Hydrogen Fueling Infrastructure Research and Station Technology

Hydrogen Meter Benchmark Testing
2016 DOE Annual Merit Review

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National Renewable Energy Laboratory

June 09, 2016

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Project ID # TV037

Overview

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TIMELINE

- Start date: 9/1/2015
- End date: 09/30/2016

BARRIERS

Multiyear RD&D Barriers

Technology Validation Barriers

- ***D.*** Lack of Hydrogen Refueling Infrastructure Performance and Availability Data
- ***E. Codes and Standards -*** *Validation projects will be closely coordinated with Safety, Codes and Standards*

Safety Codes and Standards Barriers

- ***F.*** Enabling national and international markets requires consistent RCS
- ***G.*** Insufficient technical data to revise standards
- ***J.*** Limited participation of business in the code development process

BUDGET

- Project funding FY15/16: **$500K**

PARTNERS

- SNL (Sandia National Laboratory)
- NIST (National Institute of Standards and Technology) Fluid Metrology Group
- JRC-IET (Joint Research Center – Institute for Energy and Transport)
- CDFA (California Department of Food and Agriculture) Division of Measurement Standard
- CARB (California Air Resources Board)
- BMW

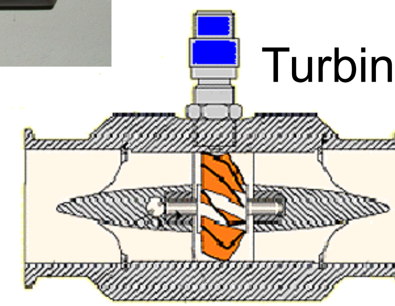
Relevance: Selling Hydrogen

Hydrogen flow meters are struggling to meet the 1.5% accuracy requirement for motor vehicle fuels impeding the sale of hydrogen by the kilogram.

Relevance: Flow Meter Comparison

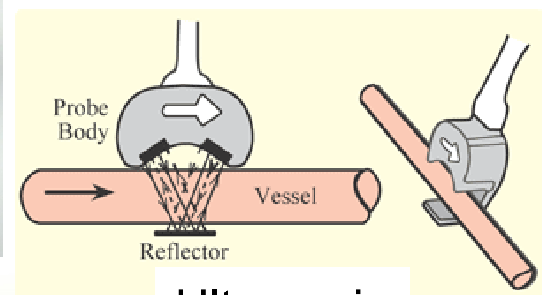
- Coriolis Meters
  - Current industry standard
  - Meeting CA accuracy class 5.0
- Turbine Meters
  - Turndown ratio of 100:1
  - Used in many high pressure applications
  - Volumetric measurement – mass will need to be calculated
- Thermal Meters
  - No meters were found to be rated for dispenser pressures
- Ultrasonic Meters
  - Requires a long run of straight tubing
  - Wall thickness of tubing needed for pressure rating has not been tested

Coriolis



Turbine

Thermal



Ultrasonic

Approach: Integrated Component Testing

Hydrogen Infrastructure Testing and Research Facility (HITRF) located at the Energy Systems Integration Facility in Golden

Successful deployment of hydrogen infrastructure will require components that are proven to meet existing performance standards

Approach: Flowmeter Benchmark Testing

- **Design** and build laboratory grade gravimetric hydrogen standard
- **Conduct** high pressure hydrogen testing of commercially available flow meters
  - **Replicate** conditions specified in SAE J2601 fueling protocol
- **Report** on flow meter performance against NIST Handbook 44 requirements and CCR accuracy classes

Approach: Project Schedule

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Description	Status	Date
Conceptual Design Review	Complete	October, 2015
Stakeholder Review	Complete	January, 2016
Interim Report	Complete	January, 2016
Final Flow Meter Selection	Complete	March, 2016
First benchmark test	On Track	May, 2016
Final Report	On Track	September, 2016

Approach: Test Plan

Testing is designed to span the range of hydrogen gas conditions that would be experienced at current light duty hydrogen vehicle fueling stations

Three types of tests per device under test (DUT)

1. Steady flow
2. Pressure ramp rate
3. Pressure pulse test

Notes on testing

- Transients are inherently built into each start and stop
- No pre-chilled hydrogen
- Testing at ambient conditions

Approach: Test Plan

1. DUT Steady Flow
   - **Objective: Identify meter performance at three different flow intervals: low, medium, high**
   - Flow ranges represent spectrum of SAE J2601 flows expected
   - Use scale as feedback loop for flow rate

