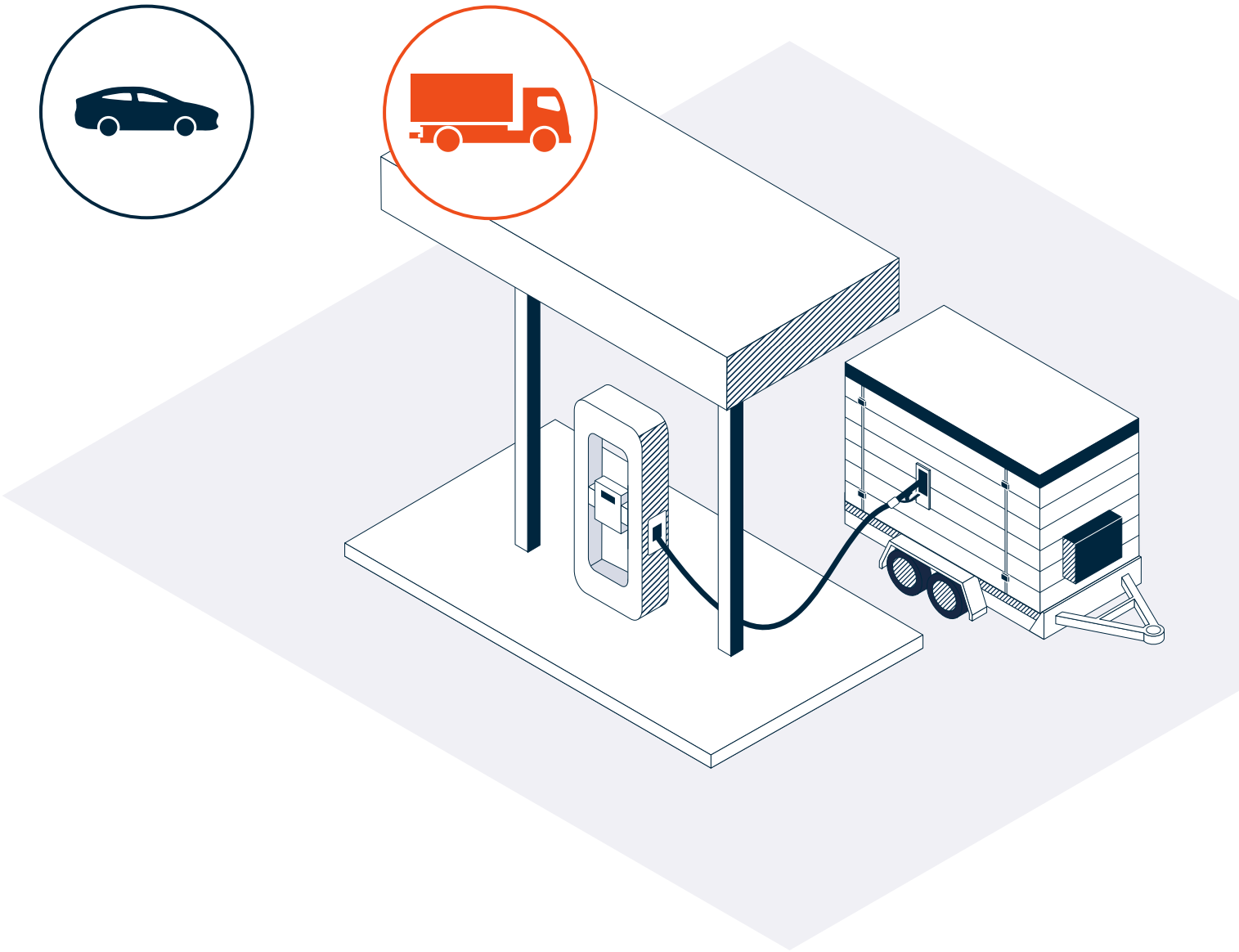
Performing SAT tests at heavy duty Hydrogen Refuelling Stations with small test benches (HSTA)



Technical and normative context

At present, several hydrogen fuelling protocols are defined for different vehicle and storage tank capacities. Each protocol establishes pressure, temperature and communication parameters that must be observed during refuelling operations. This diversity of standards directly affects the configuration and design of the test equipment used for station validation.

- SAE J2601 - Specifies fuelling procedures for vehicle fuel systems (VFS) with capacities between 49.7 l and 248.6 l for 350 bar and greater than 49.7 l for 700 bar. It targets light-duty applications and ensures safety and interoperability at hydrogen refuelling stations (HRS) within these categories.

- SAE J2601/5 - Specifies fuelling procedures for vehicle fuel systems (VFS) with capacities greater than 6 kg at 350 bar or 10 kg at 700 bar (248.6 L). It targets medium- to heavy-duty applications and ensures safety and interoperability at hydrogen refuelling stations (HRS) within these categories.

- **CEP H35 protocol for heavy commercial vehicles** - Applicable to 350-bar storage systems with capacities between 20 kg (830 l) and 42.5 kg (1750 l). It is primarily intended for heavy-duty or high-capacity applications, defining refuelling sequences optimised for this range.

- ISO 19885-3, which includes MCF-G and ALUT-G Protocol - Conceived as a harmonised method intended to cover all capacity categories within a single unified approach. However, it has not yet been published and is currently under development within ISO Working Group 24 (WG24), meaning no practical implementation guidelines are currently available.

