on vehicle characteristics (e.g. tank pressure and temperature)

PRHYDE approach (2/2):

Step 2: **vehicle selects certain t_{final} table** (e.g. based on current tank pressure and temperature) and transmits it to the station. **HRS selects t_{final} value based on station's capabilities and local conditions** (i.e. precooling performance and ambient temperature) :

The vehicle ECU selects the right t_{final} table …



… and sends it to the station.

- t_{final} table is produced by a fuelling model
- t_{final} value: **time required** to fuel the CHSS **from a minimum pressure** P_{min} **to a maximum pressure** P_{final} without:
  - exceeding the gas temperature limit (typically 85 °C), and
  - maximum mass flow rate (e.g. 300 g/s for H70)

Four protocol concepts have been developed in PRHYDE, increasingly relying on data communication.

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Comparison of different protocol concepts: Type 1 (J2601): No vehicle information used (to control the fuelling rate) (= fallback option)
Type 2 (PRHYDE): Static vehicle information used
Type 3 (PRHYDE): Static and dynamic (= real-time) vehicle information used

Assumptions / boundary conditions considered	Type 1	Type 2	Type 3		
	SAE J2601	Static	T_{gas} Initial	T_{gas} Initial+	T_{gas} Throttle
CHSS volume categories	X				
Worst case CHSS thermophysical properties	X				
Fuelling history always present	X	X			
CHSS initial temperature @ hot soak	X	X	X		
Worst case station component thermophysical properties (breakaway, hose, nozzle/receptacle)	X	X	X	X	
Station components soaked at ambient temperature	X	X	X	X	

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Modelling with NREL’s H2FillS show high performance of PRHYDE concepts with fuelling time < 10 minutes

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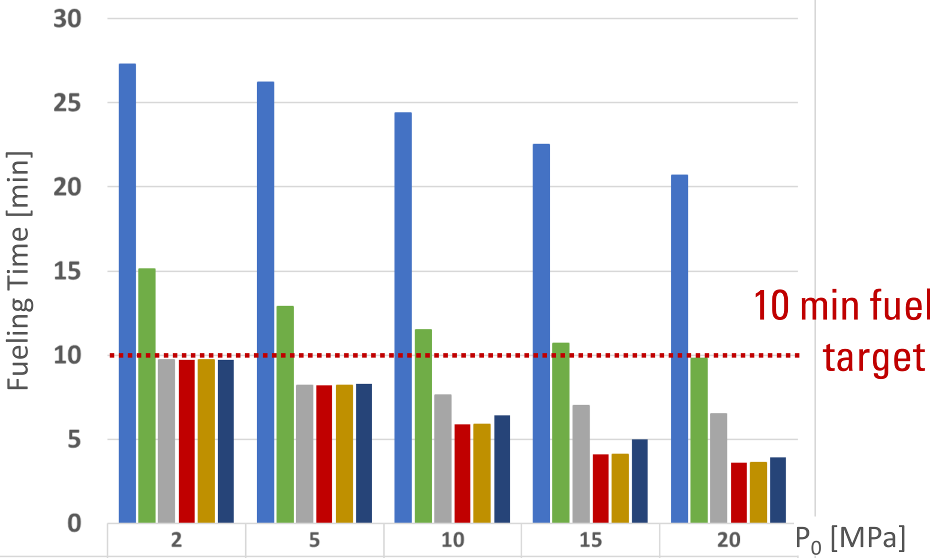
Comparison of fuelling performance of PRHYDE protocol concepts with SAE J2601 category D and MCF-HF-G (SAE *TIR J2601-5*)*

