SAE J2601- Worldwide Hydrogen Fueling Protocol: Status, Standardization & Implementation

Jesse Schneider, SAE Fuel Cell Interface Group Chair
Presentation Outline

- What is J2601?
- In-field TIR J2601 Experience
- SAE J2601 Standard Overview
- Data Confirmation Plan
Fueling Fundamentals

An optimal fueling protocol will …

- fuel all hydrogen storage systems *quickly* to a *high state of charge* (SOC)
- never violate the storage system operating limits of 85°C internal tank temperature (*don’t overheat*) or 100% SOC (*don’t overfill*)
What is SAE J2601?
Hydrogen Fueling Protocol History and Path Forward

- CaFCP I/O Guideline 2002
- OEM Fueling “Rev A” 2007
- SAE J2799 “70MPa Coupling & IrDA” 2007
- SAE TIR “L.D. H2 Fueling” Guideline 2010
- SAE J2601 Light Duty H2 Fueling and Communications Standard 2013
Prior Art existed on hydrogen fueling with communications and density targeted fueling, for example. This was documented in an NHA paper “Optimizing Hydrogen Vehicle Fueling” in 2005 from Daimler/Ford/GM/Honda/Hyundai/Toyota/Linde/Hydrogenics/HCI/GTI/NAC (J. Schneider, F. Lynch, J. Ward, S. Mathison, et al)

The *table-based* approach utilized in SAE TIR J2601 uses “Look up tables which stop the fueling at a set target pressure (for non- and with communications). This is *not* patentable as it originated from TIR J2601 document in 2010.
J2601-Editions & Timeline

- **J2601 Light Duty** Vehicle Fueling Protocols, Communications Currently Released (TIR) Guideline/ 2013 Standard

- **J2601-2 (HD)** hydrogen vehicle fueling guideline for 350 bar bus and heavy duty vehicles (>10kg): 2013 Guideline

- **J2601-3 (FL)** hydrogen vehicle fueling standard for 250 and 350 bar forklifts with small fuel tanks : 2013 Standard

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- J2601-2 Sponsor: [NBouwkamp@cafcp.org](mailto:NBouwkamp@cafcp.org)
- J2601-3 Sponsor: [Boyd.Hydrogen@gmail.com](mailto:Boyd.Hydrogen@gmail.com)
SAE TIR J2601
Light Duty
Technical Goals for Compressed Hydrogen Fueling

• **Maintain the safety limits of storage system.**
  - Max. Temperature: 85° C / Max. Pressure: 87.5 MPa (70 MPa NWP)

• **Achieve target desired customer attributes.**
  - **Fueling Time:** 3-5 minutes Ramp Rate (Type A Station, longer for other types)
  - **Typical State of Charge Range:** 90% to 100% (density based on NWP at 15° C)

Options for Compressed Hydrogen Fueling Protocol

• Vehicle to station interface strategies
  - **Communication:** vehicle transmits tank parameters through wireless interface
  - **Non-communication:** vehicle provides tank pressure only

• Station key control factors
  - **Pre-cooling of hydrogen:** station conditions H₂ temperature prior to dispensing
  - **Hydrogen delivery rate:** station provides fill rate per mass or pressure vs. time
  - **Fill termination:** station determines end pressure and/or density that meets goals
After 8 years, the guideline TIR J2601 was released in March 2010

What is SAE TIR J2601?
- First World-Wide Light Duty Hydrogen Vehicle Fueling Protocol 35 & 70MPa: *Created by Math Modeling, Confirmed by Real OEM System Testing*

What does it cover?
- **Light Duty Hydrogen Vehicle Fueling** (1-10kg@70MPa, 1-7kg@35MPa)
  Dispenser Protocol for with & without communications
- Defines Safety Limits and Performance Targets.
- Table-Based Approach
- Enables “Same as Today” fueling, < **300 mile range in 3 minutes** fueling time with Type ‘A’ Dispenser, < 7 kg hydrogen
TIR J2601 defines fueling station dispenser type by capability to dispense hydrogen fuel at a specific nozzle “pre-cooled temperature”. Note: There is a direct relation between pre-cooling and fueling speed.

- Type “A”- Dispenser has -40°C pre-cooling (70 & 35 MPa)
- Type “B”- Dispenser has -20°C pre-cooling (70 & 35 MPa)
- Type “C”- Dispenser has 0°C pre-cooling (35 MPa only)
- Type “D”- Dispenser has no pre-cooling (35 MPa only)
J2601 Fueling Tables: 70MPa with ≤ 7kg Storage Capacity*

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<th>Initial Tank Pressure, $P_i$ (MPa)</th>
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Typical: **3 Min.**

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Typical: **15 Min**

- **90% non-com**
- **98%+ comm.**

*Note: Cool Down Times may add a minute*
Hydrogen Dispenser Validation

SAE J2601
L.D.V. H2 Limits & Targets
- Non-Communication
- Communications

CSA 4.3 (or equivalent)
H₂ Dispenser Fueling Test
- Test Procedure
- Testing Device (H.D.T.A.)

