Hydrogen Fueling Infrastructure Research and Station Technology

Consolidation

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**Presenter*

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Overview

Timeline and Budget

Project start date	Oct 2015
FY15 DOE funding	$ 500k NREL $ 0 ANL
FY16 planned DOE funding	$ 674k NREL $ 200k ANL
Total DOE funds received to date	$ 1.174M NREL $ 200k ANL
Total Project Budget	$ 2.349M
Project Timeline	Oct '15 – Sep '17

Barriers

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

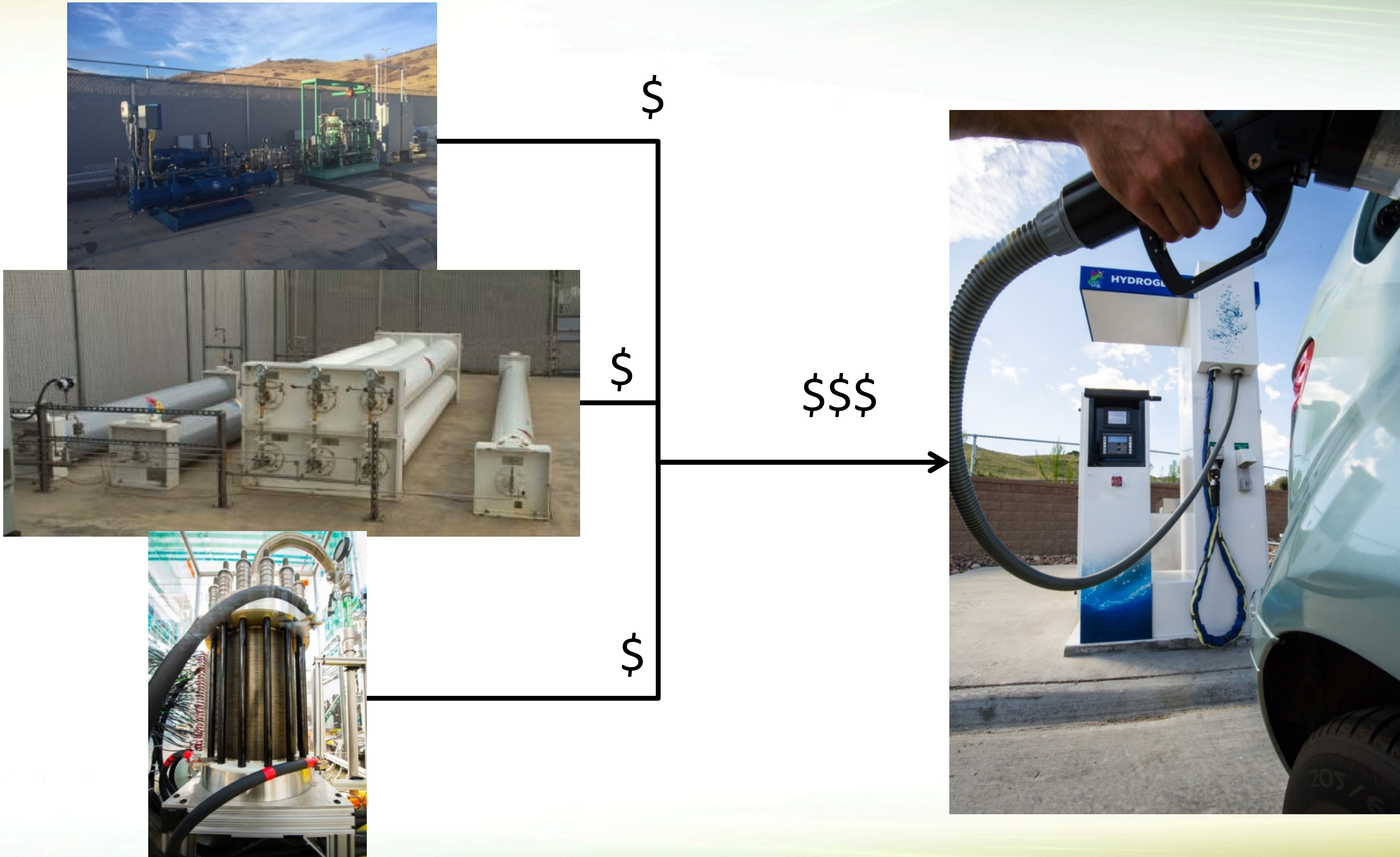
Delivery (E) – Gaseous Hydrogen Storage and Tube Trailer Delivery Costs