Fueling Conditions

T_{amb} 35 °C
$T_{gas\_initial}$ 40 °C
T_{soak} 40 °C
T_{fuel} -21 °C



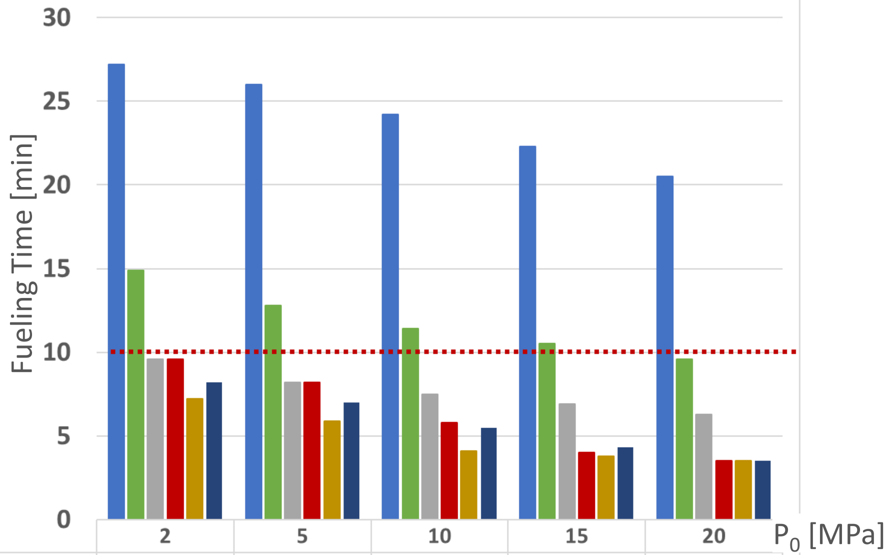
	2	5	10	15	20
SAE J2601 Category D	27.3	26.2	24.4	22.5	20.7
MC Formula High Flow General	15.1	12.9	11.5	10.7	9.8
Static	9.7	8.2	7.6	7	6.5
Tgas Initial	9.7	8.2	5.9	4.1	3.6
Tgas Initial+	9.7	8.2	5.9	4.1	3.6
Tgas Throttle Adaptable	9.7	8.3	6.4	5	3.9

10 min fuelling target

MCF-HF-G (SAE TIR J2601-5) = MC Formula High-Flow General SAE TIR J2601-5 (under development)

Fueling Conditions

T_{amb} 35 °C
$T_{gas\_initial}$ 20 °C
T_{soak} 30 °C
T_{fuel} -21 °C



	2	5	10	15	20
SAE J2601 Category D	27.2	26	24.2	22.3	20.5
MC Formula High Flow General	14.9	12.8	11.4	10.5	9.6
Static	9.6	8.2	7.5	6.9	6.3
Tgas Initial	9.6	8.2	5.8	4	3.5
Tgas Initial+	7.2	5.9	4.1	3.8	3.5
Tgas Throttle Adaptable	8.2	7	5.5	4.3	3.5

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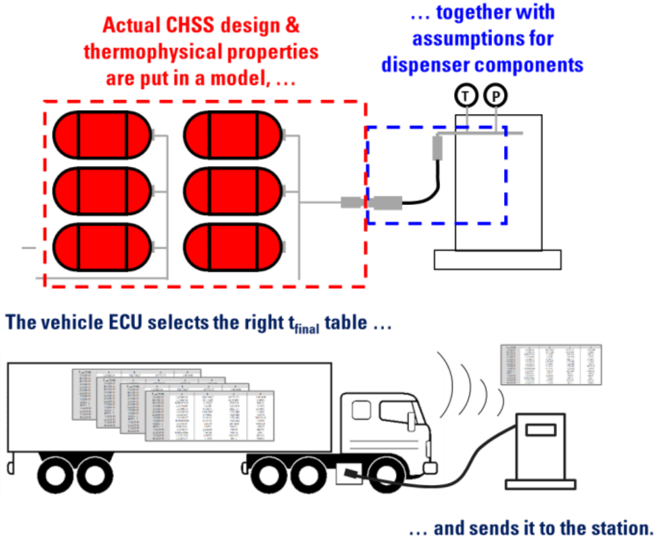
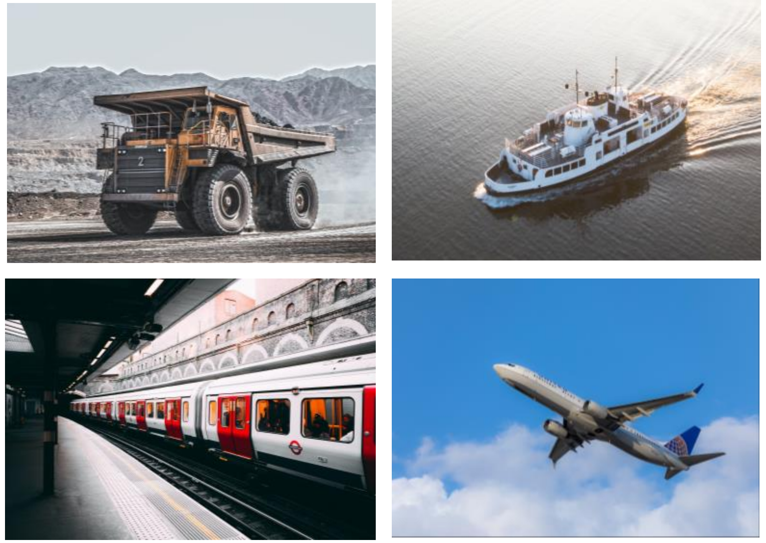
04 SUMMARY AND OUTLOOK

