Consolidation

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Project ID# PD133

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Overview

Timeline and Budget

<table>
<thead>
<tr>
<th>Project start date</th>
<th>Oct 2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>FY15 DOE funding</td>
<td>$ 500k NREL</td>
</tr>
<tr>
<td></td>
<td>$ 0 ANL</td>
</tr>
<tr>
<td>FY16 planned DOE</td>
<td>$ 674k NREL</td>
</tr>
<tr>
<td>funding</td>
<td>$ 200k ANL</td>
</tr>
<tr>
<td>Total DOE funds</td>
<td>$ 1.174M NREL</td>
</tr>
<tr>
<td>received to date</td>
<td>$ 200k ANL</td>
</tr>
<tr>
<td>Total Project Budget</td>
<td>$ 2.349M</td>
</tr>
</tbody>
</table>

Project Timeline  
Oct ‘15 – Sep ‘17

Barriers

Technology Validation (D) – Lack of Hydrogen Refueling Infrastructure Performance and Availability Data

Delivery (E) – Gaseous Hydrogen Storage and Tube Trailer Delivery Costs

Partners

- Argonne National Lab
- PDC Machines
- National Renewable Energy Lab (Project lead)
Problem Statement – Hydrogen at the pump is too expensive
Relevance – Reduce station contribution to hydrogen cost

• Objectives
  – Decrease the cost contribution of station capital to the cost per kg of hydrogen at fueling stations:
    
    projected to reduce the compression contribution to hydrogen cost (in terms of $/kgH2) by approximately 50%

    (current compressors for large stations ~500 kg/day can cost ~$1M)
  – Maximize station performance in terms of back-to-back fills
  – Investigate improvements on compressor reliability

• Where are we today?
Approach – Design and build a station to validate Consolidation algorithm

• ANL Tube-Trailer Consolidation Concept
  – Increase compressor throughput
    • Operate the compressor as high as 10 times its rated throughput
    • **Reduce the compressor size dramatically**
  – Efficient utilization of the tube-trailer payload and compressor operation
    • Compress low pressure hydrogen into high pressure storage tubes during low- or no-demand
    • **Reduce capital expenditure on stations**

• PDC Machines Novel Compressor Design
  o Two-stage diaphragm compressor
  o Inter-stage flow allowing single stage compression

• NREL Hydrogen Infrastructure Testing and Research Facility (HITRF)
  o Simultaneous bi-direction flow of storage tanks at three pressure levels
  o Centralized visual system SCADA
  o Data logging for station pressures, temperature, power, energy, etc.
  o SAE J2601 T40 back to back filling capability (goal of 5, 4 kg fills)
Approach – Three phase plan to accomplish testing

• Phase I – Demonstration Setup [Oct. 15 – Jan. 16]
  • Design of hardware and controls
  • Major equipment order
  • Operation simulations/optimization with actual performance specifications

  **Project Goal:** *Long-lead items successfully sourced*

• Phase II – Demonstration Preparation [Feb. 16 – May. 17]
  • Station, compressor and vehicle simulator build
  • Algorithm development and testing

  **Project Goal:** *System design will adequately meet the intent of the project*

  • System operation and optimization
  • Summary analysis and reporting

  **Project Goal:** *Issue report to DOE on testing results*
Accomplishments and Progress – Design complete and station build out underway

