2019 DOE HYDROGEN and FUEL CELLS PROGRAM ANNUAL MERIT REVIEW

A TOOL TO ESTIMATE THE BENEFITS OF TUBE-TRAILER CONSOLIDATION FOR STATION BUILDERS

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April 30, 2019

h2022

Overview

Timeline

- Start: July 2018
- End: April 2019
- % Complete (FY19): 80%

Barriers/Challenges

- Lack of hydrogen infrastructure options analysis
- Lack of appropriate models and analytical capability
- Conduct unplanned studies and analyses

Budget

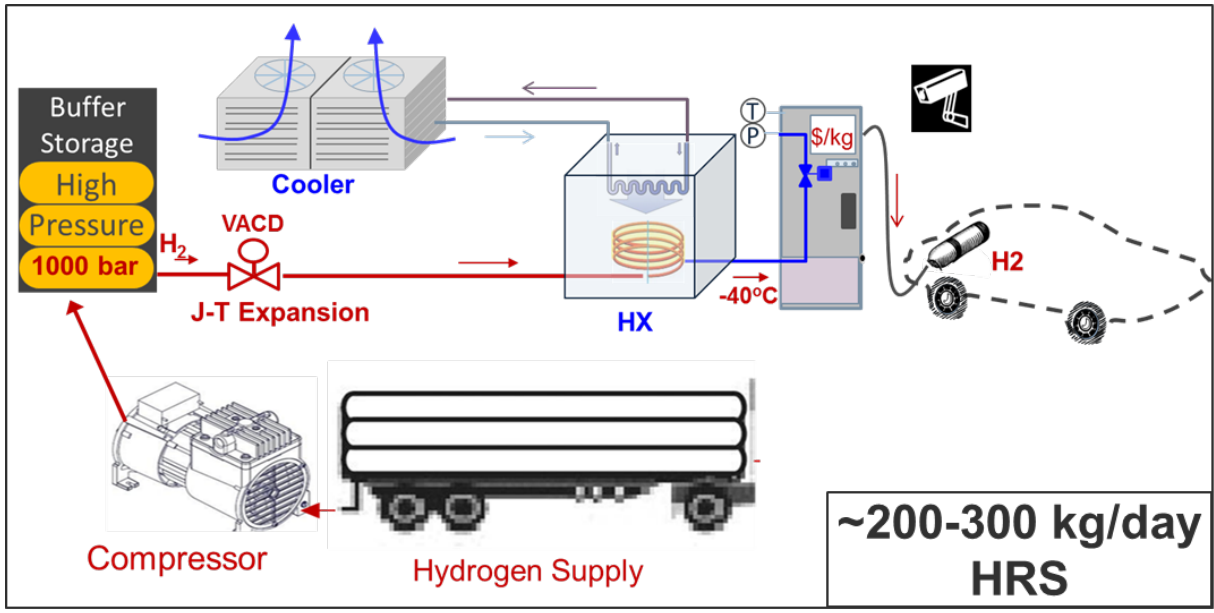
- FY18 Funding: $25K
- FY19 Funding: $25K
- 50% DOE funding

Partners and Collaborators

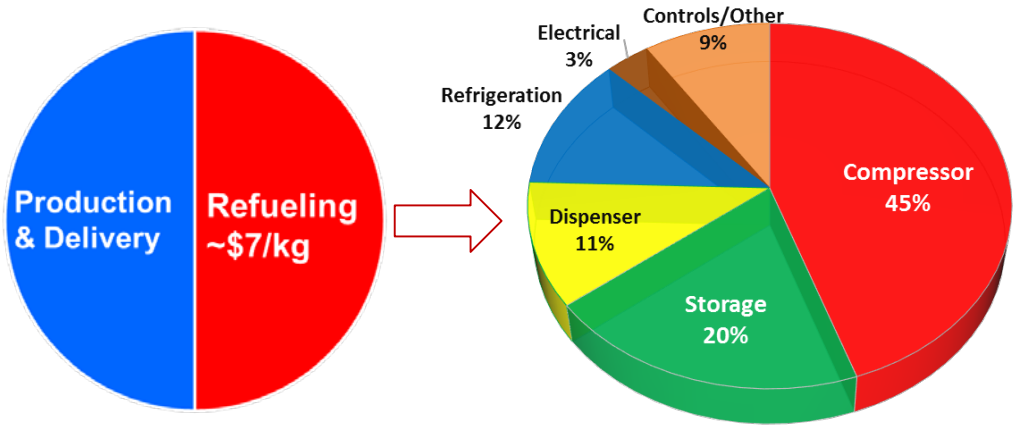
- PDC Machines Inc.

