Development of the Hydrogen Station Equipment Performance (HyStEP) Device

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Sandia National Laboratories
June 11, 2015

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Overview

Timeline
• Task Start Date: 08/22/2014
• Task End Date: 10/31/2015
• Percent Complete: 50%

Budget
• Total Task Budget: $880.5K
  – DOE Share: $828.5K
  – Cost Share: $ 52K
    • Air Liquide ($11.3K)
    • Toyota ($11.3K)
    • CARB ($21.5K)
    • Boyd Hydrogen ($7.5K)
• DOE Funds Received To-date: $828.5K

Barriers – Technology Validation
D. Lack of Hydrogen Refueling Infrastructure Performance and Availability Data
E. Codes and Standards

Partners
• Lead: Sandia National Laboratories
• National Renewable Energy Laboratory
• Air Liquide
• Boyd Hydrogen
• CA Air Resources Board
• Toyota
Relevance: HyStEP Device will shorten lengthy station acceptance process

Today’s Problem: Each OEM performs vehicle test fills to validate the station

Tomorrow’s Solution: HyStEP Device is surrogate for vehicles, operated by testing agency

[Diagram showing vehicle test fills across multiple weeks with HyStEP device tested in Week 1, Station accepted in Week 6]
Main Objective – *Accelerate commercial hydrogen station acceptance by developing and validating a prototype device to measure hydrogen dispenser performance.*

- **Fill safely:** Common goal of vehicle manufacturers, consumers, station operators, and state stakeholders

- **Follow standards:**
  - SAE J2601-2014 (fueling protocol), specifies how to fill hydrogen vehicles safely.
  - CSA HGV 4.3 (test method), defines how to test dispensers for compliance with SAE J2601.

- **Test stations:** HyStEP Device will be capable of testing to the CSA HGV 4.3 test methods.
  - Task Output: Government-owned device that has been validated to measure station performance relative to standards.
  - Once pre-deployment testing is complete, the unit will be loaned to a designated CA agency.
  - The resulting HyStEP Device design will be published and available at no cost.
Approach: Mobile device co-designed by Project Team and fabricated by industry stakeholder

Specifications for HyStEP

- Device is mobile: Mounted in a trailer
- Type IV 70 MPa tank(s) with at least a 4-7 kg capacity
- Designed to be able to perform subset of CSA HGV 4.3 tests, may add others in the future (e.g. MC fill)
- SAE J2799 IrDA for communication tests and fills
- Tank and receptacle instrumented with multiple P, T sensors to monitor pressure ramp rate, ambient, tank, and gas conditions.
- Leak simulation to check dispenser response

HyStEP Device will be fabricated by Powertech Labs

- Co-designed by H2FIRST HyStEP Project Team
- Powertech fabricates 70 MPa H2 refueling stations and has H70-T40 testing capability
- SAE J2601-2014 validation testing was performed at Powertech
- Experience with mobile, high pressure H₂ systems
- Designed and built hydrogen station test devices for commissioning fueling stations
Approach: Project milestones on track

- Issue RFQ (M)
- DOE Briefing (M)
- Place contract (M)
- Development (M)
- FMECA analysis (G)
- Design Review (G)
- Initial checkout and testing
- Testing at Air Liquide CA station (M)
- Validation testing at NREL (M, G)

M = Milestone; G = Go/No-Go Decision
Accomplishments: HyStEP Device design completed

Piping and Instrumentation Diagram (P&ID)

Trailer Layout

Electrical Equipment Layout

Mechanical Component List

Electrical Component List
Accomplishments: Design will include multiple tanks to accommodate all J2601 size classes

- Three 77L Type IV tanks from Quantum Technologies
  - 3.1 kg H₂ capacity at 70 MPa and 15 °C
  - 500 mm diameter by 720 mm length
- Allows for testing all SAE J2601 tank sizes
- Five tanks were produced in Dec. The two extra tanks will be tested at Powertech
- Tank design has been qualified to EC 79 (European standard for vehicle tanks)
  - To meet ANSI/CSA NGV2 for H₂ vehicles, a full Extreme Temperature cycle test will be completed at Powertech
  - Additionally, Powertech will perform a bonfire test with the TPRD planned for this device.
  - All testing data will be furnished to the Project Team for review
Accomplishments: Robust and flexible data acquisition and control system

- National Instruments LabVIEW software will monitor and control the device
  - Operator interface via touchscreen panel.
  - CSA HGV 4.3 test options listed for selection.
  - Real-time display of test progress and measured and calculated parameters.
  - Parameters flagged that are outside of specifications.
  - Control algorithms and screen layouts designed with flexibility for ease of modification