*Shown CaFCP Station Test Apparatus
SAE J2601 HD & FL Guideline Drafts
J2601-2 HD Bus Fueling

HD fueling assumptions (draft)
• Total vehicle tank capacity: >10kg
• 35 MPa
• Performance based
• Maximum fueling rate
  – Option A: up to 3.6 kg/min (60g/s)
  – Option B: up to 7 kg/min (120g/s)
• Communication between vehicle and station suppliers
• LD vehicles cannot fill at “Option B”

HD dispenser
J2601-3 Fork Lift Fueling

Draft

Option 1: Fill to Service Pressure

Option 2: Fill to Target Pressure
In-field TIR J2601 LD Experience
**TIR J2601 LD Experience**

**Positive:**
- Safe Fueling (no overheating with correct tables)
- Communications Fueling very robust, repeatable (high SOC)
- Good performance with proper pre-cooling
- World Wide Acceptance of Guideline

„**Room for Improvement**“
- Pre-cooling Issue to meet „cool down window“(15s)
- Issue to meet tolerances on ramp rate, temperatures
- „Too-strict“: Potential for shutdown with out-of-tolerance
- No Station met 100% of requirements (closest in EU)
SAE J2601 LD Standardization
J2601 TIR

SAE J2601 Standard

J2601 Guideline For Demo Station Build-up

- Realistic Tolerances and Sensor Locations
- New Precooling Categories
- Updated Validated Tables
- Relaxed Tolerances
- IrDA Comm
- Optional Alternative Fueling

J2601 Standard for “Initial-Phase“ Commercialization Station Build-up

Input & Coordination w/Organizations (CEP, HySuT, CaFCP)
Fueling Dispenser Types

J2601 Standard defines fueling station dispenser type by capability to dispense hydrogen fuel at a specific nozzle “pre-cooled temperature”. Note: There is a direct relation between pre-cooling and fueling speed.

JARI Proposal:
**Pressure Corridor Tolerances**

Proposed tolerances:
- $d_{\text{P lower}} = 2.5 \text{ Mpa}$
- $d_{\text{P upper}} = 7.0 \text{ Mpa}$

*Proposal is based on input from JARI/Opel Presentations*
Data Confirmation
Confirmation of Look-Up Tables
SAE J2601 Validation Testing

Purpose:
- Experimentally confirm the 35 and 70 MPa fueling targets included in the SAE J2601 look-up tables
- Experimentally confirm the tests utilize representative fueling storage

Scope of Work examines three distinct areas of interest:

1. Confirm Real World Experience to meet Original Tables from TIR
2. Over-temperature fueling
   - Testing with hot-soak conditions on Type 4 tanks
3. Over-density fueling
   - Testing with cold-soak and cooling from driving on Type 3 tanks
4. Target SoC fueling
   - Testing with “normal” conditions on all tanks to confirm non-communication SoC
5. Optional MC Fueling Confirmation
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5. Optional MC Fueling Confirmation
Conclusion

• J2601 L.D. to be published in 2013 based on simulation and validation data
  • “Field Data Lessons Learned” tolerances to be used in updated fueling tables to allow for a commercial infrastructure

Additional Features to J2601: for fueling:
→ IrDA Data Communications (from J2799)
→ Optional Alternative Methods

• J2601-2 HD Guideline publishing in 2013 (Standard 2014)

• J2601-3 FL Standard publishing in 2013
Questions?

Contact: Jesse.Schneider@web.de
IrDA Communications
Infrared Data

- Available Technology
- Transparent to customer
- Vehicle tank info for Temp. Comp.
- 10%+ Better Fueling Density
- IrDA is being taken from J2799

![Diagram of hydrogen fueling systems and vehicle interface](image-url)

- Fueling protocol created from fueling actual OEM tanks tested under extreme conditions
- Provides guidance for hydrogen fueling within reasonable time without exceeding temperature and pressure limits
- Provides pressure targets to achieve a reasonable state of charge (SOC) under diverse ambient temperature(s)
- Validated with CSA 4.3 device
**J2601 Fueling Tables: 35MPa Non-Communication**

### Type A (-40°C)

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**Typical 2 Min.**

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**Typical 3 Min.**

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**Typical 15 Min.**

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**Typical 45 Min.**
Fueling Procedure Summary

Start

Communication Signal?

Yes

Dispenser Type

Dispenser Type

No

Ambient Temperature

Vehicle Measurements

HSS Initial Pressure $P_0$
HSS Capacity

Lookup Tables - A, B, C, or D
Average Pressure Ramp Rate (APRR)
Fueling Target Pressure $P_{target}$

Fuel While

$P_{station} < P_{target} - \Delta P_{station}$

End

Vehicle Measurements

HSS Initial Pressure $P_0$
HSS Capacity

Vehicle Data

Vehicle Data Validity Check

No

Alt Ramp Rate Authorization?

Yes

APRR

Lookup Tables A, B, C, or D

Ramp Rates

Table A APRR
Alt for B, C or D

While Valid Vehicle Data Received

Fuel While
$P_{station} < 125\% \text{ NWP} - \Delta P_{station}$
$P_{station} < 110\% \left( P_{target} - \Delta P_{station} \right)$
$\text{SOC}_{station} < 100\% - \Delta \text{SOC}_{station}$
Vehicle command $\neq$ Abort
$T_{vehicle} < 85^\circ \text{C}$
$P_{vehicle} < 125\% \text{ NWP}$

End

Gray box – station only

Blue box - vehicle interaction
SAE J2601 Standard Goals

- Realistic Tolerences and Sensor Locations
  - New Catagories for Precooling
  - Define „fall back“ procedures for APRR
- New Type of Dispenser Pre-cooling
- IrDA Integration (potential for Alt-Fueling identification)
- Interpolation between tables
- Simulation Needed to update tables

- Optional „Alt“ Alternative Fueling with confirmation (TBC):
  - MC Method
  - Variable Pressure Ramp Rate