Compression cost contribution towards H_2 refueling is significant - Relevance/Impact

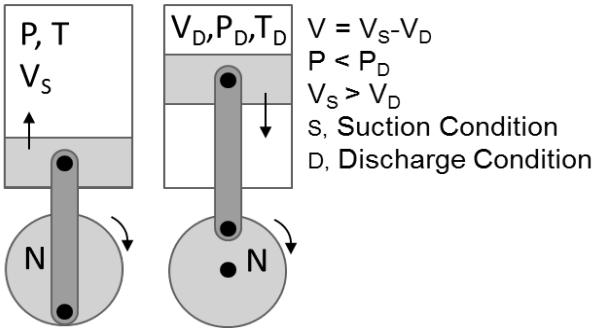
- Together, compression and storage make up 2/3rd of the total station capital cost
- Need to model the impacts of fueling strategies that lower station cost (e.g., pressure consolidation)



Typical Gaseous Hydrogen Refueling Station



Compressor operation fundamentals and sizing for hydrogen refueling station - Relevance



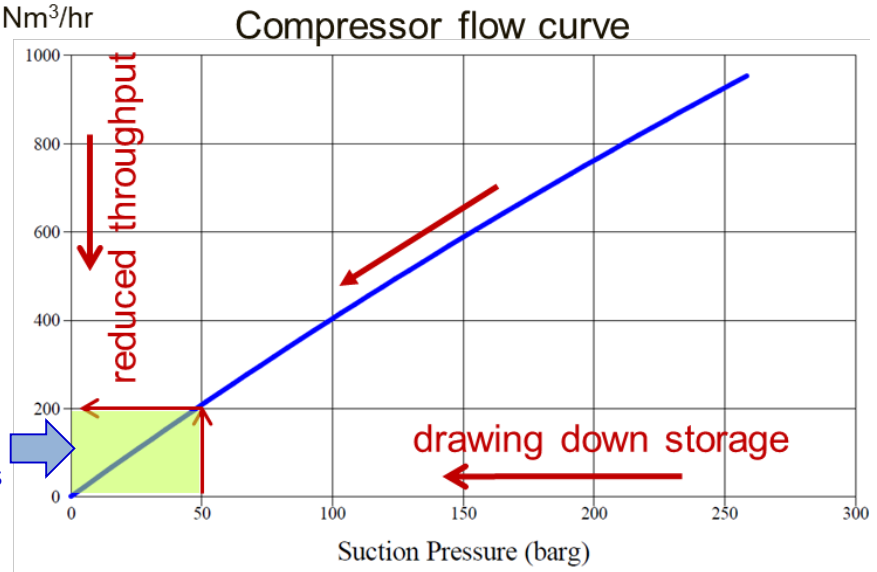
$V = V_S - V_D$
$P < P_D$
$V_S > V_D$
S, Suction Condition
D, Discharge Condition

Compressors are typically sized to provide the required compressor throughput to meet station demand at the lowest possible supply working pressure