Given this fragmented situation, it remains uncertain how an HSTA (Hydrogen Storage Test Apparatus) designed for LD testing (i.e., Category A/B/C) could technically trigger or emulate fueling sequences from higher-capacity categories. However, using the SAE J2601 categories, having an HSTA able to cover the full range and each of the categories A, B, C and D should be a good starting point.

Regarding category D, a properly configured HRS should only activate high capacity fueling protocols (HD protocols) when it recognizes a category D VFS (> 248.6 l).

Category A = 49.7 - 99.4 l

Category B = 99.4 - 174.0 l

Category C = 174.0 - 248.6 l

Category D = >248.6 l

Recommendations for conducting tests

The following recommendations aim to ensure safety, technical accuracy and proportionality between available test facilities (HSTA) and the required validation coverage.

a) Category A / B / C (49.7 – 248.6 litres)

- The following tests can be performed safely and effectively using any size of HSTA:
  - #3: Sensor verification - no fuelling required;
  - #8: CHSS starting pressure - functionality check only;
  - #16: Communication loss - functionality check only;
  - #18: Abort signal - functionality check only;
  - #36a: Non-Com 1 - in combination with #16 communication loss;
  - #37b: Com 2 - confirmation of communication functionality for the lower VFS category range.

Any HSTA volume is sufficient to validate these station functions without significantly influencing control algorithms.

- Using a larger HSTA (150 l - 175 l) is required for:
  - #36b: Non Com 2
  - #37a: Com 1

These tests demand a more representative fueling capacity in order to observe system performance under conditions that approximate real world operations.

- A vehicle can be used **only for the pre cooling capacity test #34**, and only once all relevant safety aspects have been validated at the station. This limited use minimizes risk and ensures consistency with the principles stated in existing **CEP-recommendations**.

b) Category D (> 248.6 litres)

The same group of tests, as described in paragraph a), may initially be carried out using any **HSTA size**, enabling a rapid assessment of control and safety functions under controlled conditions.

  - For **Non-Com 2 #36b** and **Com 1 #37a**, however, an HSTA of the **largest VFS capacity** expected at the station should be used to ensure realistic refuelling conditions that challenge the full performance range of the station.

Summary table

Nr	Test	50 l – 248.6 l Category	> 248.6 l Category	Comments
3	Sensor verification	Not applicable	Not applicable	No test bench required; basic station diagnostics only
8	CHSS starting pressure	Not specified	Not specified	Can be verified using any HSTA configuration
16	Communica-tion loss	Not specified	Not specified	Function confirmation in-dependent of capacity
18	Abort signal	Not specified	Not specified	Safety validation step; not capacity dependent
36a	Non Com 1	Not specified	Not specified	Can be confirmed with standard HSTA setup
36b	Non Com 2	Largest available HSTA (67 kg)	Largest available HSTA	For category > 248.6 l: vehicle may be used if justified, otherwise an HSTA which represents the vehicles fuelled at this station should be used.
37a	Com 1	Largest available HSTA (6-7 kg)	Largest available HSTA	For category > 248.6 l: vehicle may be used if justified, otherwise an HSTA which represents the vehicles fuelled at this station should be used.
37b	Com 2	HSTA 2-3.9 kg	HSTA, app. 248.6 l	For category > 248.5 l: any small HSTA in catego-ry D can be used
34	Pre cooling capacity	Vehicle allowed (contractually agreed)	Vehicle allowed (contractually agreed)	Only after all previous tests confirm the safe operation of the station

This table summarizes the appropriate test configurations for the different station categories, ensuring that each test is performed under representative yet manageable conditions.

safety and responsibility

The use of **vehicles** for validation or certification purposes by third parties is explicitly discouraged, in line with **CEP-recommendations**. Such practice involves safety risks and warranty implications that should be avoided whenever possible.

An **HSTA with a total capacity of only 2.1 kg at 700 bar** can effectively validate only **Category A** stations. Since most commercially available passenger cars already correspond to **Category B**, this approach has limited practical relevance.

The goal of the HSTA is to best represent real vehicles capacity, to perform the SAT.

Accounting for the constraints linked to large storage capacities (handling, venting time, hydrogen amount vented, etc.), different options are foreseeable, accounting for the following recommendations:

- to avoid manipulations at the fuelling station the HSTA for heavy duty refuelling should have a capacity sufficient to reach category D (e.g. >1250 l)
- if tests are performed with an HSTA not covering the real range of the station, confirm the HSTA results with additional observation of real vehicle fuellings
- if tests are performed with an HSTA not covering the real range of the station, some tests may be replaced by real vehicle fuellings, as long as all safety aspects have been previously confirmed
- if tests are performed with an HSTA not covering the real range of the station, some tests may be performed with an extension of the HSTA (sink)
- if tests are performed with an HSTA not covering the real range of the station, the HSTA may be developed and validate to simulate larger volumes from the station perspective (control valve, parallel venting, etc.)

Notes on future developments

A new **ISO standard** is expected to define procedures for hydrogen refuelling station evaluation and specify the characteristics of the required validation equipment. It is anticipated that such standardisation will involve larger hydrogen quantities **(typically exceeding 500 l)** to ensure realistic testing conditions.

To establish **future-proof test benches**, it is strongly recommended that new test infrastructure be designed to handle larger refuelling capacities – potentially above **1250 l** – even if such capability is not immediately required. This forward-looking approach will minimise future retrofit costs and align testing capabilities with the direction of forthcoming international standards.