2013 DOE Hydrogen Program Review

Hydrogen Delivery Infrastructure Analysis

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PD014

Overview

Timeline

- ☐ Start: FY 2007
- ☐ End: Continuous

Budget

- ☐ 100% DOE funding
- ☐ FY12: $325 k
- ☐ FY13: $300 k

Barriers/Challenges

- ☐ Lack of analysis of H2 infrastructure options and tradeoffs
- ☐ Cost and efficiency of delivery components
- ☐ Lack of appropriate models and tools/stove-piped analytical capability

Partners

- ☐ Argonne National Lab
- ☐ Pacific Northwest National Lab
- ☐ National Renewable Energy Lab
- ☐ Industry stakeholders

Relevance

- ☐ Provide platform for comparing alternative component, and system options to reduce cost of hydrogen delivery
  - ✓ Identify cost drivers of current technologies for hydrogen delivery to various market penetrations of fuel cell electric vehicles (FCEVs)
  - ✓ Incorporate SAE J2601 refueling protocol in the modeling of hydrogen refueling stations (HRS)
  - ✓ Evaluate role of high-pressure tube-trailers in reducing refueling station capital
  - ✓ Evaluate the potential of novel delivery concepts for future market scenarios
- ☐ Assist in FCT program planning
  - ✓ Investigate delivery pathways with potential to achieve cost goals in MYRD&D
  - ✓ Assist with defining R&D areas for future funding priorities to achieve targeted performance and cost goals
- ☐ Support existing DOE-sponsored tools (e.g., H2A Components, H2A production, SERA, MSM, JOBS FC, GREET)
  - ✓ Collaborate with model developers and lab partners
  - ✓ Collaborate with industry for input and review

Approach

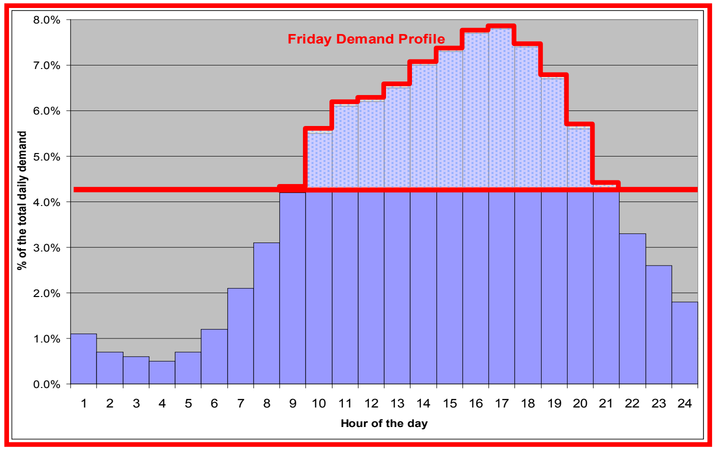
- ☐ Create **transparent, flexible, user-friendly, spreadsheet-based tool (HDSAM)** to examine new technology and options for hydrogen delivery
- ☐ Provide modeling structure to automatically link and size components into **optimized pathways** to satisfy requirements of market scenarios, and compute component and **system** costs, energy and GHG emissions
- ☐ **Collaborate** to acquire/review input assumptions, analyze delivery and dispensing options, and review results
- ☐ Provide **thorough QA**
  - ☐ Internally via partners
  - ☐ Externally, via briefings to Tech Teams, early releases to DOE researchers, industry interaction

SAE J2601 fueling protocol must be carefully incorporated in HRS configuration and cost estimates

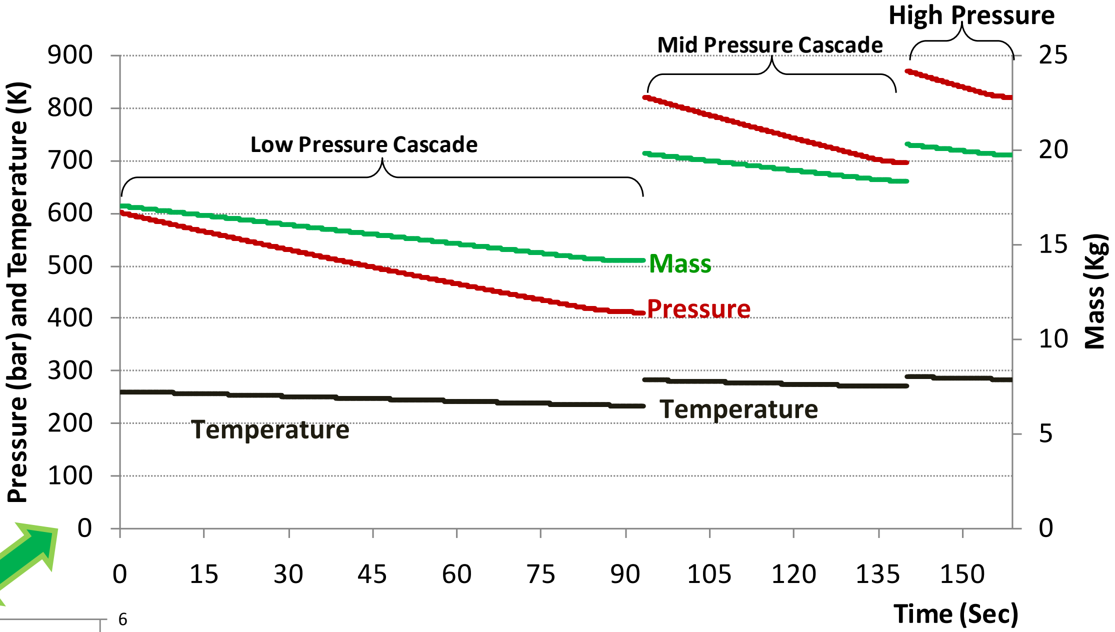
Fueling specification for 70 MPa compressed hydrogen vehicles:

- Maximum gas temperature in vehicle tank 85°C
- Maximum fueling pressure in vehicle H2 storage system 87.5 MPa @ 85°C
- Maximum fueling rate (equivalent to 10 kg /180s) 60 g/s
- Fueling time (passenger car) with capacity up to 5 kg hydrogen within 180 sec
- Percentage (%) fueling target
  - ✓ 100% Full is defined as 40.2 g/L (70MPa @ 15°C; 87.5MPa @ 85°C)