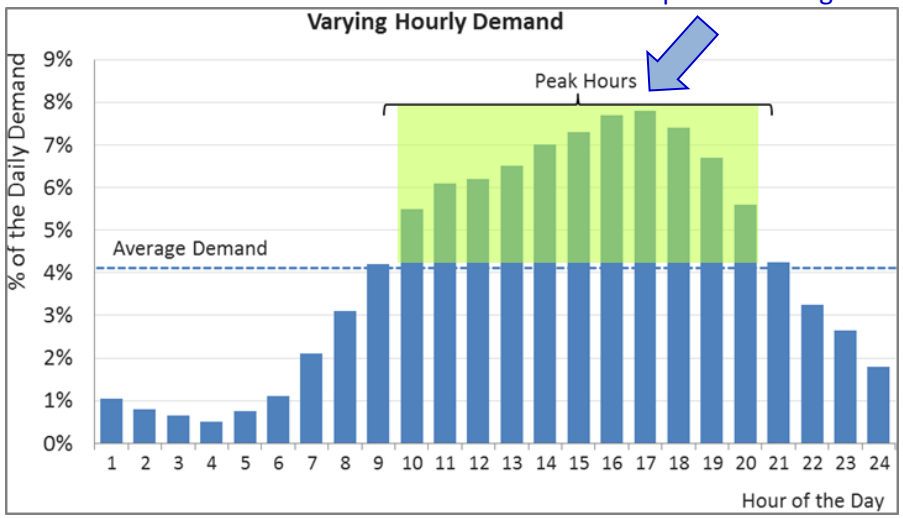
Mass flow rate = volume displacement × r.p.m. × density

Mass flow rate = volume displacement × r.p.m. × $[P/ZRT]_s$

Mass flow rate ~ suction pressure



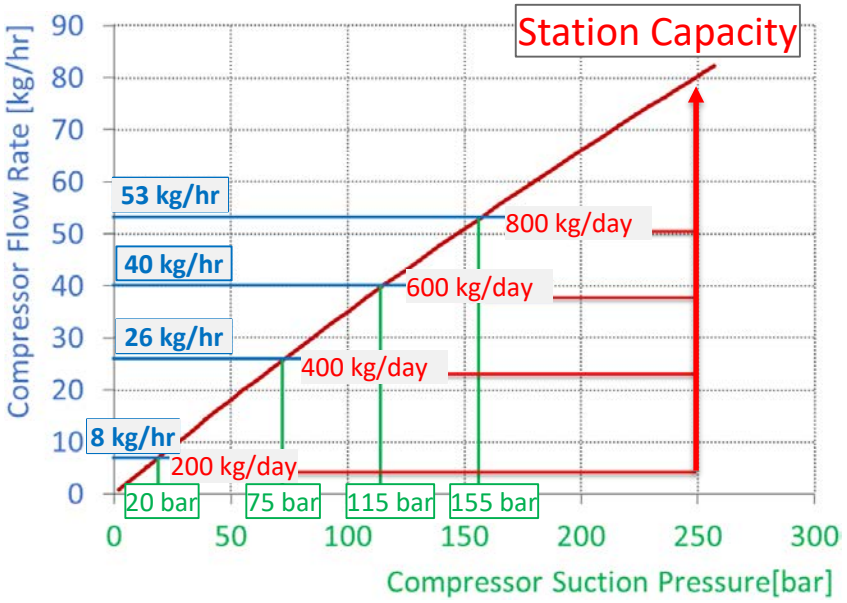
Design criteria for peak refueling hours