Configuration: Position 1 (M-H-PRV34 control) or Position 2 (M-H-PRV12 control)					
Type	Transient Up	Transient Down	Low	Medium	High
Description	Start of Flow	Stop of Flow	Stable Flow	Stable Flow	Stable Flow
Range	< 0.1	< 0.1	0.1 - 0.5	0.5 – 2.3	2.3-3.6
Units	kg/min	kg/min	kg/min	kg/min	kg/min
Number of Samples	30	30	10	10	10
Accuracy: Average					
Accuracy: Standard Deviation					
Tracking parameters: $T_{ambient}$, $P_{gas\ inlet}$, $T_{gas\ inlet}$, $P_{DUT\ upstream}$, $T_{DUT\ upstream}$, $P_{DUT\ downstream}$, $T_{DUT\ downstream}$					

Steady Flow/Pressure Test Matrix

Approach: Test Plan

2. DUT Pressure Ramp Rate
   - **Objective: Identify meter performance at three different ramp rates: low, medium, high**
   - Ramp rates based on SAE J2601 lookup tables:
     - Ramp rate high: -40 to 20 ^{o}C ambient (cool day)
     - Ramp rate medium: 20 to 40 ^{o}C ambient (typical day)
     - Ramp rate low: 40 to 50 ^{o}C ambient (hot day)

Configuration: Position 1 (M-H-PRV34 control) or Position 2 (M-H-PRV12 control)					
Type	Transient Up	Transient Down	Low	Medium	High
Description	Start of Flow	Stop of Flow	Stable Ramp	Stable Ramp	Stable Ramp
Range	< .1	< .1	5.1 - 11.5	11.5 - 21.8	21.8 - 28.5
Units	kg/min	kg/min	MPa/min	MPa/min	MPa/min
Number of Samples	30	30	10	10	10
Accuracy: Average					
Accuracy: Standard Deviation					
Tracking parameters: $T_{ambient}$, $P_{gas\ inlet}$, $T_{gas\ inlet}$, $P_{DUT\ upstream}$, $T_{DUT\ upstream}$, $P_{DUT\ downstream}$, $T_{DUT\ downstream}$					

Pressure Ramp Rate Test Matrix

Approach: Test Plan

3. DUT Pressure Pulse
    - **Objective: Identify meter performance during pressure pulses**
    - Simulate pressure pulse that happens at the beginning of SAE J2601 fill
    - Keep mass transferred under 200 grams

Configuration: Position 1 (M-H-PRV34 control) or Position 2 (M-H-PRV12 control)	
Type	Pulse
Range	< .2
Units	kg (transferred)
Number of Samples	30
Accuracy: Average	
Accuracy: Standard Deviation	
Tracking parameters: $T_{ambient}$, $P_{gas\ inlet}$, $T_{gas\ inlet}$, $P_{DUT\ upstream}$, $T_{DUT\ upstream}$, $P_{DUT\ downstream}$, $T_{DUT\ downstream}$	

