Advancing Hydrogen Dispenser Technology by Using Innovative Intelligent Networks

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Ivys Energy Solutions Inc.

2017 DOE Annual Merit Review
June 6th, 2017

Project ID: PD146

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Overview

Timeline

Project Start Date: June 2016

Project End Date: December 2018

- Delay in some project work due to contracting setup
- 6 month no-cost extension granted

Percent Complete – 25%

Barriers Addressed (Delivery)

F. Other Fueling Site/Terminal Operations*

- Dispenser reliability and cost
  2020 MYRD&D Target: $60,000
- Cooling system reliability and cost
  2020 MYRD&D Target: $70,000
- Hydrogen metering accuracy
  Commercial Target: <1.5%
- Robustness/cost of dispenser/vehicle communication hardware

Budget

Total Funding

DOE share: $1,999,947
Contractor share: $620,600

Expenditure through 3/31/2017:

DOE share: $550,756
Contractor share: $133,865

** FCTO MYRDD Section 3.2: Hydrogen Delivery*

Partners

Project Lead:
Ivys Energy Solutions, Inc.

Industry Collaborators:
Air Liquide Advanced Technologies U.S. (ALATUS)

Research Collaborators:
National Renewable Energy Laboratory (NREL)

International Partners:
Rheonik

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Relevance

Primary Objective:

Develop a robust, cost-effective system for dispensing and measuring hydrogen that further enables widespread commercialization of fuel cell vehicle technology

Technical Barriers Addressed	Project Activities
▪ Metering Accuracy over operating ranges of -40°C to 85°C / 2-60 grams per sec *Commercial Target: < 1.5%*	▪ Development of robust sensor hardware and algorithms that improve accuracy based on empirical testing and improved meter temperature measurement *Current Status: < 10%* *Project Target: < 4%*
▪ Robustness of IrDA Communication	▪ Develop, test and demonstrate the use of Dedicated Short Range Communication (DSRC) for use in vehicle refueling Project Target: Satisfy SAE J2799
▪ Dispenser Capital Cost *DOE 2020 Target: $60k Dispenser + $70k Cooling*	▪ Simplification and cost reduction of flow control and hydrogen pre-cooling systems *Current Status: >> $250k (Dispenser + Cooling)* *Project Target: <$150 k (Dispenser + Cooling)*

Approach

To be successful the deployment of new dispensing, metering and communication hardware must be:

- *Safe*
- Able to meet or exceed performance expectations
- Able to communicate SAE J2799 messages via DSRC
- Provide cost benefit over current state of the art

Therefore future actives include:

- Demonstrate ability for DSRC system to reliably communicate SAE J2799 messages using IEEE 1609 security architecture while ensuring nozzle to vehicle pairing
- Design and manufacture dispenser hardware to applicable codes / standards
- Validate prototype hardware to industry accepted refueling protocols at NREL's Hydrogen Infrastructure Testing & Research Facility
- Partner with automotive OEM to enable successful demonstration of communication method at demonstration site

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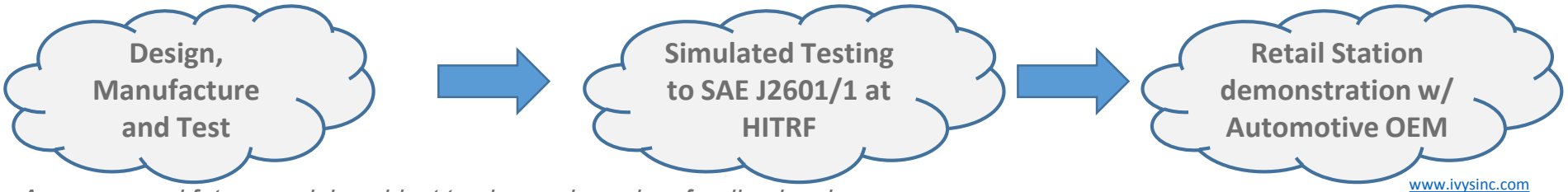
RHEONIK THE CORIOLIS EXPERTS

NREL NATIONAL RENEWABLE ENERGY LABORATORY

Air Liquide



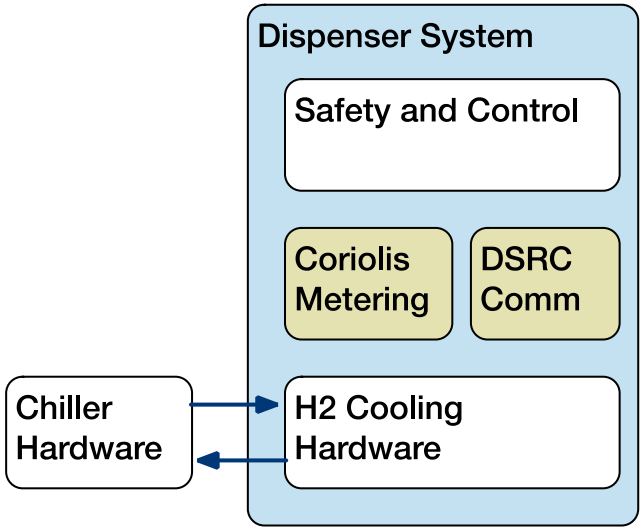
Any proposed future work is subject to change based on funding levels