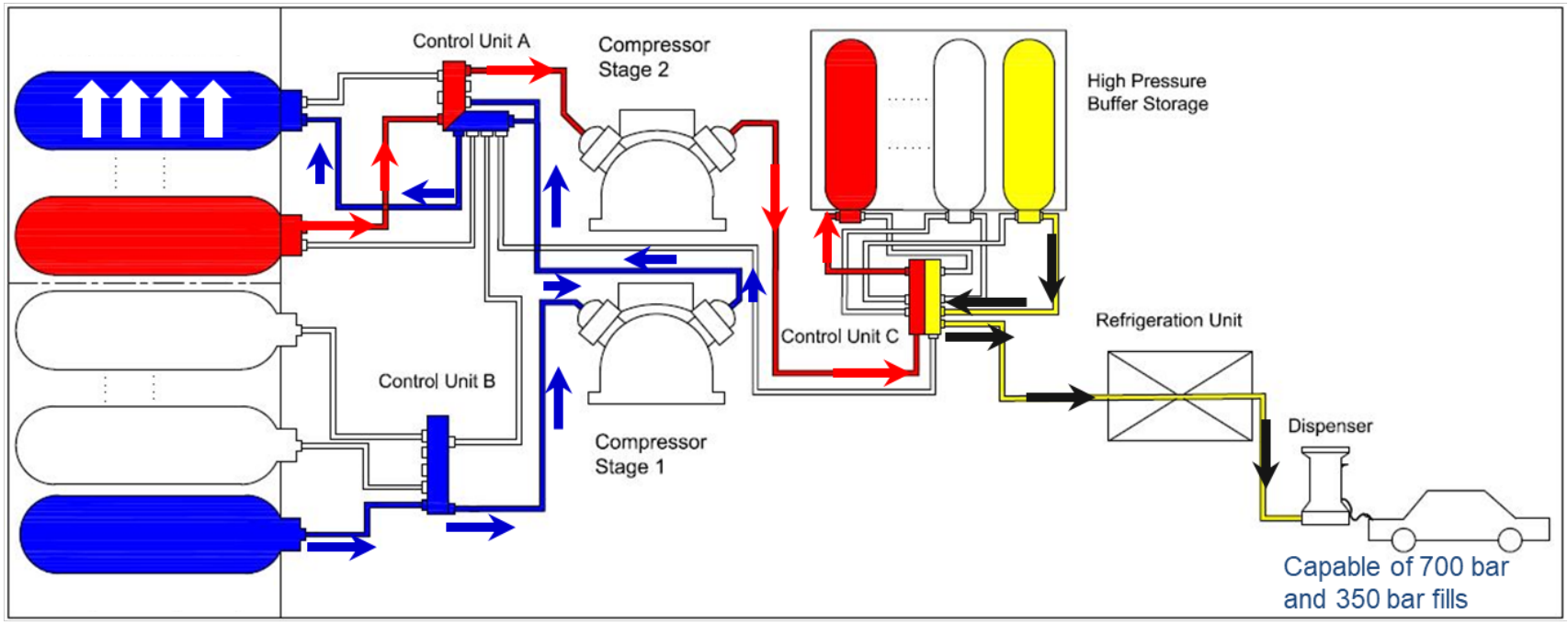


- Compressors are oversized for better utilization of hydrogen supply storage and are typically underutilized during off-peak hours

Pressure consolidation underlying concept and benefits –Relevance/Impact

- Reduces the station capital cost by up to 25–30%; alternatively, the station's refueling capacity could be increased by a factor of 2–3
- Enables consistent high-state-of-charge fueling
- Improves compressor operational reliability
- Allows significant utilization of the tube trailer (or supply storage)





Objective of pressure consolidation benefits tool - Relevance/Impact

- Develop a tool that estimates the performance of a station using pressure consolidation hydrogen refueling algorithm
- Provide a tool to help station builders quantify the benefits of the pressure consolidation hydrogen refueling, and to compare these benefits to typical baseline station operation
- Provide the refueling cost and state of charge of vehicle fills among other metrics to compare the performance of pressure consolidation against baseline station operation