- Chassis based DAQ system designed for robustness
  - Handle up to 50g shocks and 5g operational vibration testing.
  - Data stored on DAQ computer hard drive will be easily searchable and transferable
Accomplishments: Communication tests and fills enabled with IR system per SAE J2799

Communications Tests

- Abort
- Halt
- Data Loss then Abort
- Data Loss and resume
- ID Protocol
- Version #
- CHSS Volume
- Receptacle Type
- Fueling Command
- Measured Pressure
- Measured Temperature

Vehicle side communications will be provided by IRDI System, Inc.

Labview interface will be integrated with HyStEP control software
Accomplishments: FMECA identified safety hazards and risks which will be mitigated

- Intertek Consulting facilitated the FMECA carried out by Powertech and the Project Team
- 7 functional blocks were analyzed
- 44 functions were defined
- 202 failure modes and effects were identified
- Each effect was assigned severity, occurrence, and detection/prevention ratings
- 47 failure mode effects had severity of 9 or 10 indicating a safety hazard
- 20 failure mode effects had RPN* > 100 and all have recommendations to lower the risk

*Risk priority number (RPN) = Severity x Occurrence x Detection
Max RPN possible = 10 x 9 x 9 = 810
Accomplishments: Go/No-Go criteria met for device fabrication

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Criteria</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>HyStEP Device Design Review</td>
<td>HyStEP Device is ready for Fabrication. (Task 2.10, Go/No-Go 10.1)</td>
<td>HyStEP device design reviewed by the Project Team, DOE HQ, and the Hydrogen Safety Panel and found acceptable.</td>
<td>3/31/2015</td>
</tr>
</tbody>
</table>

Review and Acceptance by Project Team

Status: Project Team has had extensive reviews and has approved the design (“Go”)

Review and Acceptance by Hydrogen Safety Panel

Status: Project Team has determined that the current design addresses all HSP comments and recommendations (“Go”). Response submitted to HSP for confirmation of acceptance.

Review and Acceptance by DOE HQ

Status: Based on the above reviews and a briefing on March 26, 2015 the DOE Managers have determined that the HyStEP device design is acceptable and ready for fabrication.
Accomplishments: Responses to Previous Year Reviewer’s Comments

- This project task was not specifically reviewed last year.
Collaborations: HyStEP Project Team consists of key stakeholders

<table>
<thead>
<tr>
<th>Partner</th>
<th>Project Roles</th>
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</thead>
<tbody>
<tr>
<td>Sandia National Laboratories</td>
<td>Project lead, management and coordination; device design; safety analysis</td>
</tr>
<tr>
<td>National Renewable Energy Laboratory</td>
<td>Device design; safety analysis; device validation testing</td>
</tr>
<tr>
<td>Air Liquide</td>
<td>Device design; safety analysis; facilitate pre-deployment testing</td>
</tr>
<tr>
<td>Boyd Hydrogen</td>
<td>Device design and safety analysis</td>
</tr>
<tr>
<td>CA Air Resources Board</td>
<td>Device design; safety analysis; facilitate pre-deployment testing</td>
</tr>
<tr>
<td>Toyota</td>
<td>Device design; safety analysis; vehicle participation/comparison for pre-deployment testing</td>
</tr>
<tr>
<td>PNNL H$_2$ Safety Panel</td>
<td>HyStEP design and safety review by HSP</td>
</tr>
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</table>
Remaining Challenges and Barriers

Control software

**Challenge 1:** Simple operation with user-friendly interface. Information easy to understand and interpret resulting in clear decision making. No manual data processing required by operator.

**Challenge 2:** Achieving functionality when CSA HGV 4.3 is in draft form and achieving flexibility such that changes to 4.3 can be easily incorporated.

– SAE J2601-2014 includes a number of changes: five tank size classes, three pre-cooling temperatures, new protocols, new definitions, large number of tables (30 standard tables; 24 optional).