Pressure Pulse Test Matrix

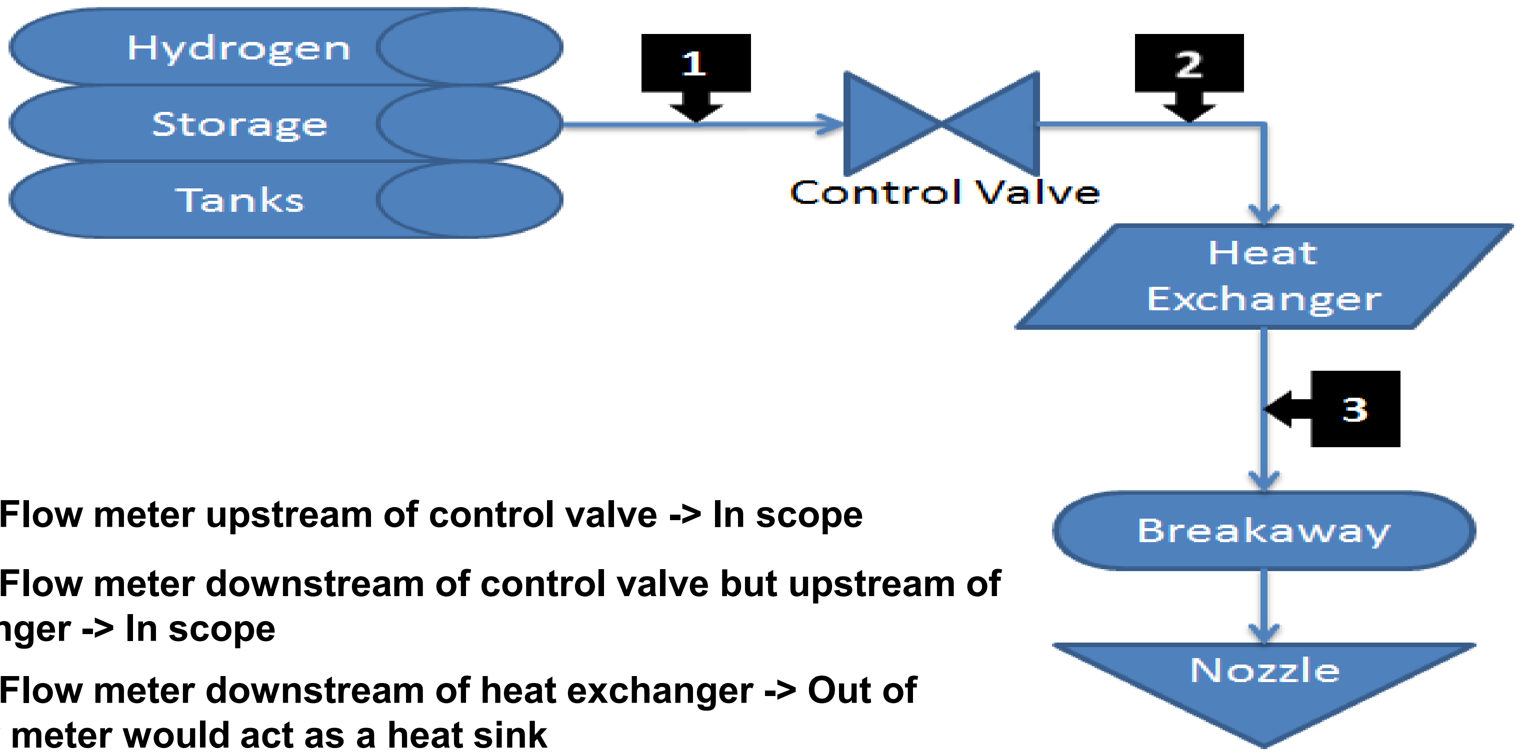
Accomplishment: Meter Selection

- Market survey to narrow flow meter choices
  - Different flow meter technologies
  - Pressure and temperature ranges
  - Material compatibility
  - Flow ranges and accuracy
- Received industry feedback on which meters are worth testing
- Two Coriolis meters (industry standard) and one turbine meter were selected for testing

Accomplishment: System Design

Meter Location

- Benchmark testing will replicate flow meter placement in locations 1 and 2
- Location 3 creates challenges related to thermal mass and chill down time



Position 1: Flow meter upstream of control valve -> In scope

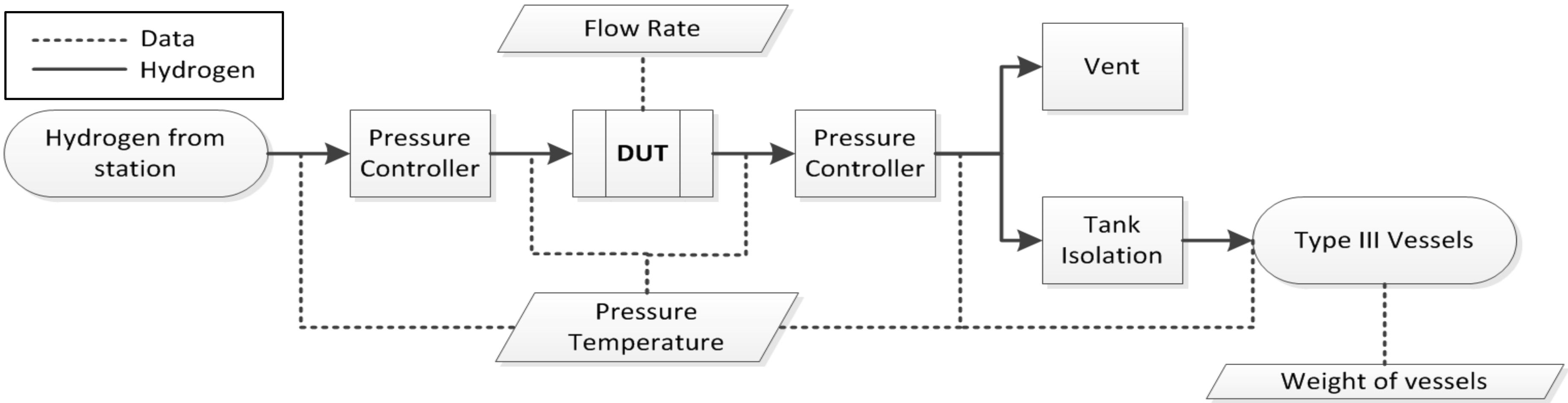
Position 2: Flow meter downstream of control valve but upstream of heat exchanger -> In scope