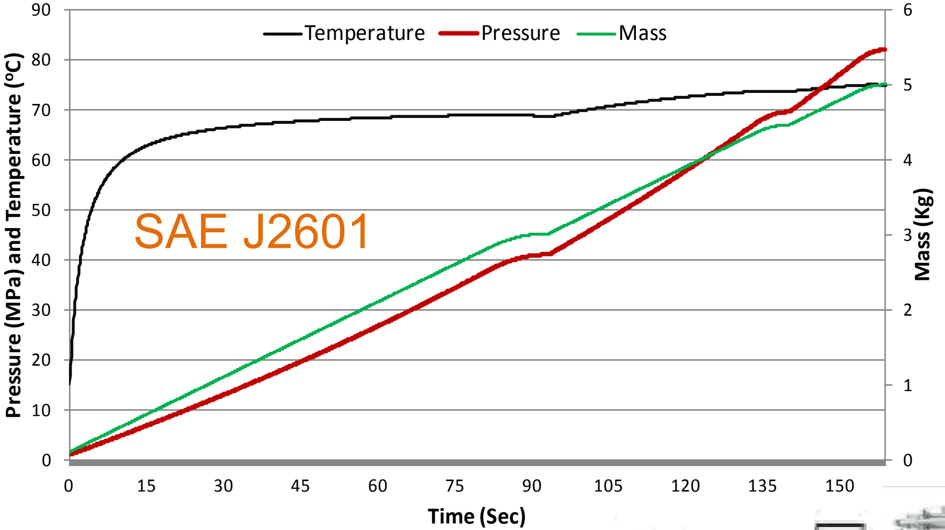
Improved modeling of HRS requires new considerations



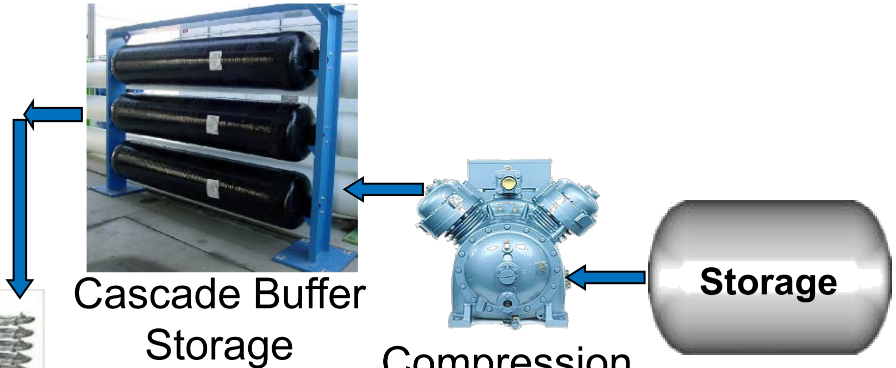
Hourly demand profile must be satisfied with HRS equipment



Dynamic interaction of cascade buffer storage with vehicle tank



SAE J2601



Cascade Buffer Storage

Compression (900 bar)

Refrigeration (-40°C)

700 bar Dispensing

Gaps with previous modeling

- Limiting the number of cascade banks to three
- Switching point between cascade vessels not optimized
- Does not guarantee an average fill rate of 1.66 kg/min (5 kg in 180 s)
- Pressure drop between cascade buffer and dispenser nozzle is not modeled
- Tracking of vehicle tank conditions (temperature, pressure) is not modeled
- Vehicle overshooting pressure (875 bar) is not accounted for

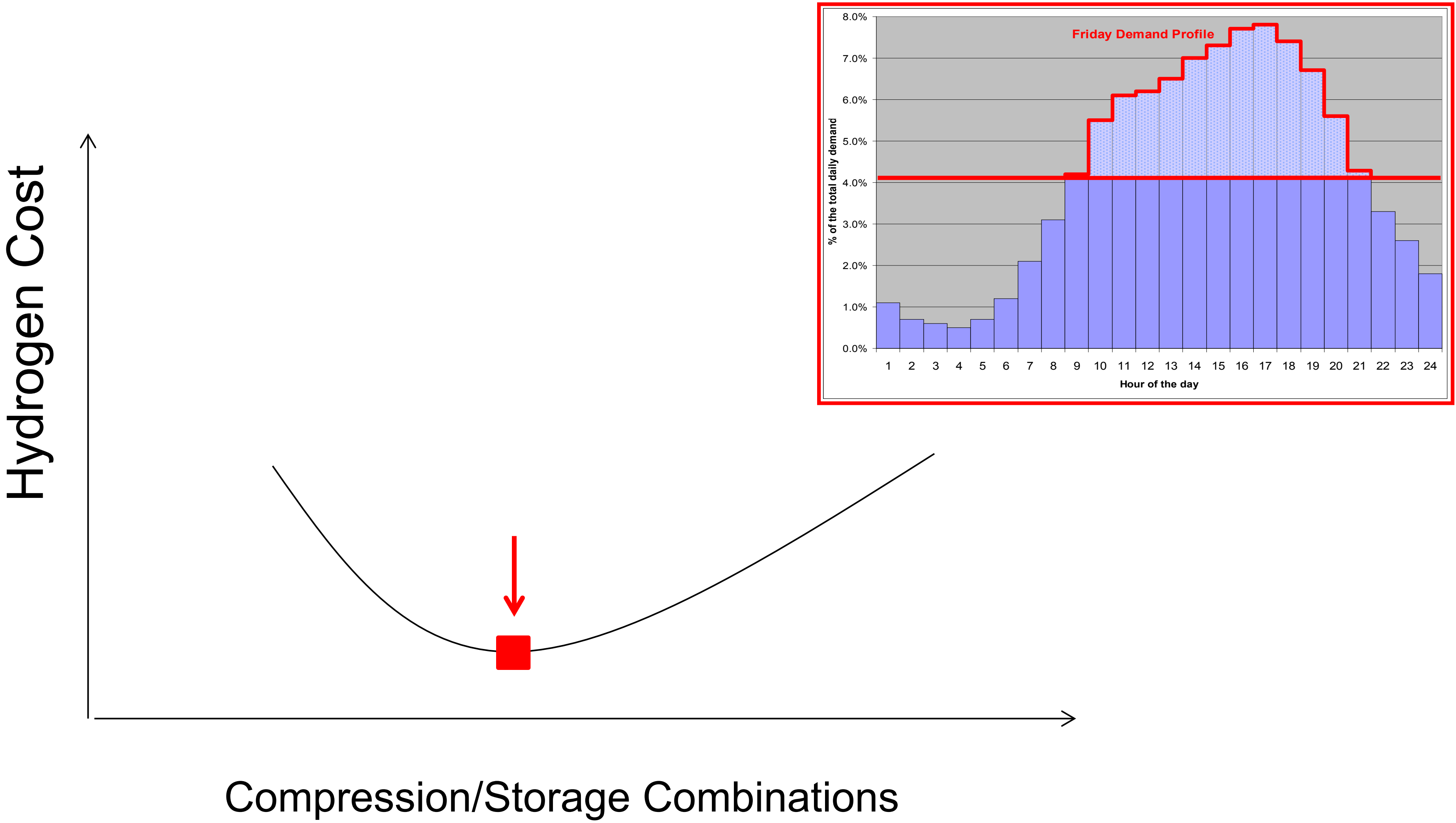
Scope of modeling and analysis in FY13

- Key issues to address with modeling and analysis
  - Incorporate SAE J2601 refueling protocol in the modeling of hydrogen refueling stations
  - Ways to reduce station capital investment
  - Ways to improve utilization of installed equipment
  - How to optimize station configuration for different market scenarios
- Role of tube-trailers in reducing station compression investment
- Update estimates for the H2 delivery cost and contribution of refueling station components