- NREL HITRF Station build-out

<table>
<thead>
<tr>
<th>HITRF Major System Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Pressure Storage</td>
</tr>
<tr>
<td>200 b, 189 kg</td>
</tr>
<tr>
<td>5 banks</td>
</tr>
<tr>
<td>Type 1 ground storage</td>
</tr>
<tr>
<td>Med Pressure Storage</td>
</tr>
<tr>
<td>400b, 103 kg</td>
</tr>
<tr>
<td>3 banks</td>
</tr>
<tr>
<td>Type 1 ground storage</td>
</tr>
<tr>
<td>High Pressure Storage</td>
</tr>
<tr>
<td>875b, 62 kg</td>
</tr>
<tr>
<td>4 banks</td>
</tr>
<tr>
<td>Type 2 ground storage</td>
</tr>
<tr>
<td>Pre-cooling</td>
</tr>
<tr>
<td>16HP</td>
</tr>
<tr>
<td>Triple block</td>
</tr>
<tr>
<td>R404a, aluminum block</td>
</tr>
<tr>
<td>Dispenser</td>
</tr>
<tr>
<td>350b, 700b</td>
</tr>
<tr>
<td>1 hose per pressure</td>
</tr>
<tr>
<td>SAE J2601 T40</td>
</tr>
</tbody>
</table>
Accomplishments and Progress – Design complete and build out underway

- NREL HITRF Vehicle Simulator build-out

Vehicle Simulator Major System Components

<table>
<thead>
<tr>
<th>Component</th>
<th>Details</th>
<th>Quantity</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage Tanks</td>
<td>875b 1.45 kg each (1.25 kg Usable)</td>
<td>15 tanks</td>
<td>Type 4 storage</td>
</tr>
<tr>
<td>IRDA Communication</td>
<td>Receptacle Mounted</td>
<td></td>
<td>CSA HGV 4.3 SAE J2799 compliant</td>
</tr>
<tr>
<td>Back-to-back capability</td>
<td>3 tanks per fill line</td>
<td></td>
<td>Fill and vent simultaneously</td>
</tr>
<tr>
<td>User Interface</td>
<td>PLC touch screen</td>
<td></td>
<td>Automated safety features</td>
</tr>
<tr>
<td>Utility</td>
<td>80 psi air or nitrogen</td>
<td>120V</td>
<td>NEC Class 1 Div 2</td>
</tr>
</tbody>
</table>
Accomplishments and Progress – Flow curves satisfactory for algorithm validation

- PDC Machines demonstrated flow curves

Stage 1 Flow Curve

Stage 2 Flow Curve
Accomplishments and Progress – Build underway at PDC Machines Inc.

- PDC Machines base compressor manufactured and built
Accomplishments - Simulated station performance shows 4-5x increase in vehicle fills

- Fill operation with 3.7 kg fills and 2-bank buffer storage (1-hose)

![Graph showing state of charge and vehicles filled]

- Baseline operation
- Consolidation operation

- Green → 95% < SOC (i.e., Full Charge)
- Blue → 95% > SOC > 90%
- Red → 90% > SOC
Accomplishments and Progress: Responses to Previous Year Reviewers’ Comments

- This project was not reviewed last year
Collaborations

- Argonne National Laboratory
  - Partner DOE lab
  - Design and simulation of the consolidation concept and algorithm
  - Station build support
  - Results and optimization analysis

- PDC Machines
  - Subcontractor to NREL
  - Leading industry member in hydrogen compressors
  - Compressor design and build
  - System optimization
Remaining Challenges and Barriers

• Compressor Installation
  – Build underway at PDC Machines
  – NREL site location determined
  – Electrical upgrades being planned

• Pre-cooling Upgrade
  – Chiller is drop-in replacement
  – Electrical changes required
  – NREL working on siting for large heat exchanger

• System Integration
  – NREL SCADA upgrades
  – NREL hazard review board
Proposed Future Work

• Major Component Installation (complete by Dec 2016)
  – PDC to finish compressor build November 2016 and ship to NREL
  – NREL to install new pre-cooling system with APCI

• System Integration
  – NREL to update HITRF SCADA system

• Modeling and Optimization (ongoing)

• Testing (to begin Jan 2017)
Technology Transfer Activities

- Vehicle Simulator
  - Ability to test station performance without vehicle OEM involvement
  - Significant interest from hydrogen station and vehicle industry
  - Self contained system than can be transported
Summary