Desired tool's inputs and outputs - Approach

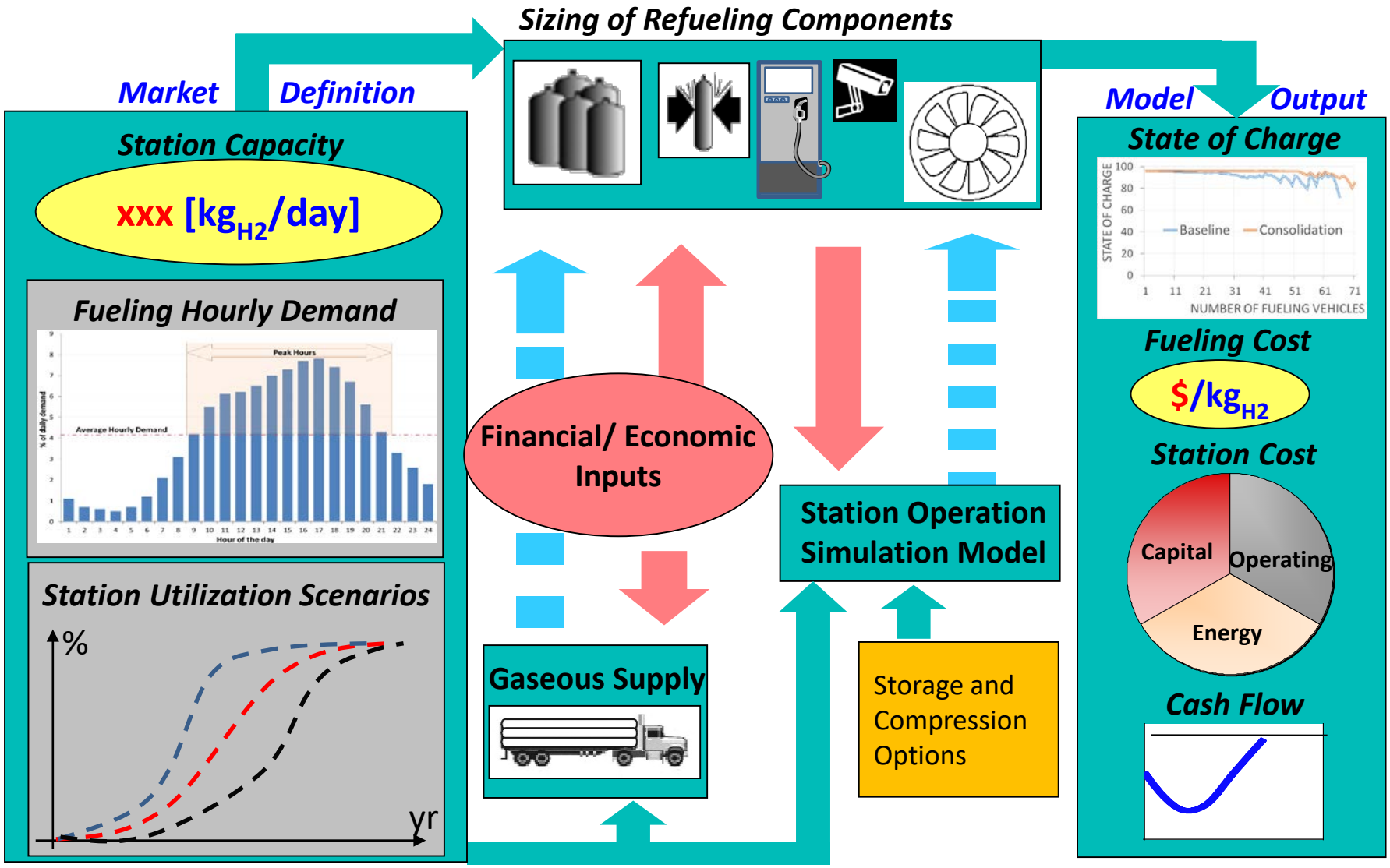
Tool Inputs:

- Station capacity, hourly refueling profile, and number of dispensers
- Supply storage pressure, and dispenser-rated vehicle fill pressure
- Supply and buffer storage size and configuration
- Economic and financial parameters