Partners

- Argonne National Lab
- PDC Machines
- National Renewable Energy Lab (Project lead)

Problem Statement – Hydrogen at the pump is too expensive

H2FIRST

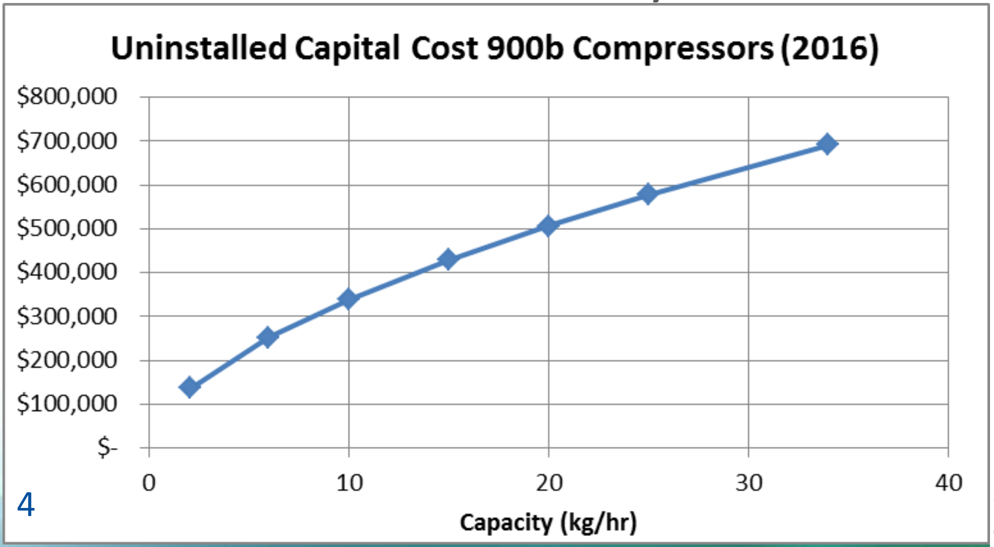


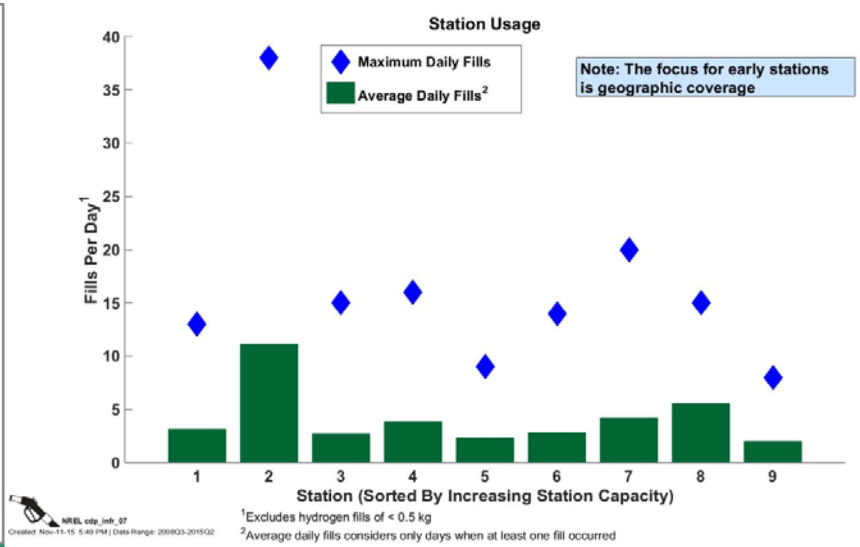
Relevance – Reduce station contribution to hydrogen cost

- 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?