Approach (2)

Integrated Approach including DSRC and Coriolis Technology

- DSRC, improved Coriolis meter, and dispenser system design all impact total cost
- DSRC hardware is low cost and leverages existing vehicle components
- Coriolis meter addresses fueling measurement accuracy requirement
- Close integration of meter with dispenser system is critical to realize bench-level meter accuracy in field applications
- Dispenser design will also include cost-optimized hydrogen safety system and cooling system designed to reduce system cost significantly.

Project Scope



Key Milestones & Deliverables

Phase 1	Bench verification of DSRC wireless communication performance (transmit SAE J2601 data) and advanced Coriolis meter accuracy (≤4%)
Phase 2	Test data for prototype dispenser at NREL HIRTF and Air Liquide LAX H2 refueling station, demonstrating performance to project targets.

Project Targets

Metric	Current State-of-the-Art	Project Target	MYRD&D/FOA Target
Communication Method	Nozzle Infrared (IR)	DSRC - Wireless	Nozzle IR Alternative
Dispenser Capital Cost	$250k to $400k	$150k (Low Vol.)	$40,000 (2020, Hi Vol.)
Metering Accuracy -40°C to 85°C	Widely variable to >10%	≤2%	≤4%, Commercial Goal 1.5%

Any proposed future work is subject to change based on funding levels

Approach (3)

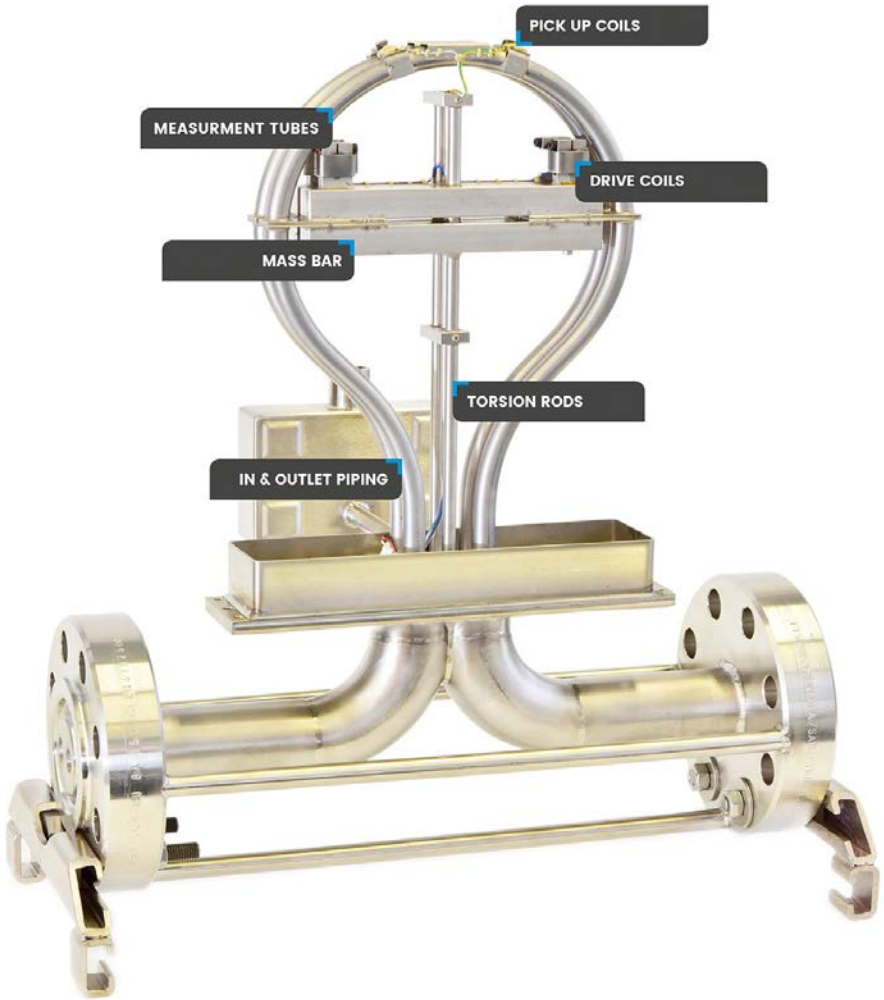
Core Technology: Coriolis Flow Meter

Advantages

- Widely used in hydrogen applications
- Accurate over large pressure, temperature, density and turndown ranges
- Project partner Rheonik is expert in the field, with unique technology