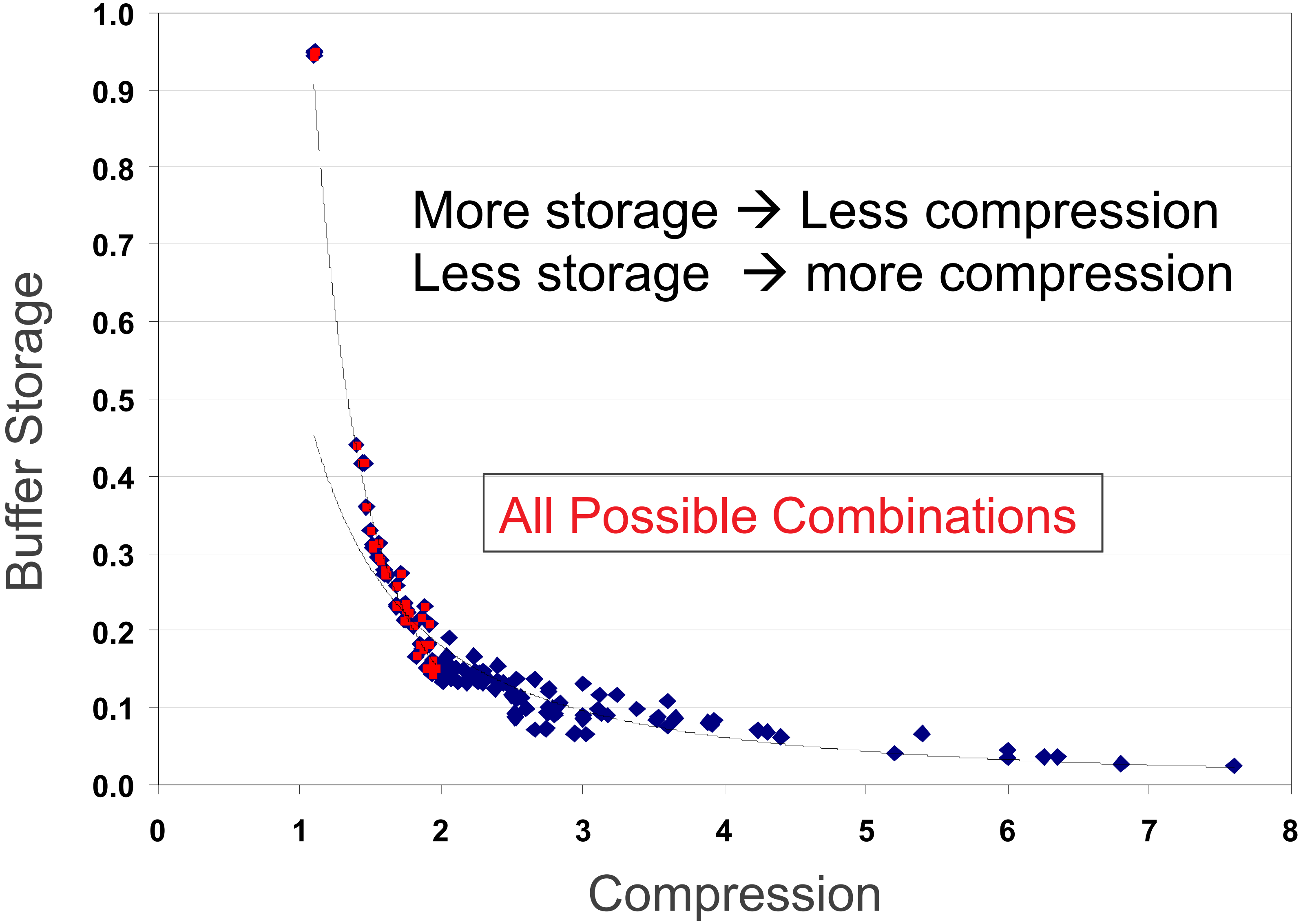
FY2013 Accomplishments

Month/Year	Milestone
November 2012	Investigate the combination of cascade vessels that results in maximum back to back vehicle fills while observing SAE J2601
January 2013	Identify minimum compression requirement to address the additional demand in peak hours and target the lowest combined cost of compressor and cascade buffer system
March 2013	Investigate the role of high-pressure tube-trailers in reducing station capital investment
July 2013	Evaluate the impact of SAE J2601 on refueling station capital investment
August 2013	Update and publish model with the new capabilities
September 2013	Document and publish analysis and results

Goal: minimize compression/storage contribution to hydrogen cost, observing SAE J2601



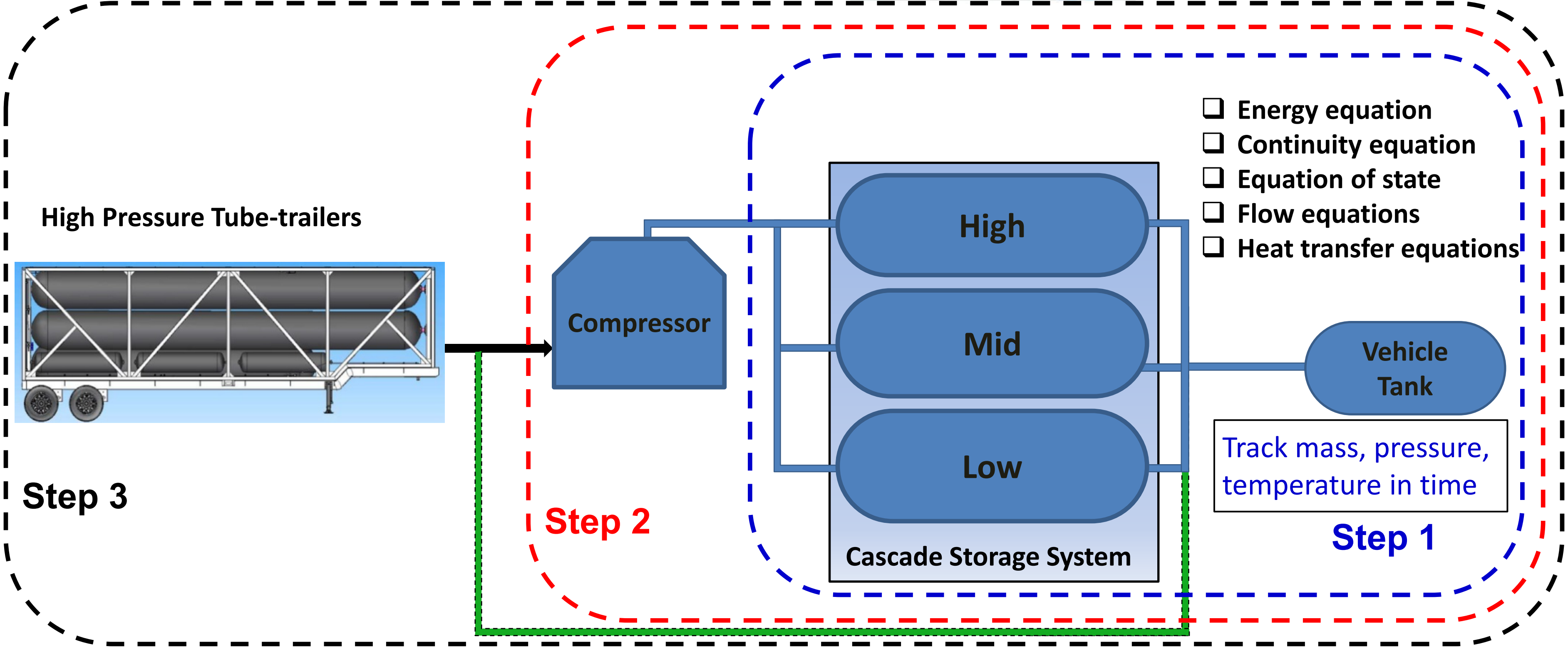
Incremental increase in buffer storage can reduce compression requirement at HRS