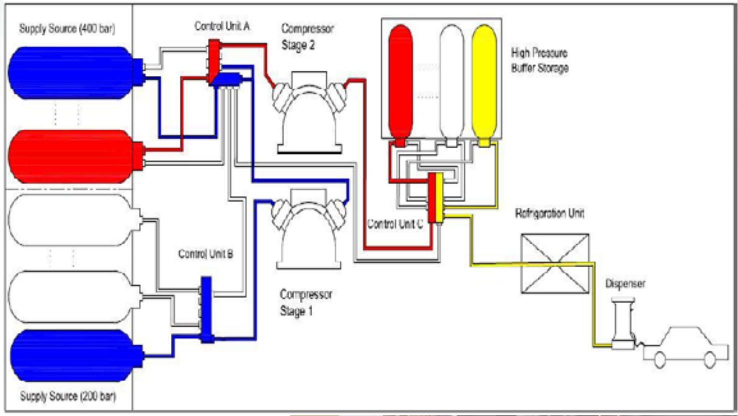




Approach – Design and build a station to validate Consolidation algorithm

H2FIRST

- **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**
  - Two-stage diaphragm compressor
  - Inter-stage flow allowing single stage compression
- **NREL Hydrogen Infrastructure Testing and Research Facility (HITRF)**
  - Simultaneous bi-direction flow of storage tanks at three pressure levels
  - Centralized visual system SCADA
  - Data logging for station pressures, temperature, power, energy, etc.
  - 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]** O
  - Station, compressor and vehicle simulator build
  - Algorithm development and testing

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

- **Phase III – Demonstration Testing [Jun. 17 – Sep. 17]** O
  - 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

HITRF Major System Components			
Low Pressure Storage	200 b, 189 kg	5 banks	Type 1 ground storage
Med Pressure Storage	400b, 103 kg	3 banks	Type 1 ground storage
High Pressure Storage	875b, 62 kg	4 banks	Type 2 ground storage
Pre-cooling	16HP	Triple block	R404a, aluminum block
Dispenser	350b, 700b	1 hose per pressure	SAE J2601 T40

Accomplishments and Progress – Design complete and build out underway

- NREL HITRF Vehicle Simulator build-out

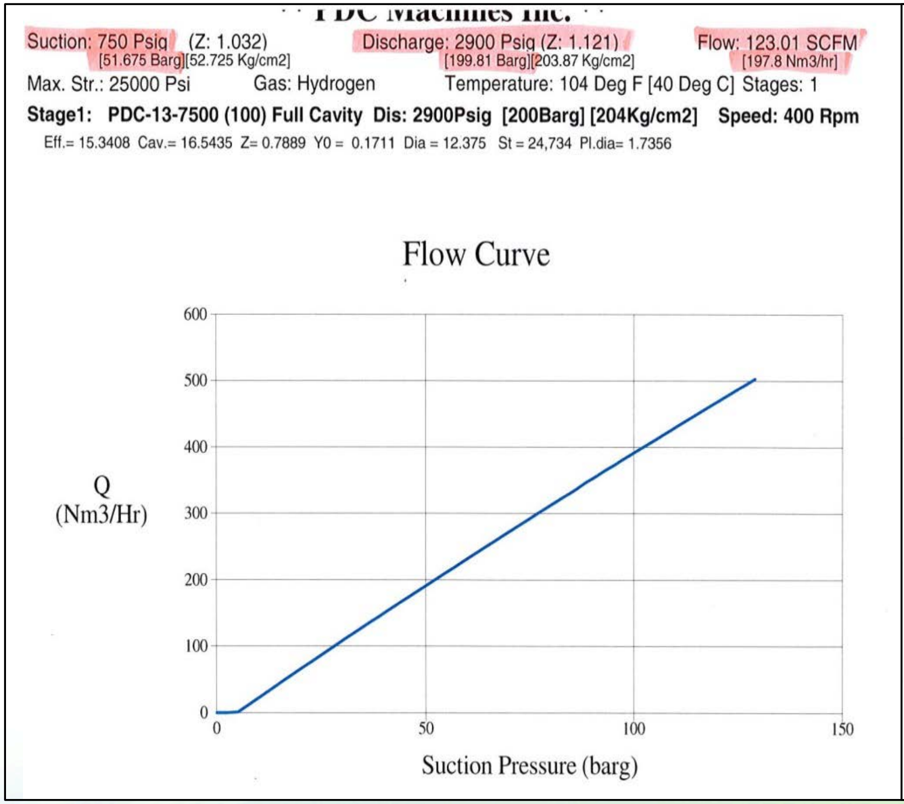
Vehicle Simulator Major System Components