PRHYDE protocol concepts offer performance improvements in and outside HD road vehicles segment

- PRHYDE (2020 – 2022) developed a **suite of fuelling concepts** for HD vehicle fuelling (based on Advanced MC Formula framework (see also SAE J2601) and serves **as key input for new ISO standards** under development
- **OEMs can choose most appropriate approach** for their vehicles
  (Note: vehicle & tank design with impact on fuelling performance. Communication as key requirement)
- Outlook: Advanced MC-F and PRHYDE concepts may be utilized for a **wide range of HD applications**


Nikola Tre FCEV with Trailer Attached (Source: Nikola)





Standardization process with PRHYDE protocol concepts continues in ISO TC197 WG 24 SG 3B (04/2023 – 02/2024)

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PRHYDE: Next steps for implementation:

- **Standardization:**
  PRHYDE protocol to be part of ISO 19885-3
  Work started in ISO TC197 WG 24 subgroup 3B (04/2023-02/2024)
- **Fuelling Nozzles:**
  PRHYDE protocol intended for high flow (HF). High flow nozzles currently in development (see also ISO 17268-3).
- **FCEV-Dispenser Communication:**
  Biggest hurdle!
  Currently being handled in ISO 19885-2
- **Industry-accepted model:**
  Tool needed for OEMs to generate t_{final} tables

Landscape for H_2 HD fuelling standards (CGH_2 and LH_2):

- **35 MPa, HF** (e.g. HYZON)
  SAE J2601-2 High Flow, ~5 kg/min avg., TRL 9
- **70 MPa, MF** (e.g. NIKOLA)
  J2601-5, ~4 kg/min avg., TRL 5
- **70 MPa, HF** (e.g. Toyota, Hyundai, NIKOLA)
  ISO TC197 WG24, ~10 kg/min avg., TRL 6
- **sLH2** (e.g. Daimler Trucks)
  Subcooled LH_2 (1.6 MPa), ISO TC197 WG35, 8 kg/min, TRL 7
- **sLH2** (e.g. HYZON)
  Subcooled LH_2 (x MPa), ISO TC197 WG35, 8 kg/min, TRL 5
- **CcH2** (e.g. MAN, Cryomotive)
  Cryo compressed (40 MPa), ISO TC197 WG36, 8 kg/min, TRL 6

Source: HOW workshop: How to Bring Together Standards to Fuel HD Fuel Cell Trucks, 23 March 2023.

Thank you for your attention

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Project Description

What is PRHYDE?

With funding from the Fuel Cells and Hydrogen 2 Joint Undertaking (FCH 2 JU, now CHJU), the PRHYDE project is aiming to develop recommendations for a non-proprietary heavy duty refuelling protocol used for future standardization activities for trucks and other heavy duty transport systems applying hydrogen technologies.

Based on existing fuelling protocols and current state of the art for compressed (gaseous) hydrogen fuelling, different hydrogen fuelling protocols are to be developed for large tank systems with 35, 50, and 70 MPa nominal working pressures using simulations as well as experimental verification. A broad industry perspective is captured via an intense stakeholder participation process throughout the project.

The work will enable the widespread deployment of hydrogen for heavy duty applications in road, train, and maritime transport. The results will be a valuable guidance for station design but also the prerequisite for the deployment of a standardized, cost-effective hydrogen infrastructure.

For feedback on the PRHYDE project or the published deliverables, please contact **info@prhyde.eu**.

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Thank you for your attention