Position 3: Flow meter downstream of heat exchanger -> Out of scope, flow meter would act as a heat sink

Accomplishment: System Design

Process

- A final piping and instrumentation diagram (P&ID) was developed after safety and performance metrics were finalized.
- NREL performed a hazard and operability study in November, 2015 and added safety features to the device as a result of that study
  - Safety Features: Pressure relief device, check valves, pressure high/low, temperature high/low, temperature relief devices, controls measures



Accomplishment: System Design

Hardware

Weighing Standard

- High-resolution weighing platforms designed for use in tough industrial environments
- 300 kg capacity, resolution enhanced to **± 0.2 gram**

Pressure Vessels

- Luxfer-Dynecell Type III composite overwrapped cylinders
- Each vessel: 40 liter water volume, ~1.6 kg of H_2 at full pressure, 41 kg load
- Type III tank preferred for heat transfer benefit during filling and venting

Hardware

- High pressure, hydrogen compatible valves, fittings, transducers, and indicators

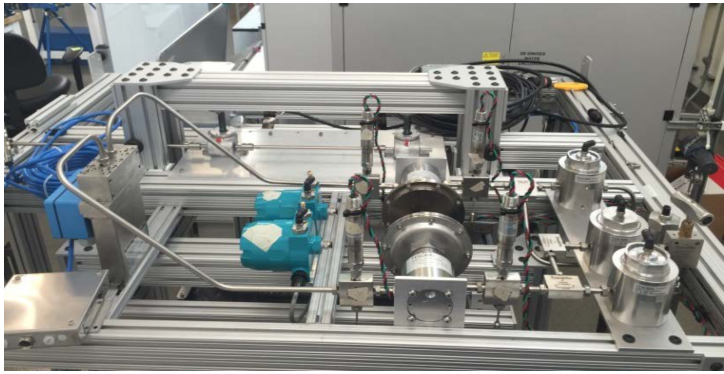
Accomplishment: Pre-Testing of System

Objective

- Determine where the scale reading starts
- Determine the pressure, volume, temperature (PVT) method for stagnant conditions
- Determine the PVT method correction for dynamic conditions
- Four tests proposed

Why pre-tests are necessary

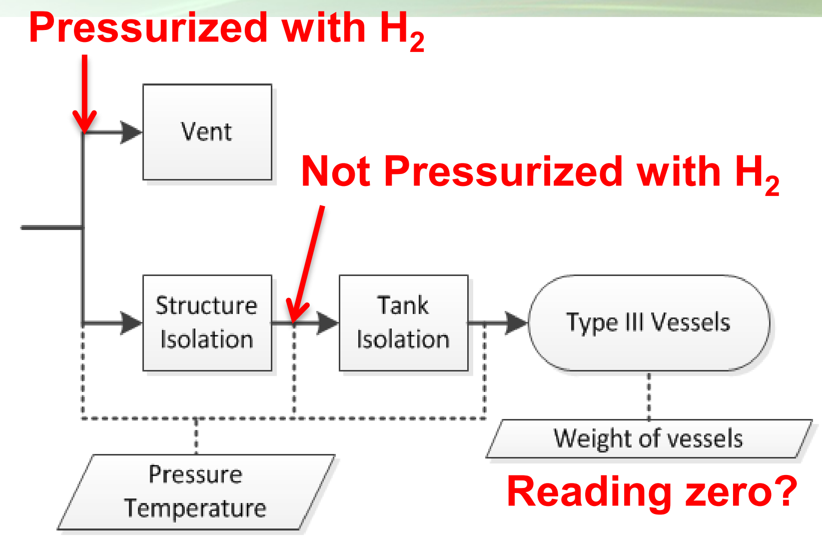
- Experience with CDFA device has brought a lot of questions about device functionality
- Proving interactions between the gas in the lines and the scale is difficult but best effort at minimizing inaccuracies need to be taken
- Can use a combination of PVT method and weighing scales to get best accuracy