Storage Tanks	875b 1.45 kg each (1.25 kg Usable)	15 tanks	Type 4 storage
IRDA Communication	Receptacle Mounted	CSA HGV 4.3 SAE J2799 compliant	
Back-to-back capability	3 tanks per fill line	Fill and vent simultaneously	
User Interface	PLC touch screen	Automated safety features	
Utility	80 psi air or nitrogen	120V	NEC Class 1 Div 2

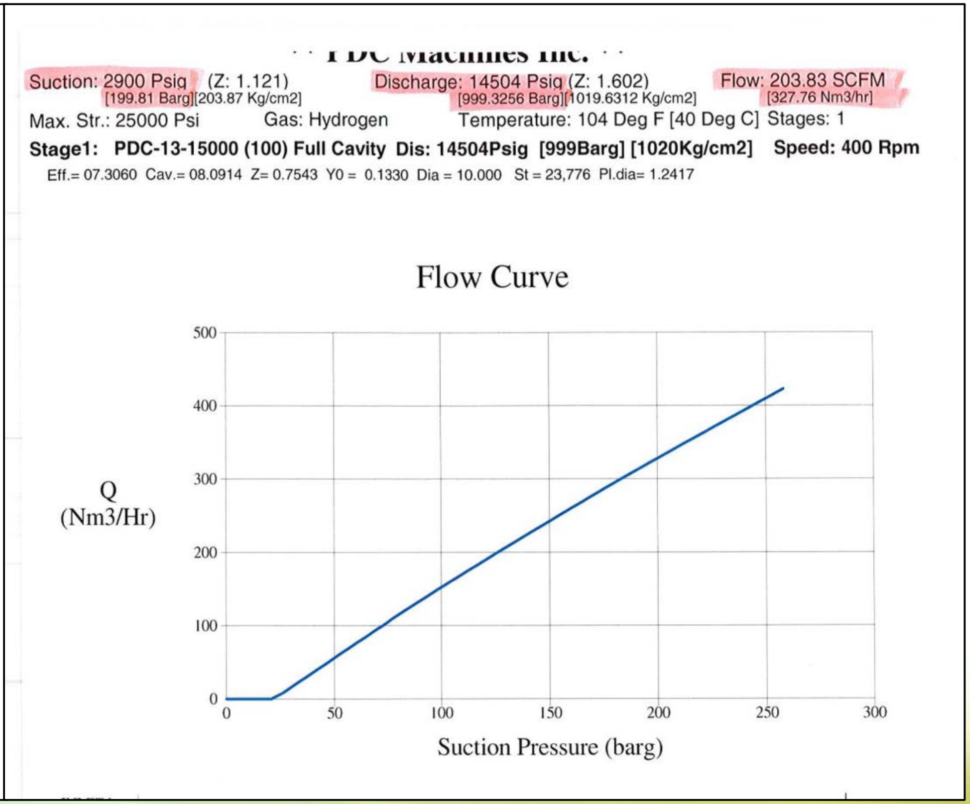
Accomplishments and Progress – Flow curves satisfactory for algorithm validation