Challenges Being Addressed

- Component selection for improved sealing and reduced cost
- Modeling and measurement to address thermal impacts on meter hardware
- Development of robust temperature compensation algorithms to allow highest accuracy



Approach (4)

Core Technology: DSRC

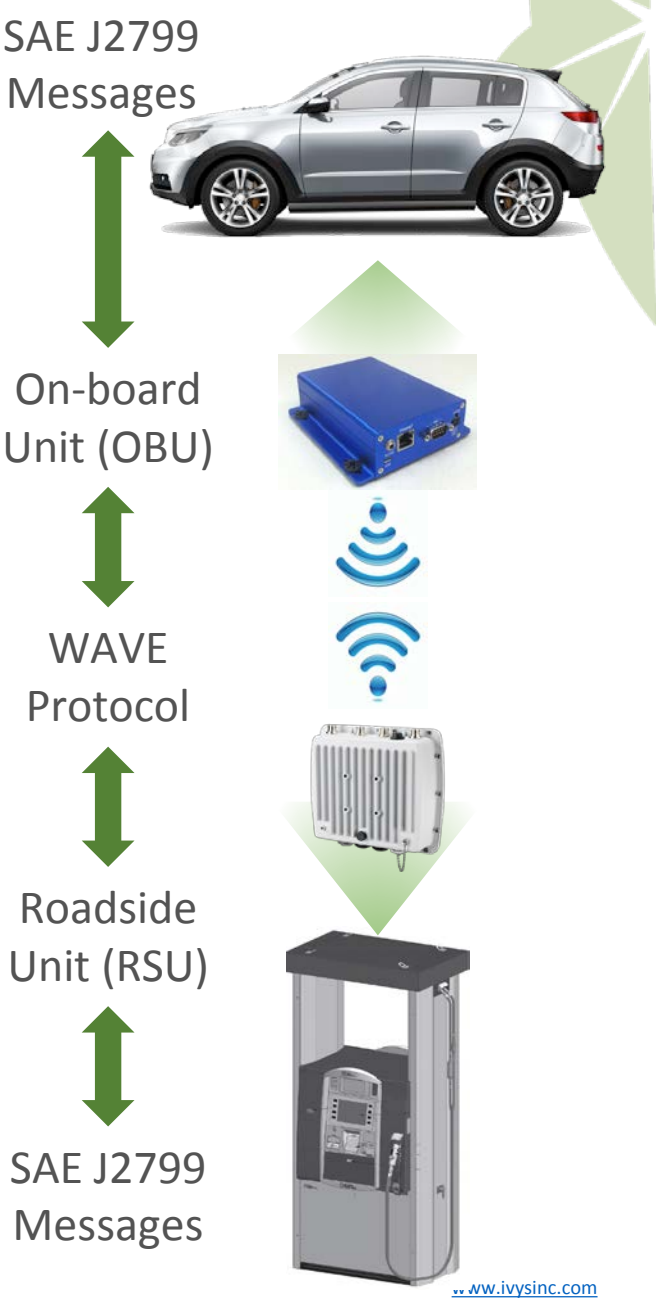
(Dedicated Short Range Wireless Communication)

Advantages

- Existing technology that is commercially available
- Robust – no hardware for user to damage
- Established security protocols (IEEE 1609 & SAE J2735)
- One RSU for whole station / multiple nozzles
- On board units are plug and play
- Very low latency (5-10 ms)

Challenges

- Developing applications to transmit SAE J2799 messages via DSRC
- Bench Validation – confirm system meets or exceeds SAE J2601 / SAE J2799 requirements
- Handshake – ensure nozzle is paired to vehicle