• Modeling and Simulation of Consolidation Concept
  – Various refueling configurations simulated for baseline and consolidation operation
  – Identified size of buffer storage and fill amount as key factors impacting station refueling capacity/performance
  – Consolidation operation can extend capacity of station for full vehicle fills, with back-to-back capability, by a factor of 400-500%

• Station Upgrades
  – Station design is complete and satisfactory for project goals
  – Pre-cooling, storage and compression upgrades are underway
  – Testing is scheduled to begin January 2017

• Compressor Build
  – Major components on hand
Technical Back-Up Slides
Key Simulation Parameters - Relevance

- **Pressure limits/ constraints**

<table>
<thead>
<tr>
<th>Process Limits</th>
<th>Max</th>
<th>Min</th>
<th>MAWP</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Pressure Cascade Pressure [MPa]</td>
<td>91</td>
<td>42</td>
<td>93</td>
</tr>
<tr>
<td>400 bar Storage Pressure [MPa]</td>
<td>44</td>
<td>5</td>
<td>45.9</td>
</tr>
<tr>
<td>200 bar Storage Pressure [MPa]</td>
<td>26</td>
<td>2</td>
<td>27.5</td>
</tr>
<tr>
<td>1st Stage Independent Suction (2 to 40 MPa)</td>
<td>20</td>
<td>2</td>
<td>N/A</td>
</tr>
<tr>
<td>2nd Stage Independent Suction (13 to 95 MPa)</td>
<td>40</td>
<td>13</td>
<td>N/A</td>
</tr>
<tr>
<td>2 Stages Combined Suction (5 to 95 MPa)</td>
<td>20</td>
<td>5</td>
<td>N/A</td>
</tr>
<tr>
<td>Tube-Trailer Direct Vehicle Fill Pressure [MPa]</td>
<td>44</td>
<td>13</td>
<td>N/A</td>
</tr>
</tbody>
</table>

- **Fueling parameters**

<table>
<thead>
<tr>
<th>Fueling Protocol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAE Fill Pressure Ramp Rate @25°C Ambient, for 4-7 kg Tank Capacity [MPa/min]</td>
<td>18.5</td>
</tr>
<tr>
<td>Final Vehicle Tank Pressure [MPa] (Typical State Of Charge at 25°C ambient)</td>
<td>81 (96%)</td>
</tr>
<tr>
<td>Leak Checks Duration for Every 20MPa Rise [sec]</td>
<td>10</td>
</tr>
<tr>
<td>Lingering Time Between Fills [sec]</td>
<td>120</td>
</tr>
<tr>
<td>Number of Back-To-Back Fills During Peak Hour</td>
<td>5</td>
</tr>
</tbody>
</table>
Simulated Station Performance - Accomplishments

- Fill operation with 5.0 kg fills and 3-bank buffer storage (1-hose)

State Of Charge (SOC) [%]

- Green → 95% < SOC (i.e., Full Charge)
- Blue → 95% > SOC > 90%
- Red → 90% > SOC

Baseline operation
Consolidation operation

# of Vehicles Filled Each Hour
Total # of Refueled Vehicles
Simulated Station Performance - Accomplishments

- Fill operation with **3.7 kg fills** and **3-bank buffer storage (2-hose)**

<table>
<thead>
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<th>State Of Charge (SOC) [%]</th>
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<td>Baseline operation</td>
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<td>Consolidation operation</td>
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- **Green** → 95% < SOC (i.e., Full Charge)
- **Blue** → 95% > SOC > 90%
- **Red** → 90% > SOC

![Graph showing the number of vehicles filled each hour (per hose) and state of charge (SOC)]
Simulated Station Performance - Accomplishments

- Fill operation with 5.0 kg fills and 4-bank buffer storage (2-hose)

Green $\rightarrow$ 95% < SOC (i.e., Full Charge)
Blue $\rightarrow$ 95% > SOC > 90%
Red $\rightarrow$ 90% > SOC