– Current CSA HGV 4.3 draft: Protocol Tests (com/non-com, H35/H70, T40/30/20, size class, top-off, cold dispenser), Communication and Fault Detection Tests (expanded from HGV 4.3-2012)

Schedule

**Challenge:** Timeline to pre-deployment testing is aggressive. Delays in component delivery, fabrication, integration or validation testing will result in schedule slips.
Proposed Future Work

- Procurement/fabrication – Powertech - April
- Mechanical assembly and integration – Powertech - May
- Control and DAQ integration – Powertech – May
  - Challenge: CSA HGV 4.3 is currently being re-written
- Initial checkout and testing – Powertech - June
  - Subtask 14.1: On-site visit prior to shipment – Project Team
  - M14.1 – July 16: HyStEP device received by NREL for testing.
- Final checkout and verification – NREL/ Powertech /SNL – July/August
  - Go/No-Go 15.1: Results of the NREL testing will be reviewed by the project team, DOE HQ, and communicated to H2USA members and additional DOE-approved stakeholders
- Publication of Documentation – Powertech/SNL - July
- Pre-deployment test #1 – SNL/Project Team - September
  - Milestone 17.1: Testing has been completed at the first CA station
- Pre-deployment test #2 – SNL/Project Team - October
- Performance analysis and report – NREL – October
- Initiate loan to State of CA agency (CARB/DMS) – SNL - November
Proposed Future Work/Tech Transfer: CA Implementation Plan

• CA HyStEP Task Force is working to develop an implementation plan
• Task Force is led by Mike Kashuba from CARB and includes representatives from CaFCP, CDFA, CEC, SCAQMD, vehicle OEMs, station providers, NREL and Sandia
• Task Force provides input or develop solutions for the following:
  – Real-time data display and report template
  – Data reporting/sharing (what and with whom)
  – Legal consequences of test results and enforcement agency
  – Operators: Identified a two-person team – Measurement Standards Specialist from CDFA/DMS and Air Resources Engineer from CARB
  – Funding: Proposing a $625K budget co-funded by CARB, CaFCP, CEC and SCAQMD
  – Implementation/testing schedule: Proposed a 2-year loan starting Q4 2015 for operating HyStEP in CA
Technology Transfer Activities: HyStEP Device design package will be published

1. Device specification
2. User manual including operating instructions and a troubleshooting guide
3. Maintenance schedule and instructions
4. A final piping and instrumentation diagram (P&ID)
5. Dimensioned drawings of the overall system
6. Electrical wiring diagram
7. Control software code, description, and instructions for modification
8. Report summarizing the HA/FMEA
9. List of components (Bill of Materials) and the manufacturer’s documentation (if applicable)
10. Component certifications
11. Documented leak and pressure tests
12. Device Validation Test Report
Summary – Progress and Accomplishments

• HyStEP Device will enable more rapid hydrogen station commissioning
• A diverse team of experts are collaborating to design the device
• Powertech is an extremely well qualified supplier
• Device design completed and “Go” decision made for device fabrication as of March 26, 2015
• The project is on schedule to test the first CA H2 station in September, 2015
Technical Back-Up Slides
## Approach: Milestones and Go/No-Go Decisions

### Milestone Name/Description

<table>
<thead>
<tr>
<th>Milestone Name/Description</th>
<th>End Date</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post the RFQ for the HyStEP Device (Task 1)</td>
<td>9/30/2014</td>
<td>Complete</td>
</tr>
<tr>
<td>A detailed specification for the HyStEP device including main components, instrumentation, test requirements, and data collection and reporting will be completed by the project team and provided to DOE HQ for review and acceptance prior to including in the RFQ. (D1, Task 1)</td>
<td>9/30/2014</td>
<td>Complete</td>
</tr>
<tr>
<td>Brief DOE HQ on the review processes and justification for the choice of HyStEP device supplier. (SNL/NREL Task 2)</td>
<td>10/31/2014</td>
<td>Complete</td>
</tr>
<tr>
<td>Contract for the HyStEP device placed for the fabrication of the station test device (SNL Task 4)</td>
<td>11/30/2014</td>
<td>Complete</td>
</tr>
<tr>
<td>HyStEP device received by NREL for validation testing. (M14.1, Task 14)</td>
<td>7/16/2015</td>
<td>Not Started</td>
</tr>
<tr>
<td>Complete at least 3 rounds of CSA HGV 4.3 tests 2.2.1 - 2.2.5, 2.3.1 - 2.3.3, and 2.4.1 - 2.4.2 at a station. Successful operation includes that the HyStEP device temperature and pressure measurements for each round of testing are within a target value of 10% depending on the station variation and the results of the NREL validation tests. The data output of the device will also be compared with the station temperature and pressure measurements. (M17.1, Task 17)</td>
<td>9/30/2015</td>
<td>Not Started</td>
</tr>
<tr>
<td>Publish the HyStEP design documentation per Task 19 (SNL D2-D12, Task 19)</td>
<td>9/30/2015</td>
<td>Not Started</td>
</tr>
<tr>
<td>Final performance report of HyStEP from operation at three different stations. (Task 20)</td>
<td>10/31/2015</td>
<td>Not started</td>
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</table>