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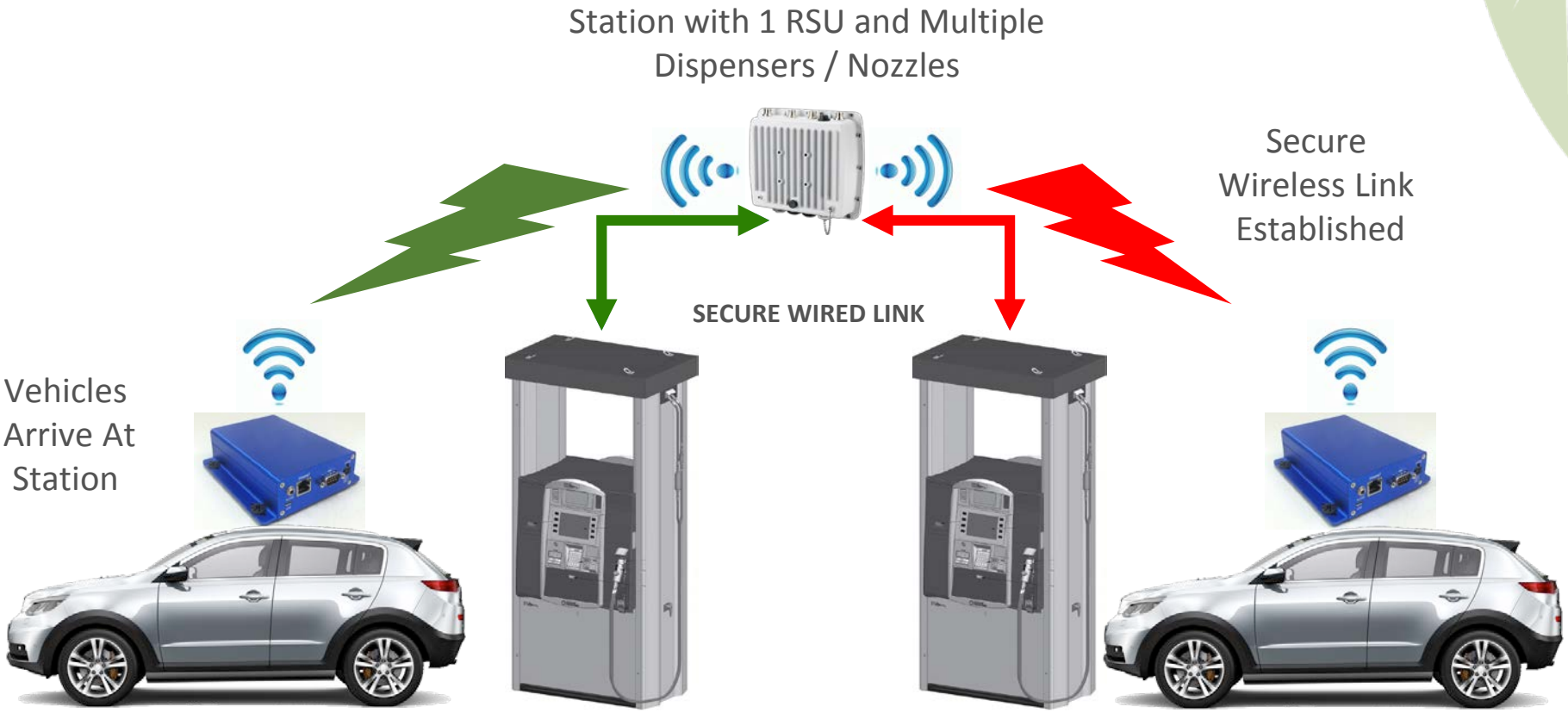
DSRC with Multiple Vehicles



Opportunity for reduced component count at multi-nozzle stations

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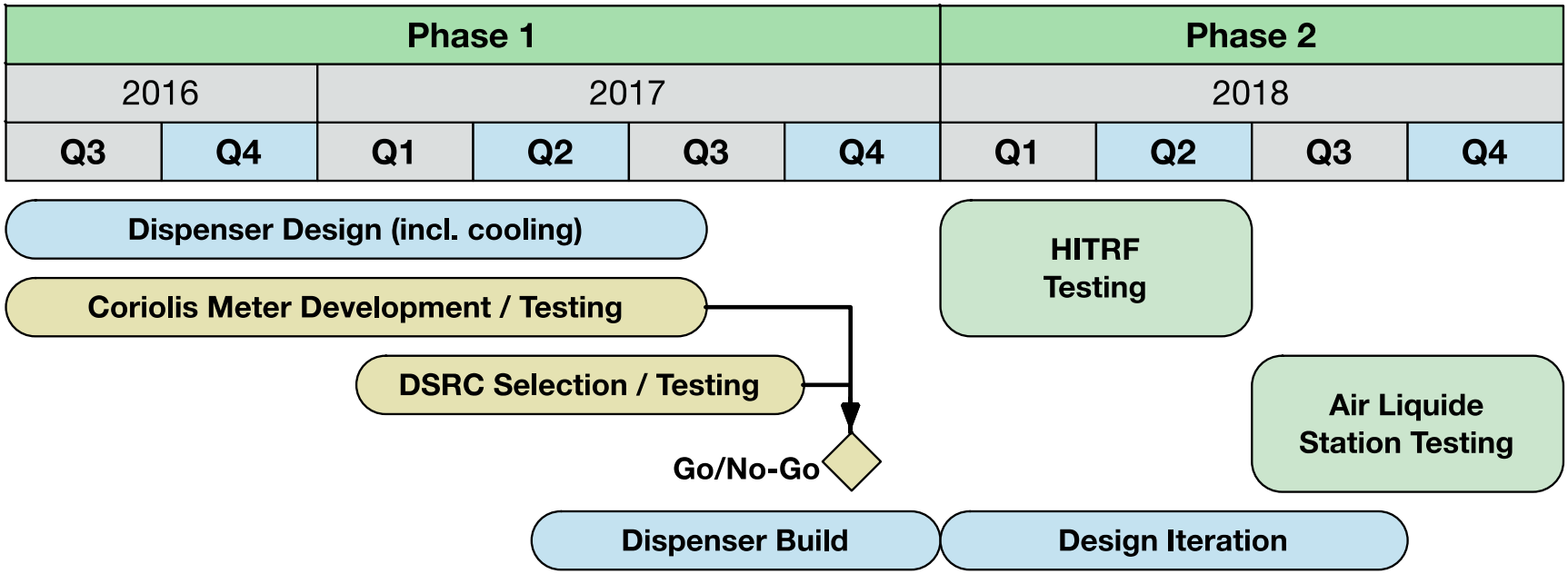
Schedule Summary