- **PDC Machines demonstrated flow curves**

Stage 1 Flow Curve



Stage 2 Flow Curve

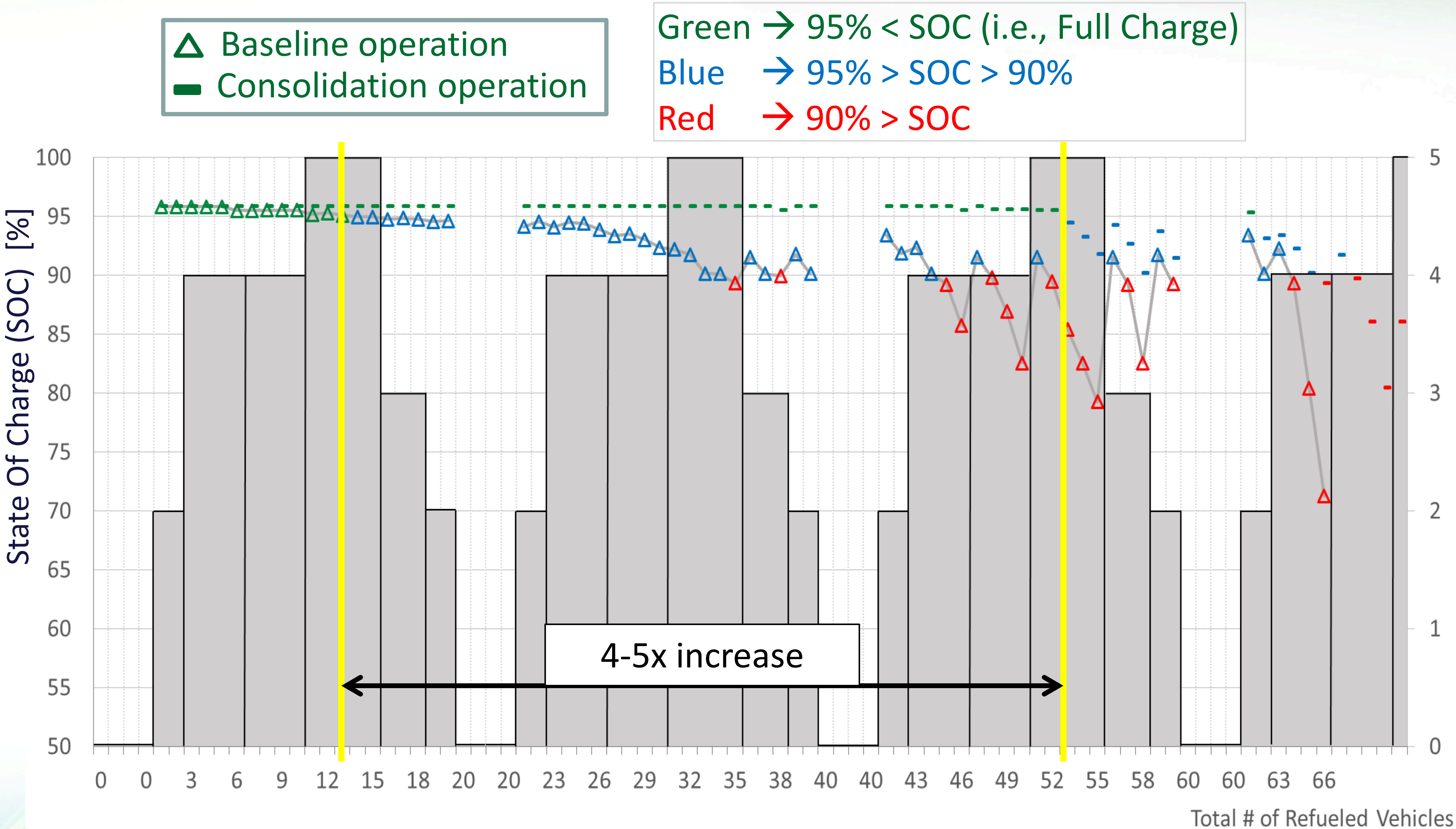


Accomplishments and Progress – Build underway at PDC Machines Inc.

- 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)



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

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- 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
  - Assembly underway. Delivery slated for November 2016.