Accomplishment: Pre-Testing of System

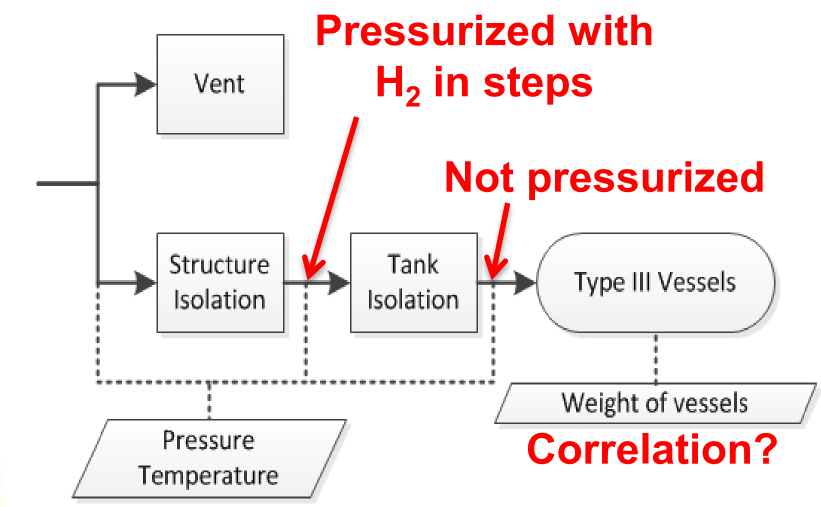
Outer & inner structure interaction

- Confirm separation between the outer and inner structure
- Pressurize lines up to isolation valve separating inner and outer structure and confirm zero readout on scale when pressurized



Slow & fast step up of hydrogen

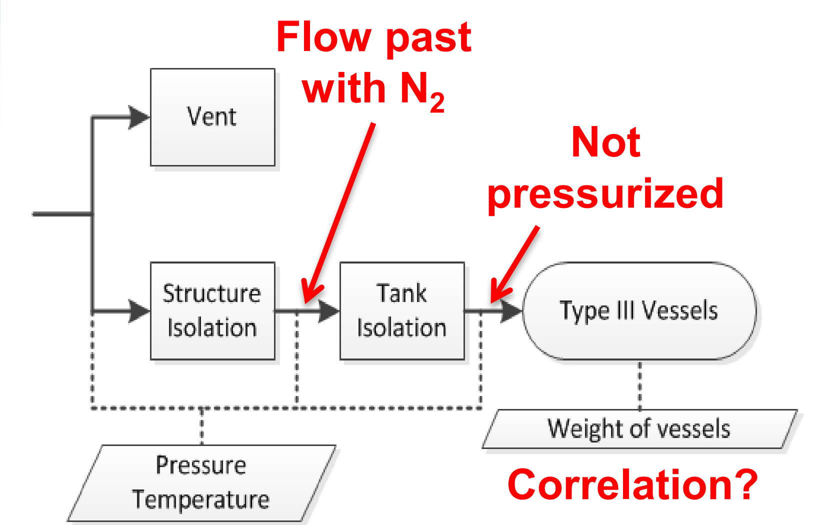
- Step up pressure in hydrogen lines up to vessels and compare static scale reading to PVT estimate
- Establish correlation between PVT estimate and scale reading under static conditions