Phase 1: Core Technology Bench Test, Dispenser Design and Build

Phase 2: Field Testing (NREL HITRF, Air Liquide Commercial Station)

- Schedule reflects 6 month no-cost extension
- System design overlaps with bench testing of key technologies
- Phase 2 allows for testing of prototype dispenser up to TRL 7 (field testing)

Any proposed future work is subject to change based on funding levels

Milestones

Note: *All Milestone dates adjusted to reflect contract extension*

Date	Milestone #	Milestone	% Complete
4/17	M10.0	Program safety plan complete	90%
5/17	M1.0	Functional requirements and test plan documentation	50%
8/17	M2.3	Complete bench verification of DSCR communication	15%
7/17	M3.2	Bench testing of Coriolis meter to demonstrate ≤ 4% accuracy	75%
9/17	M3.5	Go / No-Go: Bench Verification of DSCR and Coriolis Meter	40%
10/17	M3.8	Prototype dispenser system design freeze and safety review	10%
1/18	M4.0	Prototype dispenser procurement, assembly and manufacturing testing	10%

Milestone Status as of 4/2017

Milestones

Note: *All Milestone dates adjusted to reflect contract extension*

Date	Milestone #	Milestone	% Complete
1/18	M5.0	Vehicle Simulator & HITRF station upgrades complete	0%
2/18	M6.2	Prototype dispenser installation at NREL complete	0%
4/18	M6.5	Passed simulated environment testing of dispenser system	0%
7/18	M7.1	Dispenser integration at demonstration HRS site complete	0%
7/18	M7.2	Vehicle upgrade to support DSRC communication complete	0%
7/18	M7.3a	First live refueling event	0%
9/18	M7.3b	Successful test of system in relevant environment	0%
4/17	M10.0	Program safety plan complete	90%

Milestone Status as of 4/2017

Accomplishments & Progress

Dispenser Prototype Design and Build

Dispenser Enclosure:

- Dispenser enclosure provided by Air Liquide to Ivys team
- Includes full point of sale and enclosure ventilation system

Requirements Definition:

- Definition of functional requirements 50% complete – target 5/17
- Leveraging expertise of project partners to develop test plans for prototype dispenser testing at HITRF
- Requirements also include testing at commercial site

Project Management:

- H2 Safety Plan completed and submitted for review
- All program partners involved in Safety Plan development

Status as of 4/2017

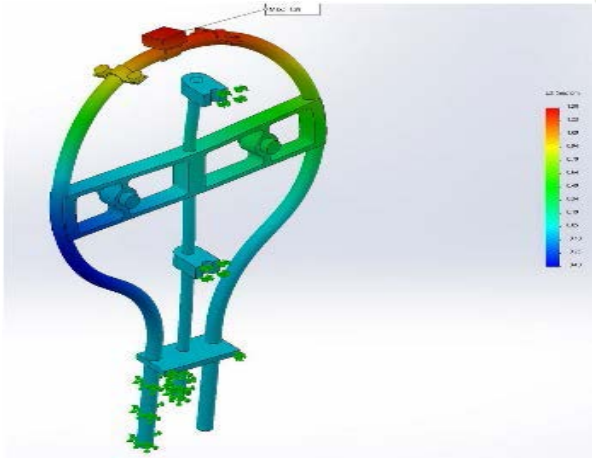
Any proposed future work is subject to change based on funding levels