### Go/No-Go Name/Description

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<td>HyStEP Device is ready for Fabrication. (Go/No-Go 10.1)</td>
<td>HyStEP device design reviewed by the Project Team, DOE HQ, and the Hydrogen Safety Panel and found acceptable.</td>
<td>3/31/2015</td>
<td>Met</td>
</tr>
<tr>
<td>HyStEP device performance is acceptable (Go/No-Go 15.1)</td>
<td>Results of the HyStEP validation testing show that the device accuracy and precision are acceptable. The results are to be reviewed by the project team and DOE HQ as well as communicated to H2USA members and additional stakeholders identified by DOE via webinar.</td>
<td>8/31/2015</td>
<td>Not started</td>
</tr>
</tbody>
</table>
## Approach: Safety and Performance Validation

### Safety
- Safety features by design:
  - Emergency Shutdown System activated by hardware, software or the operator
  - PRVs and TPRDs
  - \(H_2\) detection
  - Class 1 Zone 2 electrical
  - Grounding connection
- Facilitated HA/FMEA will be carried out by Powertech and Project Team
- Final design review by Project Team
- H2 Safety Panel review
- Onsite visit to Powertech for initial acceptance testing
- Testing at NREL’s ESIF facility
  - Training and technical support from Powertech

### Performance
- At Powertech:
  - Control and DAQ communications
  - IrDA operation
  - Leak checks and proof test of the pressure components
  - Automated procedures
- NREL-ESIF: Device validation testing
  - H70-T40 research dispenser
  - All required tests will be carried out and verified per CSA HGV 4.3.
  - Measured and calculated parameters checked for completeness and accuracy.
- Pre-deployment station testing in CA
  - Air Liquide Anaheim station
  - 2nd station TBD
Accomplishments: Trailer-based system chosen based on Powertech’s experience

- **Powertech experience:**
  - Mobile fueler for HCEV road rally
  - 45 MPa Hydrogen Transport Trailers
  - Standard dual axle spring suspension cargo trailer used for field testing

- **Trailer pros:**
  - Protection from the environment/weather
  - Easy to hand off to various end-users
  - Allows for isolation of hazardous location
  - Easy access to controls/user interface
  - Doesn’t require a dedicated vehicle
  - Better access to system for maintenance

- **Trailer options investigated by Powertech:**
  - Similar design to mobile refueler, but smaller: 6-7’ wide and 10-12’ long.
  - Partitioned with front room for electrical/DAQ and rear for H2 system.
  - Tandem axle design with torsion axles to provide a smooth ride and mitigate road vibrations.
Accomplishments: HyStEP Device design completed

- WEH 70 MPa SAE J2600 Receptacle
- Headline 3 μm particulate filter
- Tescom Regulator: 0-15,000 psi inlet, 0-500 psi outlet
- Parker MPI Series: 3/8" tubing; 15,000 psi rated
- FM Valve 1511 Series PRV
- Parker- Autoclave MAN Series Normally Closed, Air to open 15,000 psi rated
- Stellar GT2250 Series high accuracy model (0.10% FSO)
- 1/8" TC Probe with HiP Adaptor (15,000 psi rating)
- Quantum 77L Type IV Tanks
- Parker- Autoclave Needle Valve

Notes:
2. For Air Valve Manifold details see drawing PL-00742-11-15
Accomplishments: Instrumentation will include multiple pressure and temperature sensors

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Measurement Range</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Receptacle Pressure</td>
<td>0 to 100 MPa</td>
<td>0.1% of full scale</td>
</tr>
<tr>
<td>Receptacle Temperature</td>
<td>-45 to 100 °C</td>
<td>± 1 °C</td>
</tr>
<tr>
<td>Tank Gas Pressure</td>
<td>0 to 100 MPa</td>
<td>0.1% of full scale</td>
</tr>
<tr>
<td>Tank Gas Temperature*</td>
<td>-45 to 100 °C</td>
<td>± 1 °C</td>
</tr>
<tr>
<td>Ambient Temperature</td>
<td>-45 to 55 °C</td>
<td>± 1 °C</td>
</tr>
<tr>
<td>Tank Inlet Temperature</td>
<td>-45 to 55 °C</td>
<td>± 1 °C</td>
</tr>
</tbody>
</table>

*Temperature measurement for the tank gas includes a correction to account for the ambient temperature.