More storage → Less compression
Less storage → more compression

All Possible Combinations

Analysis approach



- ☐ Energy equation
- ☐ Continuity equation
- ☐ Equation of state
- ☐ Flow equations
- ☐ Heat transfer equations

High Pressure Tube-trailers

Compressor

High

Mid

Low

Cascade Storage System

Vehicle Tank

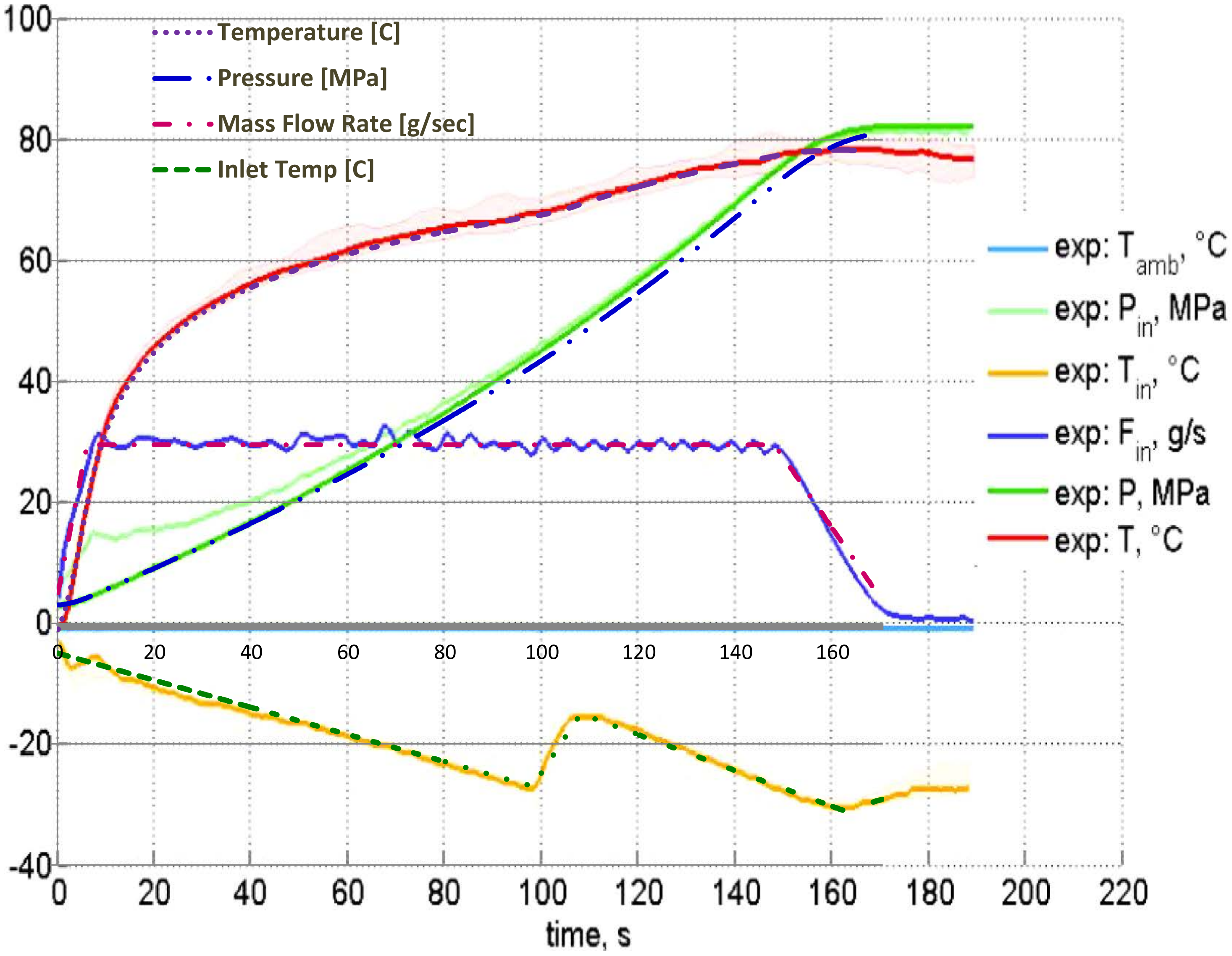
Track mass, pressure, temperature in time

Step 1

Step 2

Step 3

Simulation results are validated against published experimental data — Accomplishment*