Technical Back-Up Slides

Key Simulation Parameters- Relevance

- Pressure limits/ constraints

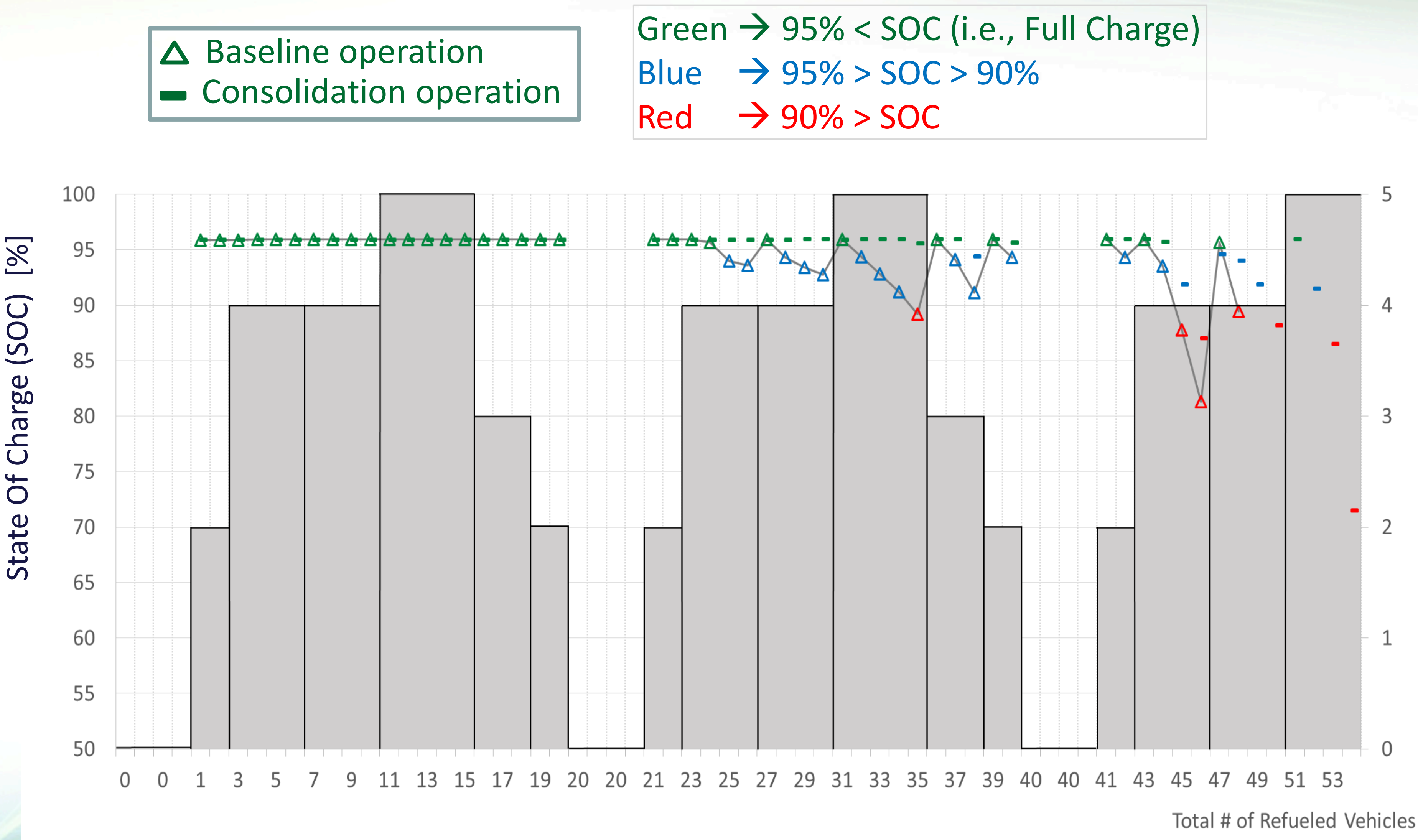
Process Limits	Max	Min	MAWP
High Pressure Cascade Pressure [MPa]	91	42	93
400 bar Storage Pressure [MPa]	44	5	45.9
200 bar Storage Pressure [MPa]	26	2	27.5
1st Stage Independent Suction (2 to 40 MPa)	20	2	N/A
2nd Stage Independent Suction (13 to 95 MPa)	40	13	N/A
2 Stages Combined Suction (5 to 95MPa)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

- Fueling parameters

Fueling Protocol	Value
SAE Fill Pressure Ramp Rate @25^{o}C Ambient, for 4-7 kg Tank Capacity [MPa/min]	18.5
Final Vehicle Tank Pressure [MPa] (Typical State Of Charge at 25^{o}C ambient)	81 (96%)
Leak Checks Duration for Every 20MPa Rise [sec]	10
Lingering Time Between Fills [sec]	120
Number of Back-To-Back Fills During Peak Hour	5