Accomplishments & Progress

Hydrogen Meter Development

Identification of Key Factors Reducing Coriolis Meter Accuracy

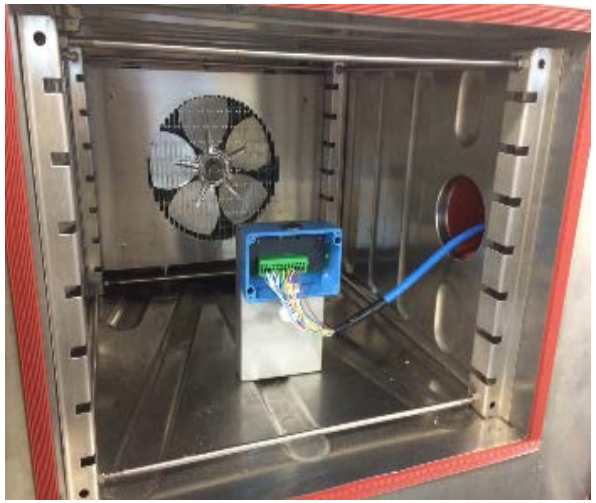
- Thermal shifts in mechanical structure
- Zero Drift
- Pressure and temperature shocks caused by current filling protocols and non-integrated design
- Repeatability of component dimensional precision during manufacturing
- Condensation / humidity within housing



CAE Simulation of tube wall thermal shift

CAE Simulations & Lab Testing

- Understand temperature impacts on mechanical assemblies
- Climate chamber testing used to validate CAE simulations
- Chilled glycol flow testing used to simulate “cold shock” experienced in H2 dispensing applications



Prototype meter testing in climate chamber

Status as of 4/2017

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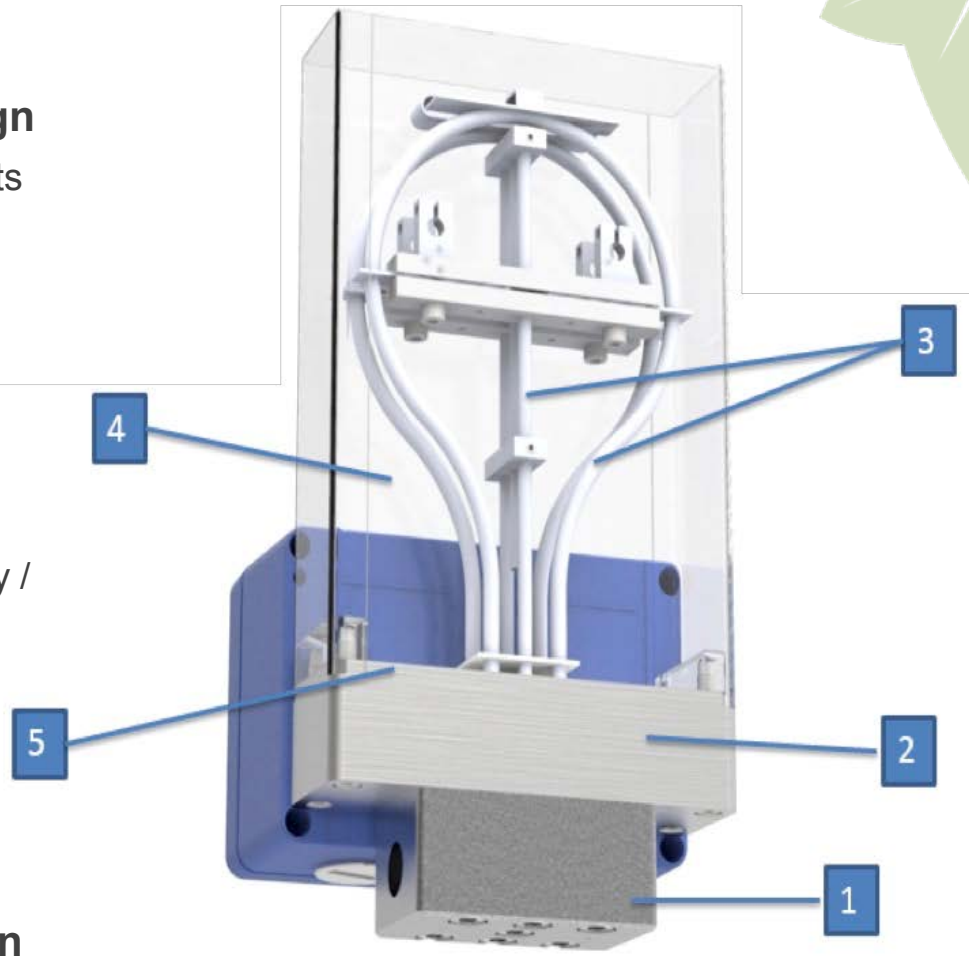
Accomplishments & Progress

Hydrogen Meter Development

Testing results informed new meter design

1. New “Mono-block” design tube reduces impacts of temperature changes & decreases flow turbulence
2. Two temperature measurements added to optimize software temperature compensation
3. Addition of two temperature measurement devices strategically located within the omega tube and housing
4. Argon / N2 housing purge to eliminate humidity / condensation impacts
5. Replacement of PTFE seal with FVQM