Accomplishment: Pre-Testing of System

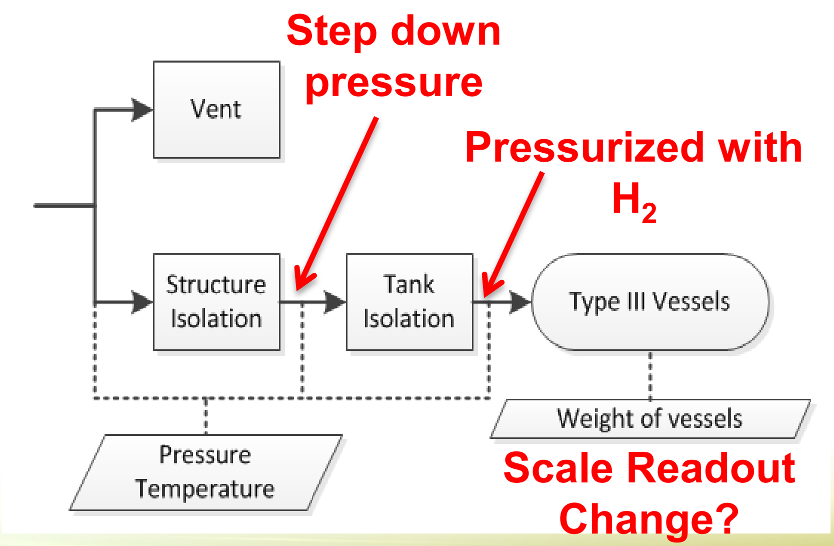
Flow on gravimetric measurement

- Effects of flow on scale reading to explore if real time flow measurements is plausible
- Flow past vessel isolation valves and determine correlation between flow and scale reading



Step Down

- Effects of depressurizing fill lines on the weighing scale
- Fill the hydrogen vessels and record the scale readout, slowly step down pressure in lines will maintaining hydrogen in vessels



Responses to Reviewer Comments

This project was not reviewed last year.

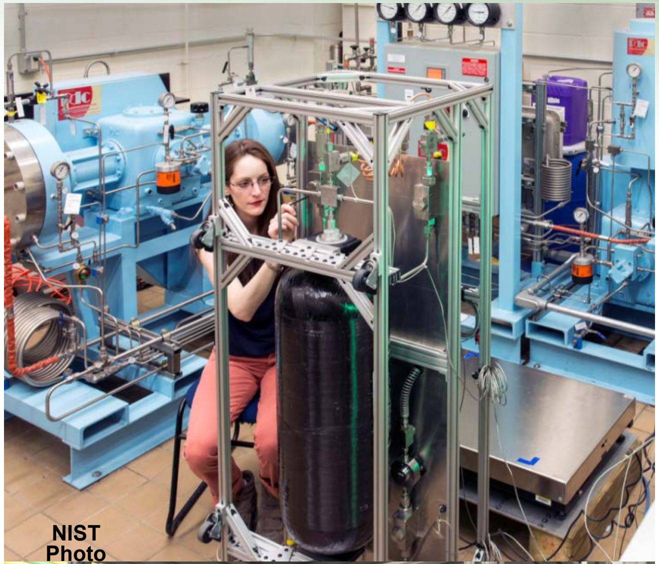
Collaboration: Design Reviews

NIST Fluid Metrology Group – October, 2015

- NIST experience with hydrogen dispensing includes design and testing of a field test apparatus, shown at left
- Discussed and modified initial design of the metering apparatus and the proposed test plan
- NIST participants: Jodie Pope, John Wright, Mike Moldover

Stakeholder Project Review – January, 2016

- Review team: Pietro Moretto (JRC), Jodie Pope (NIST), Norman Ingram & Kevin Schnepp (CDFA), Mike Kashuba (CARB), Jesse Schneider (BMW), Terry Johnson & Joe Pratt (SNL), DOE
- The group will reconvene for data review after the flow meters have been tested



NIST Photo

NREL Photo

Collaboration: Hydrogen Metrology

- Metrology information exchange meeting held January 14, 2015, at NREL
- U.S. representation from DOE, NREL, NIST
- Japan representation from AIST, HySUT, Tatsuno, Iwatani
- Sharing of lessons learned from station metrology efforts in United States and Japan
- Outcome
  - Metrology methods
  - Flow standards development
  - Future joint test projects

Picture of NREL, NIST, DOE, and NEDO project members at the January 14, 2015, joint meeting held at NREL. From left to right: Mr. Komiyama (HySUT), Dr. Otaki (Tatsuno), Mr. Ito (Iwatani), Mr. Osawa (Tatsuno), Mr. Kaneko (HySUT), Dr. Rivkin (NREL), Dr. Morioka (AIST), Mr. Burgess (NREL), Dr. James (DOE), Dr. Buttner (NREL), and Dr. Pope (NIST).