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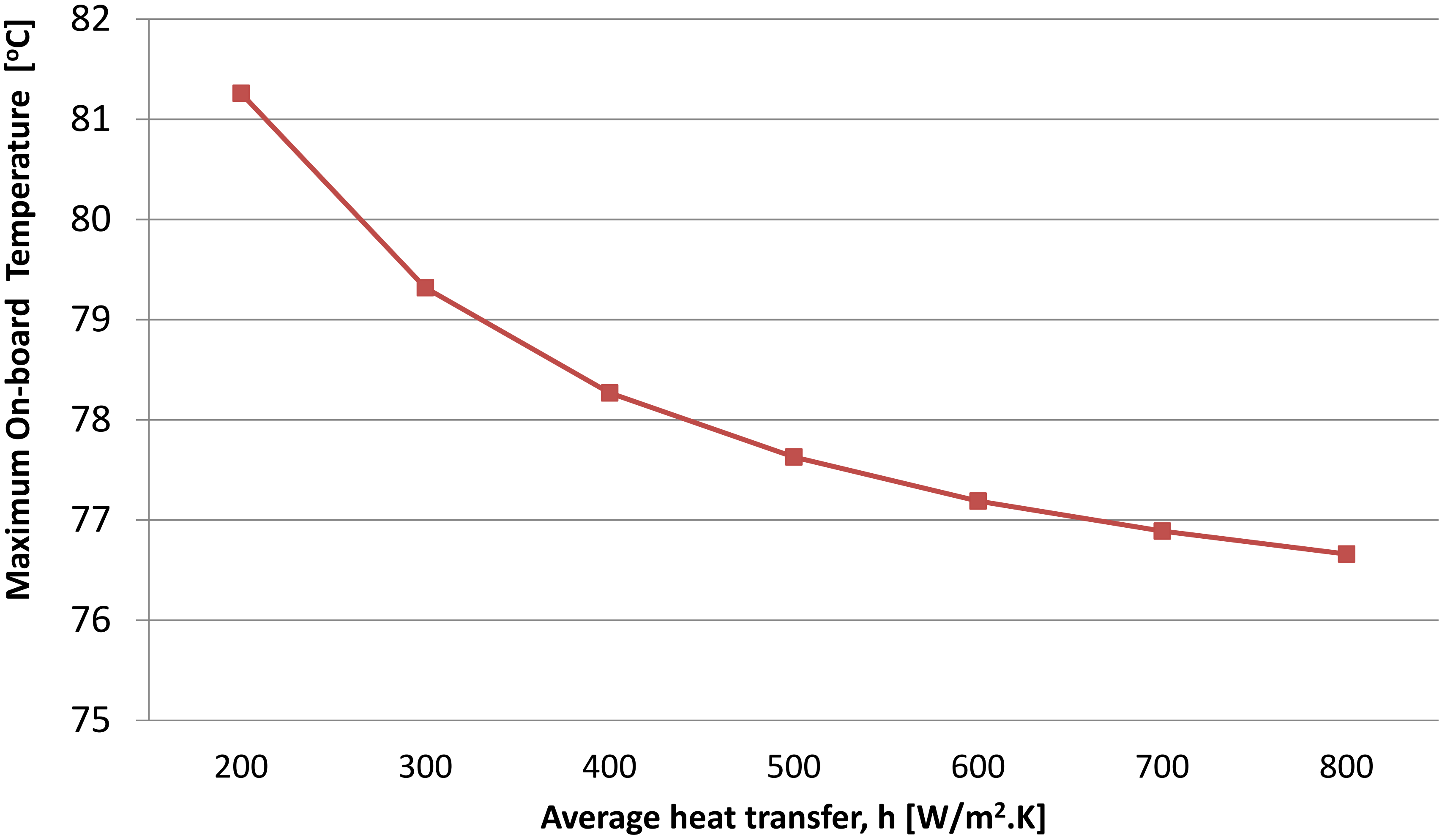
Effect of average heat transfer coefficient on maximum predicted temperature is significant

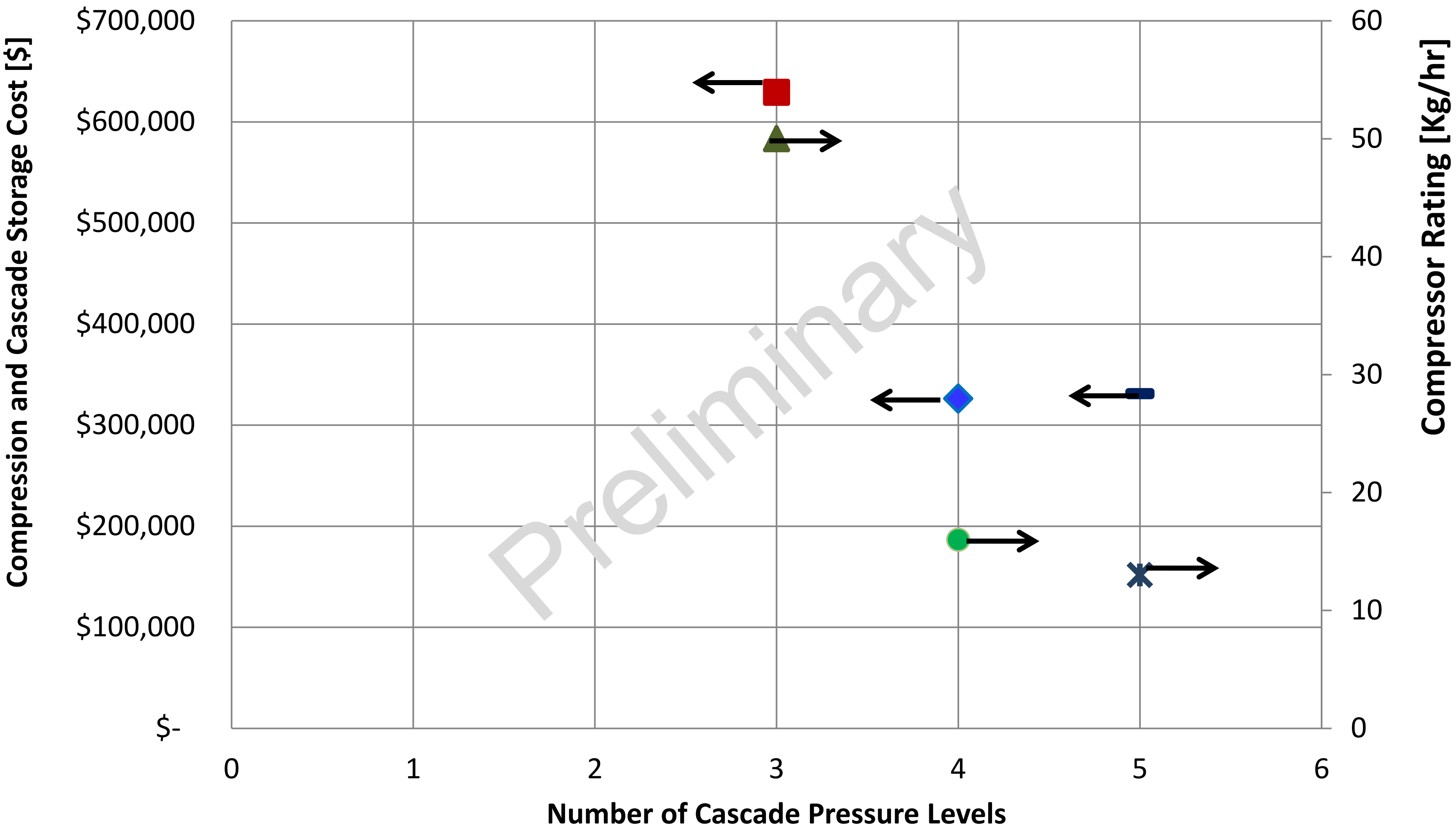


Identify optimum cascade storage configurations for lowest cost and better utilization