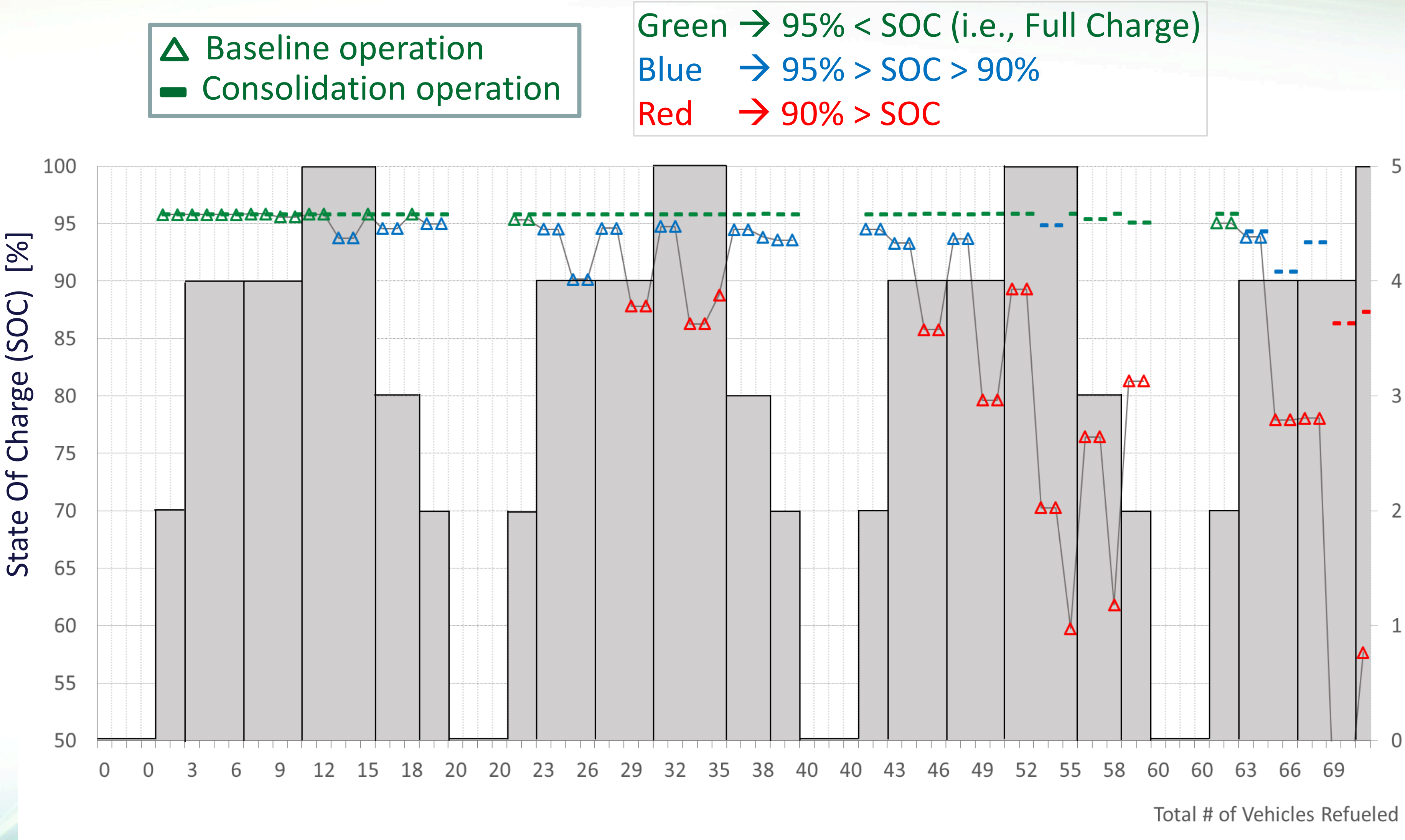
Simulated Station Performance -Accomplishments

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



Simulated Station Performance -Accomplishments

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



Simulated Station Performance -Accomplishments

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