Challenges and Barriers

- Long lead times on items have slowed the project down
  - 700 bar pressure vessels were delayed months
  - Factory certification issues limit the amount of tank cycles available for testing
  - Specialty fittings are hard to find and have long leads
- The in-tank solenoid valve are not Class I, Div II Group B rated so they needed special approval
  - Approved in March, 2016

Proposed Future Work

Project Closeout

- Finish pre-test sequence to verify scale interactions with pressure vessels and tubing
- Test the three meters under proposed test plan
- Finalize and publish report on the testing

Post project

- Conduct joint projects with flow meter manufacturers to develop and test improved flow meter technologies
- Support NIST Handbook 44 committee
- Provide validation testing of proposed SAE J2601 slow fill protocol for home fueling and road side assistance

Technology Transfer Activities

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- Prototype flow meter testing
  - Interest to test non-commercial flow meters and compare performance to current commercial meters

Summary

Relevance:
- Inform DOE and industry of the current state of the technology as the state of California and others work towards dispenser certification and selling hydrogen by the kilogram

Approach:
- Design and build laboratory grade gravimetric hydrogen standard
- Conduct high pressure hydrogen testing of commercially available flow meters
- Report on flow meter performance against NIST Handbook 44 requirements

Technical Accomplishments:
- Flow meters selected: Two Coriolis and one turbine meter
- System design: Flow meter location, process, safety, hardware, assembly in progress
- Pre-test of system: Parameters defined

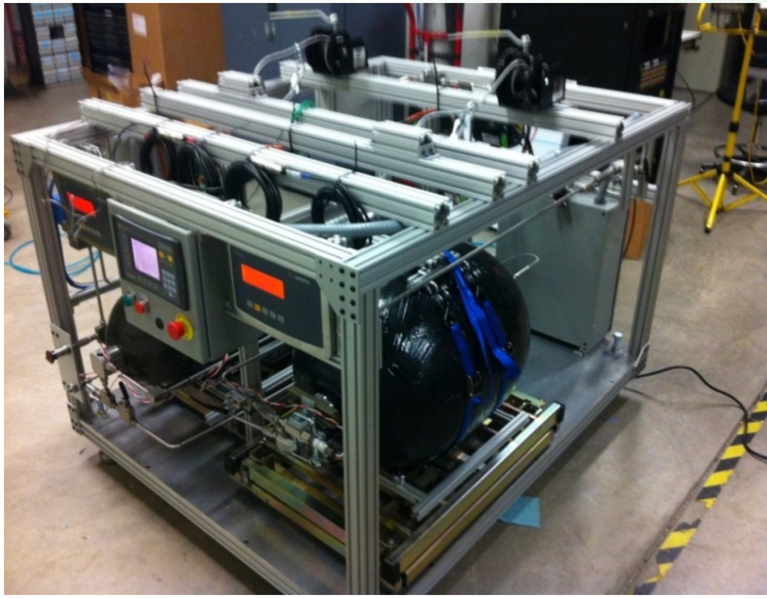
Collaborations:
- SNL (Sandia National Laboratory)
- NIST (National Institute of Standards and Technology) Fluid Metrology Group
- JRC-IET (Joint Research Center – Institute for Energy and Transport)
- CDFA (California Department of Food and Agriculture) Division of Measurement Standard
- CARB (California Air Resources Board)
- BMW

Proposed Future Research:
- Finish pre-test sequence to verify scale interactions with pressure vessels and tubing
- Test the three meters under proposed test plan
- Finalize and publish report on the testing