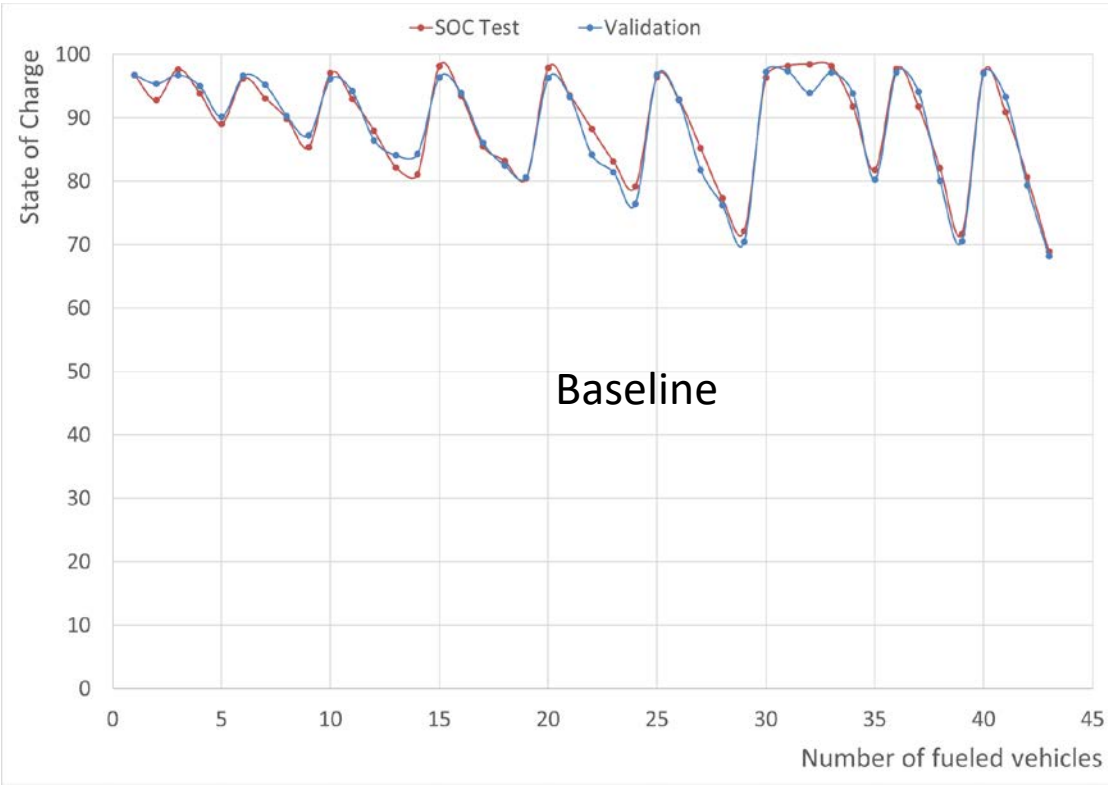
Tool Outputs:

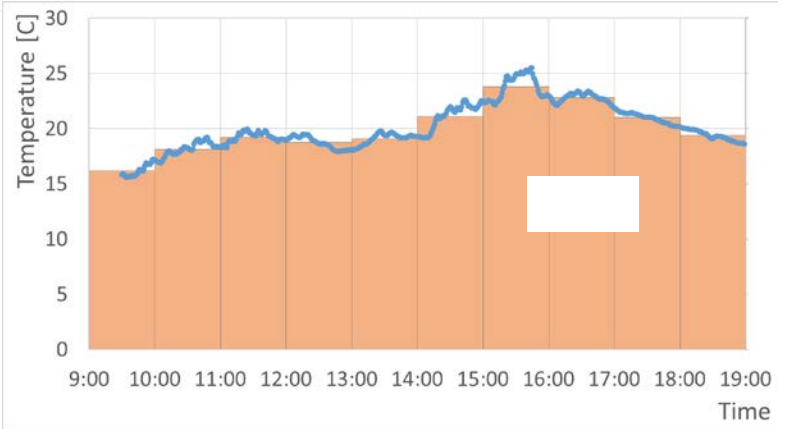
- Levelized hydrogen refueling cost
- Capital cost of the refueling station
- Number of fueled vehicles with corresponding state of charge
- Tube-trailer utilization rate