Configuration Number	Cascades at each Pressure Level (High to Low)	Flow Rate [Kg/min]	Vehicles Filled	No. of Cascades	Utilization (U)	Cascades Cost(C) [$]	Economy Index (C/U)
1	**1-1-1**	**1.611**	**1**	**3**	**0.137**	**$69,000**	**500,000**
2	1-1-2	1.610	2	4	0.206	$92,000	450,000
3	1-2-1	1.593	2	4	0.206	$92,000	450,000
4	2-1-1	1.612	1	4	0.103	$92,000	900,000
5	2-2-1	1.593	2	5	0.165	$115,000	700,000
6	1-2-2	1.612	2	5	0.165	$115,000	700,000
7	2-2-2	1.612	2	6	0.137	$140,000	1,000,000
8	2-2-3	1.609	3	7	0.177	$160,000	900,000
9	2-3-3	1.612	3	8	0.154	$185,000	1,200,000
10	2-3-4	1.74[illegible]	3	9	0.137	$210,000	1,500,000
11	**1-1-1-1**	**1.650**	**3**	**4**	**0.309**	**$92,000**	**300,000**
12	**1-1-1-1-1**	**1.683**	**4**	**5**	**0.329**	**$115,000**	**350,000**
13	1-1-1-1-1-1 (6)	1.593	5	6	0.343	$140,000	400,000
14	1-1-1-1-1-1-1 (7)	1.604	7	7	0.412	$160,000	390,000
15	1-1-1-1-1-1-1-1(8)	1.630	8	8	0.412	$185,000	450,000
16	1-1-1-1-1-1-1-1-1 (9)	1.585	10	9	0.458	$210,000	450,000

Filling129L fuel tanks from 10bar to 700bar using cascade vessels carrying 12kg of H2 at 950bar

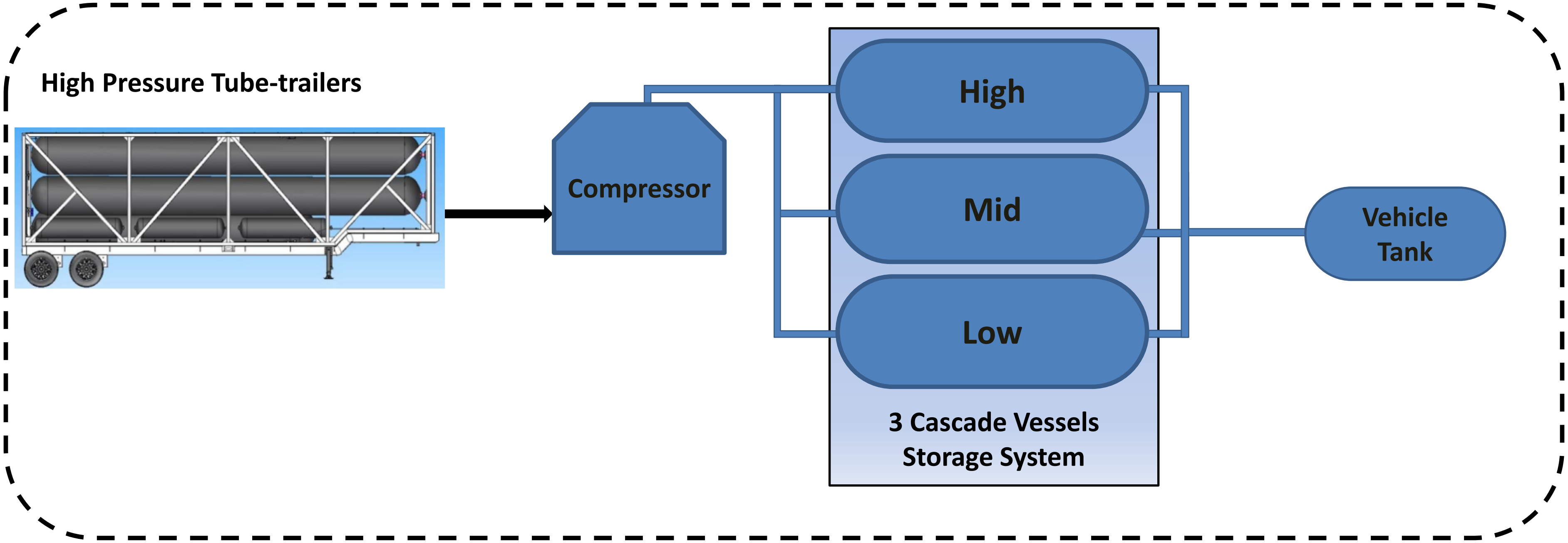
Refueling station cost can be reduced by optimizing buffer storage and compression



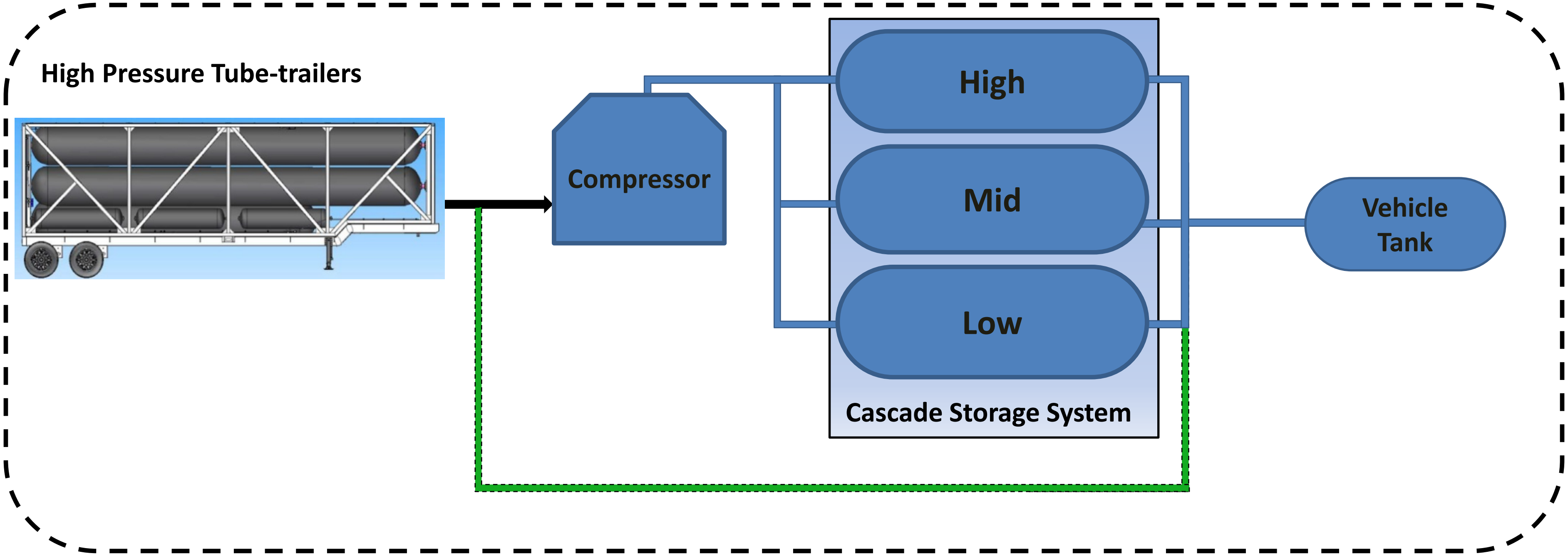
ROLE OF HIGH PRESSURE TUBE-TRAILERS IN REDUCING REFUELING STATION COST

Scenario 1:

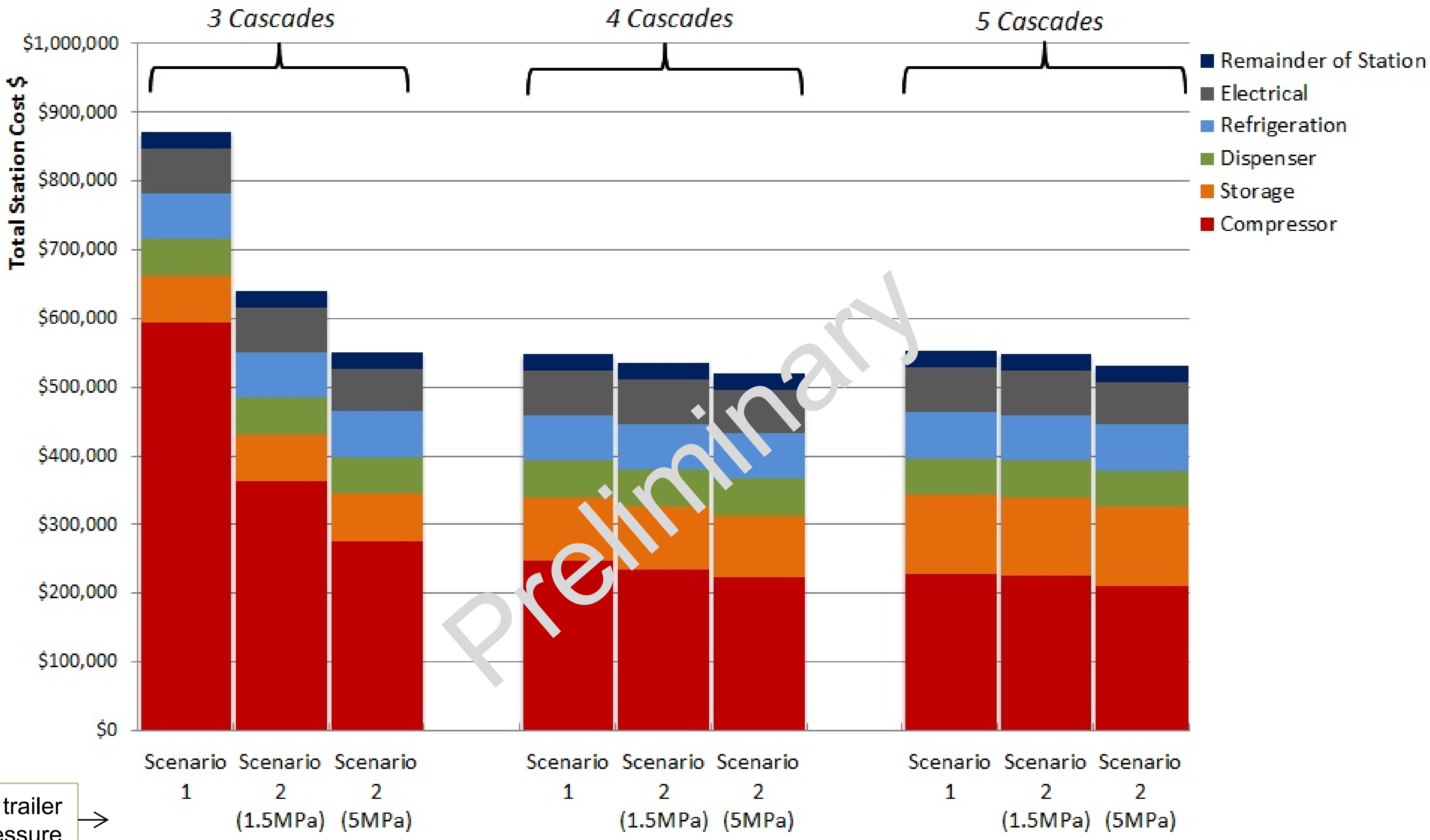
Tube trailer used as storage (supplying compressor)