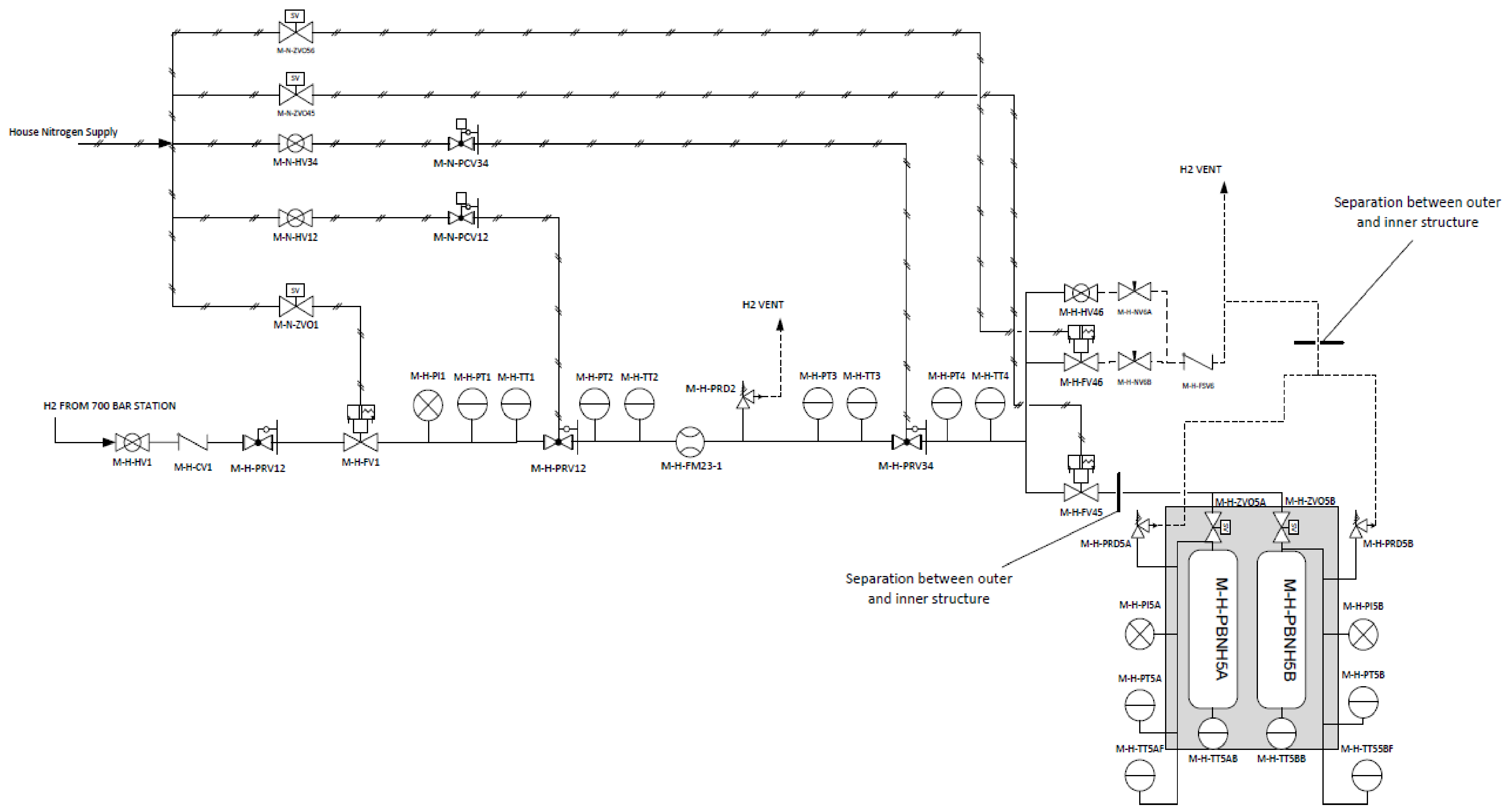
Technical Back-Up Slides

Relevance: California Station Metrology

- NREL hydrogen metrology standard is being used by California DMS for permitting hydrogen stations (contracted through CEC funding)
- Station metrology testing by California DMS is being conducted to facilitate the sale of hydrogen as a motor vehicle fuel
- NIST Handbook 44 requirements for ± 1.5% accuracy are adopted by California Code of Regulations (CCR)
- CCR has been amended to add temporary relaxed accuracy classes of 3%, 5% and 10%



Piping and Instrumentation Diagram



Acronyms and Abbreviations

AIST: National Institute of Advanced Industrial Science and Technology

CARB : California Air Resources Board

CCR: California Code of Regulations

CDFA: California Department of Food and Agriculture

CEC : California Energy Commission

DMS : Division of Measurement Services

DUT : Device Under Test

ESIF : Energy Systems Integration Facility

GUI : Graphic User Interface

HySUT: The Research Association of Hydrogen Supply/Utilization Technology

IET : Institute for Energy and Transport

JRC: Joint Research Centre

MPa : Mega-Pascal

NIST: National Institute of Standards and Technology

PLC : Programmable Logic Controller

SAE: Society of Automotive Engineers

SNL: Sandia National Laboratories