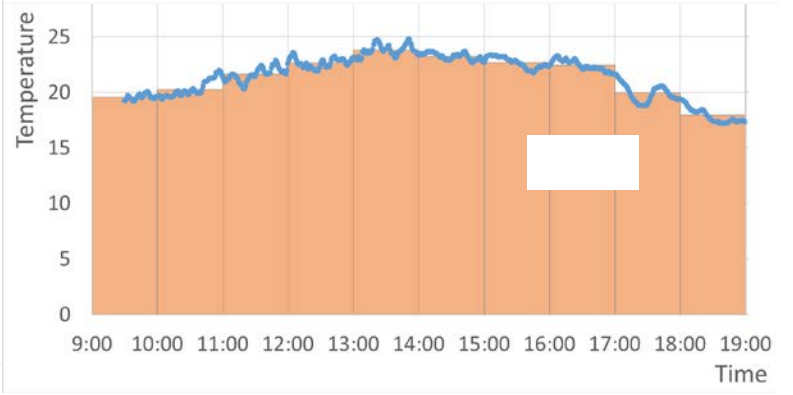
Tool framework - Accomplishment



Tool validation: baseline station operation - Approach







- Validated the model using testing data of NREL's station operation
- Majority of the fills were within 3% of the testing data
- Deviations have been analyzed and attributed to station component behavior like lag in shutting opening of valves resulting in movement of mass between cascade storage vessels

Station operation configuration for estimating the state of charge of vehicle fills -Accomplishment

Tool Inputs	Consolidation Operation	Baseline Operation
Supply Storage	Vessel sizes and configuration	Vessel sizes and all the vessels are manifolded together
High Pressure Cascade Buffer Storage	Vessel sizes and configuration	Vessel sizes and configuration
Refueling Procedure	Vehicle initially filled directly from supply storage, followed by the high-pressure buffer	Vehicle filled by the high-pressure buffer
Compressor Operation	Both stages are always assumed to operate in series to consolidate supply storage and replenish the high-pressure buffer	Both stages are always assumed to operate in series to replenish the high-pressure buffer

Summary - Accomplishment

- Communicated with PDC Machines Inc. to define the scope of the tool, in terms of desired inputs and outputs
- The tool quantifies the benefits of tube-trailer/supply storage consolidation by estimating and comparing the refueling cost of hydrogen against the baseline station operation
- Developed a engineering model to simulate the station operation and estimate the state of charge of vehicle fills

Technology Transfer Activities

- Licensed the pressure consolidation technology to PDC Machines, Inc.

Collaborations and Acknowledgments

- Collaborated with PDC machines Inc. to define the scope of the tool

Future work

- Test the tool and verify the state of charge and refueling cost estimates
- Release the tool to PDC for testing and use

Project Summary

- **Relevance**:
  - Pressure consolidation enables consistent high-state-of-charge fueling with better utilization of the supply storage
  - Tool is needed to estimate the refueling cost and state of charge of fills as metrics to compare the performance of pressure consolidation against baseline station operation
- **Approach**: Develop a new tool to simulate the refueling station operation and to estimate the state of charge of vehicle fills. Incorporate techno-economic modeling to estimate refueling cost.
- **Collaborations**: Collaborated with PDC Machines Inc. to determine the scope of the tool and define inputs and desired outputs.
- **Technical accomplishments and progress**:
  - Defined the scope of the tool
  - Developed the code to simulate the station operation to estimate the stated of charge of the fills
- **Future Research**:
  - Test the tool and verify the state of charge and refueling cost estimates
  - Release the tool to PDC for testing and use

Publications

- Reddi, K., & Elgowainy, A. (2019). “Two-tier tube-trailer operation method and system to reduce hydrogen refueling cost.” U.S. Patent Application 15/272,622, issued and currently at Final Data Capture (FDC).
- Reddi, K., Elgowainy, A., Rustagi, N., & Gupta, E. (2018). “Two-tier pressure consolidation operation method for hydrogen refueling station cost reduction,” International Journal of Hydrogen Energy 43(5), 2919–2929.
- Elgowainy, A., & Reddi, K. (2017). “Enhanced methods for operating refueling station tube-trailers to reduce refueling cost.” U.S. Patent 9,739,418.
- Elgowainy, A., Reddi, K., Sutherland, E., & Joseck, F. (2014). “Tube-trailer consolidation strategy for reducing hydrogen refueling station costs.” International Journal of Hydrogen Energy 39(35), 20,197–20,206.

Data Management Plan

- The documentation of analysis results and underlying data will be completed by end of project time
- The data generated by this project will be preserved in in machine-readable, digital format, thus will incur minimum cost to preserve

Response to Reviewers' Comments from 2018 AMR

This project is new in FY19 and thus was not reviewed last year