Scenario 2:
Tube trailer used also for initial vehicle fill

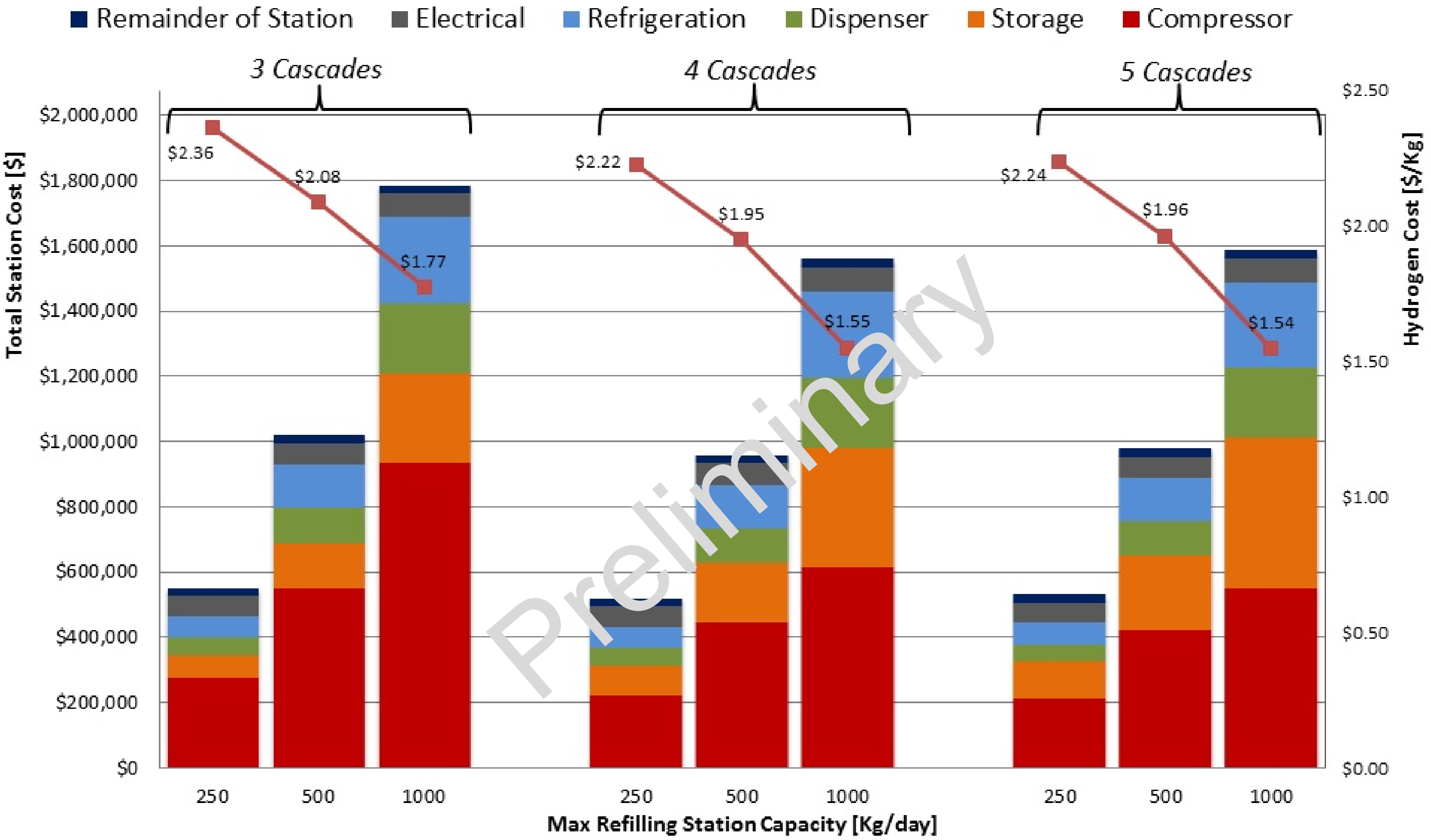


Higher return pressure of tube trailer provides an opportunity for lower refueling station compression



Tube trailer return pressure →

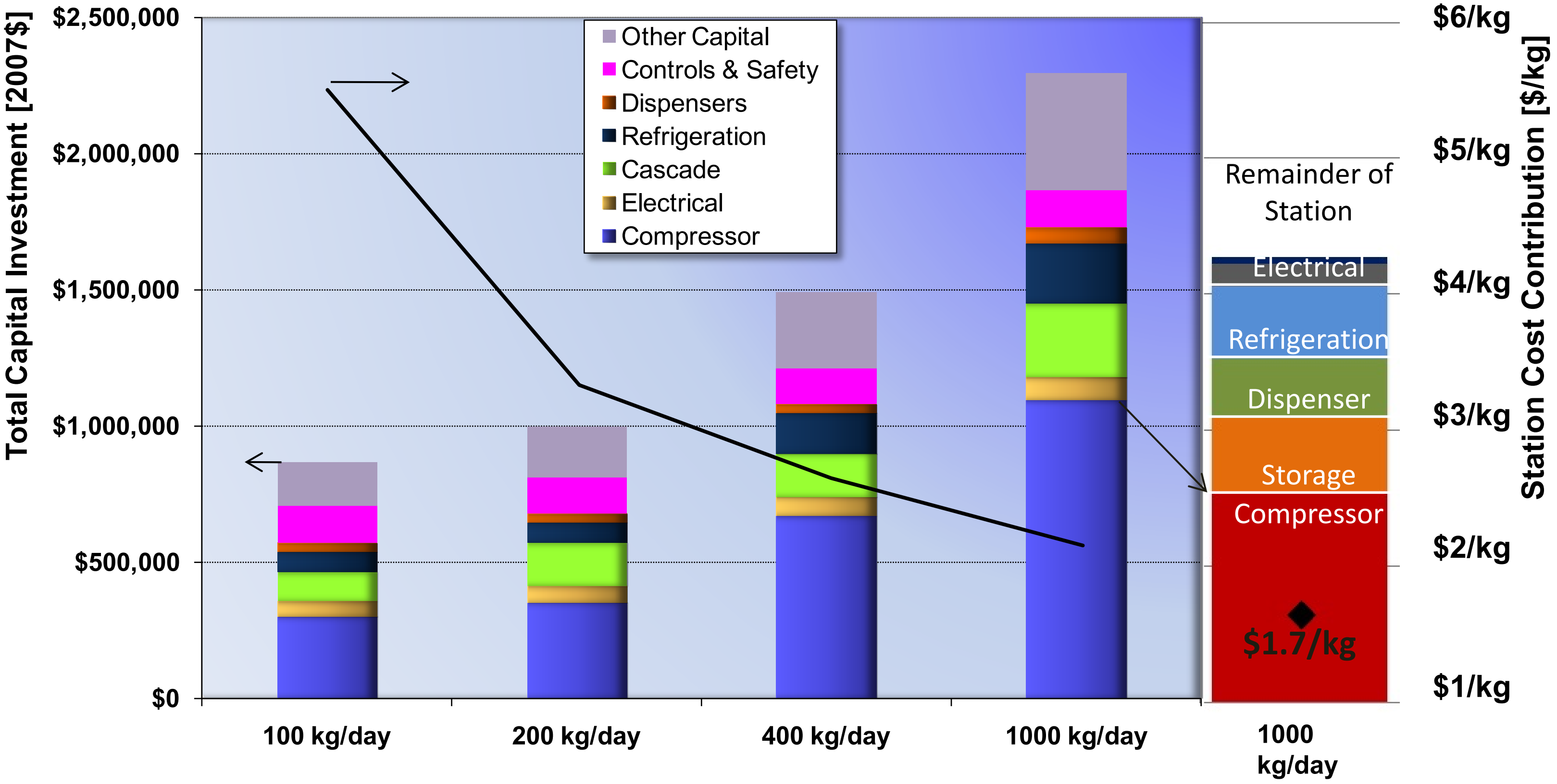
HRS contribution to H2 cost decreases with economies of scale



Improved modeling of HRS predicts lower compression requirement and reduced HRS cost

Previous modeling results

Improved modeling results



Preliminary

Preliminary insights

- Considering trade-off between compression and storage identifies potential low cost options for any station demand
- A four- or five-cascade system configuration is economical compared to the 3-cascade system configuration
- High-pressure tube trailers decrease the station cost when used for initial vehicle fill and returned at a higher pressure

Future Work

- Evaluate advanced compression technologies and novel compression concepts
  - e.g., liquid ionic compressors and electrochemical compression
- Examine issues related to liquid delivery options
  - e.g., liquefaction efficiency and GHG emissions
- Evaluate storage technology options and new concepts
  - e.g., pre-stressed steel/concrete composite tanks for bulk storage
- Evaluate impact of chemical storage options
  - e.g., MOF material delivery and refueling cost

Project Summary

- **Relevance:** Provide platform to evaluate hydrogen delivery (in $, energy and GHG emissions), estimate impact of alternative conditioning, distribution, storage and refueling options; incorporate advanced options as data become available; assist Hydrogen Program in target setting.
- **Approach:** Develop models of hydrogen delivery components and systems to quantify costs and analyze alternative technologies and operating strategies.
- **Collaborations**: Active partnership among ANL, PNNL and NREL, plus regular interaction with Fuel Pathways and Delivery Tech Teams, DOE researchers and industry analysts.
- **Technical accomplishments and progress:**
  - Identified minimum compression requirement to address the refueling demand in peak hours
  - Evaluated impact of SAE J2601 protocol
  - Evaluated role of high-pressure tube-trailers in reducing refueling station capital investment
- **Future Research**: Examine new concepts and technology options for refueling station cost reduction by considering various pressures and temperatures along the delivery pathway, revise/update data, and respond to reviewers and Tech Team recommendations.

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