- Improved manufacturing processes
- Improved algorithms that actively compensate flow reading based on pressure & temperature



Meter test results inform dispenser design

- Thermal and pressure integration of meter into dispenser
- Dispenser control will integrate active meter feedback on measurement conditions

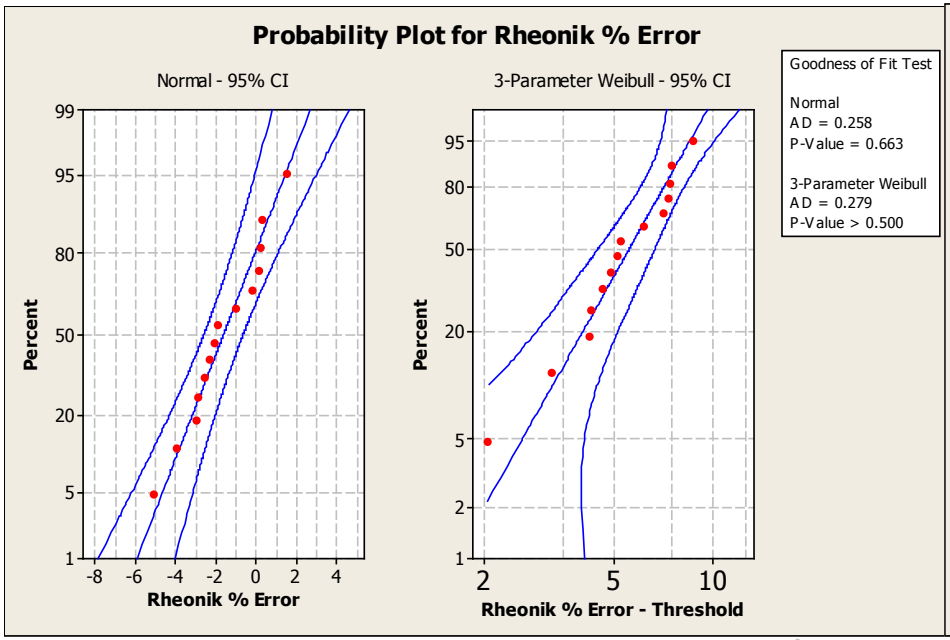
Accomplishments & Progress

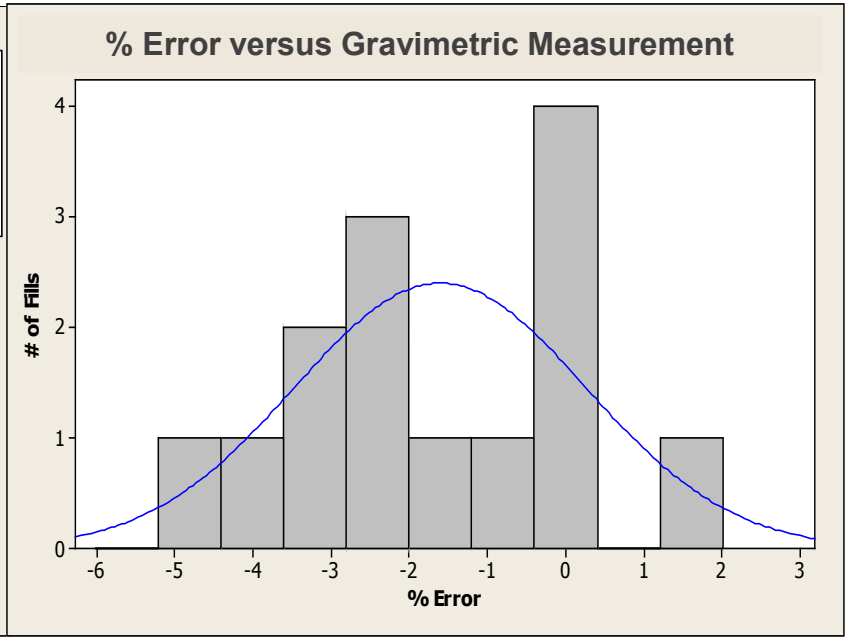
Hydrogen Meter

New meter tested in simulated and relevant environments

- Bench and H2 dispenser testing
- Preliminary testing shows high confidence that meter can obtain ≤4% accuracy & shows 1.5% accuracy is obtainable
- Accuracy improvement will come from controlling meter H2 inlet conditions
- Detailed bench testing now underway for Go/No-Go milestone data

Category	DOE Long Term Target	Project Target	Tested (Dispenser Application)
Accuracy during fill	≤ 1.5%	≤ 4.0%	2.5 – 5%





Status as of 4/2017

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Collaboration

Ivys Energy Solutions Inc. – Contract Lead

Air Liquide Advanced Technologies U.S. (ALATUS)

- *Demonstration site*
- *H2 expertise*
- *Retail style hydrogen dispenser enclosure with point of sale*

National Renewable Energy Laboratory (NREL)

- *Hydrogen Infrastructure Testing & Research Facility – used to validate dispenser to SAE J2601/1 (2014) prior to demonstration*
- *Facilities, personnel and equipment to validate hydrogen meter accuracy*
- *Vehicle simulator hardware used in equipment validation*

Rheonik

- *Leader in area of high accuracy mass flow measurement*
- *Design, manufacturing & validation of high accuracy meter*
- *Aiding in system integration of meter*
- *Providing two meters for test and integration*

Remaining Challenges & Barriers

1. Adapt and Maintain Project Schedule

- 6 month no-cost extension granted due to time for contracting setup
- Additional full time staff added at Ivys to coordinate efforts
- Ensure timely delivery of prototype hardware to partners so that testing is not impacted

2. DSRC Communication – test in new application

- DSRC is a developed technology but not yet used in this case
- Ensure DSRC communication is fully validated at bench level including fringe failure modes
- Develop “handshake” to ensure dispenser & nozzle pairing is maintained

3. Find OEM vehicle partner for demonstration

- Begin OEM vehicle partnership process by end of year 2017

Any proposed future work is subject to change based on funding levels

Proposed Future Work
FY 2017 (Phase 1)

Bench validation of DSRC hardware & H2 flow meter

- Secure transfer of SAE J2601/1 filling protocol messages
- Identification & testing of failure modes
- Development of hardware/software required for communication between vehicle and dispenser
- Bench testing of simulated fills with full SAE J2799 communication (Go/No-Go target)
- Hydraulic bench testing of Coriolis meter to demonstrate ≤ 4% fill measurement accuracy (Go / No-Go target)

Prototype dispenser design and build

- Requirements Development
- Safety Review
- Design, procurement and manufacturing

Upgrade NREL HITRF site for prototype dispenser installation

(Phase 2 Work: Begins after positive Go/No-Go result)

- Vehicle simulator upgrade with DSRC simulator
- Equipment operator training
- Completion of all safety processes and procedures for prototype dispenser installation at NREL

Any proposed future work is subject to change based on funding levels

Proposed Future Work
FY 2018 (Phase 2)

Installation & Test of Prototype Dispenser to SAE J2601/1

- Complete training and safety review for dispenser hardware
- Validate DSRC hardware in simulated vehicle environment at NREL
- Complete partnership with vehicle OEM
- Validate hydrogen meter accuracy

Installation & Test of Dispenser in Relevant Environment

- Install hardware at Air Liquide demonstration site
- Training and safety review of hardware at demonstration site
- Successfully refuel vehicle using DSRC communication

Any proposed future work is subject to change based on funding levels

Summary

Objective	Develop a robust system for dispensing and measuring hydrogen that further enables widespread commercialization of fuel cell vehicle technology
Relevance	Development of robust sensor algorithms combined with better understanding of meter operation in H2 filling applications can improve accuracy. Replacing IrDA communication with IEEE compliant DSRC systems can offer a robust and cost effective alternative to current state of the art Simplification of flow control and hydrogen pre-cooling systems can reduce overall hydrogen dispenser station costs
Approach	Demonstrate ability for DSRC to reliably communicate SAE J2799 messages using IEEE 1609 security architecture while ensuring nozzle to vehicle pairing Design and manufacturing of dispenser hardware to applicable codes / standards Validate prototype hardware to industry accepted refueling protocols at NREL's Hydrogen Infrastructure Testing & Research Facility Partner with automotive OEM to enable successful demonstration of communication method at demonstration site
Accomplishments	Bench testing of H2 meter shows 4% accuracy is very achievable. Accuracy of 1.5% will require additional testing and special attention to system integration 6 month no-cost extension granted Prototype dispenser hardware enclosure provided by Air Liquide
Collaborations	Strong team with extensive knowledge in hydrogen system design, hydrogen refueling and hydrogen meter technology

Summary (Continued)

- **Project Schedule modified with 6 month extension**
  - Ivys has hired additional full-time resources to ensure completion of this project within proposed timeline
- **Bench and dispenser testing of improved meter hardware indicates accuracy of ≤ 4% is very achievable**
- **Meter accuracy of ≤ 1.5% is within reach**
  - Requires additional meter and system integration improvements
  - Manage thermal conditions at meter inlet
- **Extensive bench testing will occur to ensure DSRC hardware reliably communicates SAE J2601/1 messages per SAE J2799 protocol**
- **Currently on schedule for completion of dispenser prototype in Q4 2017**