SBIR: Highly Efficient Smart Tanks for Hydrogen Storage

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Project ID: ST221

TDA Research

May 30, 2020

Project Overview

Barriers

- **Barriers addressed**
  - H_2 gas temperature rise is the major issue in the refilling process
  - H_2 gas is currently cooled to -40°C to counter temperature rise
  - 3 main constraints: (i) safe temperature limit, (ii) maximum filling pressure, (iii) state of charge of the tank

Timeline

- SBIR Phase II Project DE-SC0018757
- Project Start: 7/2/2018
- Project End: 8/18/2021

Partners

- **Interactions/ collaborations**
  - Hyper Comp Engineering - fabricate full scale versions of our prototype unit
  - NREL – test full scale-prototype units to evaluate the merits of the technology
  - GTI – develop CFD models to further improve key parameters in tank design
- **Project lead**
  - TDA – Concept development, Prototype design, initial testing, cost analysis

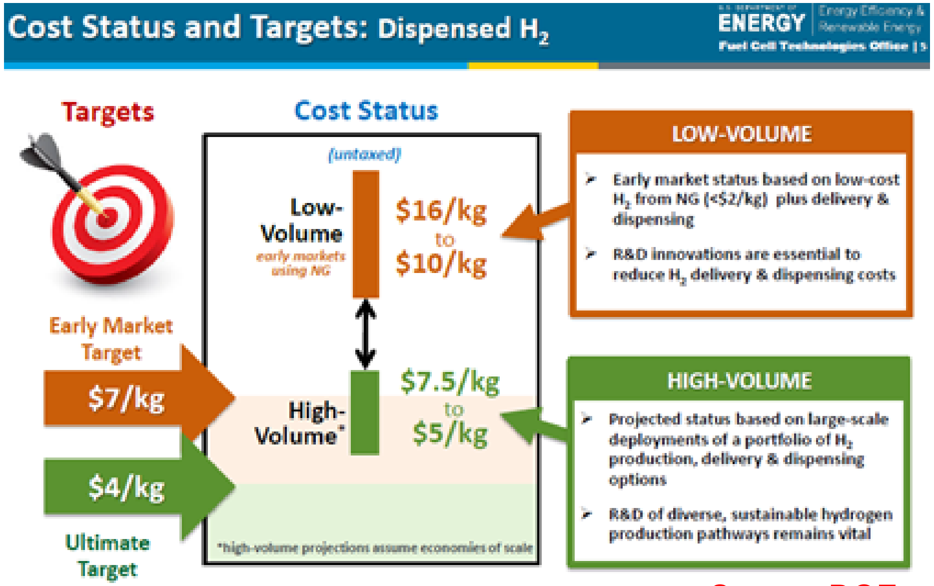
Budget

- Total Funding Spent*: $275,000
- Total Project Value: $1,150,000
- Cost Share Percentage: None

* as of 4/30/2020

Relevance: FCEVs & H_2 Cost

- Fuel Cell Electric Vehicles (FCEVs) are now commercially available in certain parts of the U.S. and around the world and many of these FCEVs meet the initial DOE goal of a 300 mile driving range using conventional Type IV polymer lined 700 bar compressed tanks (fueleconomy.gov).



Source: DOE

- However, growth in the FCEV market beyond early adaptors will require significant reductions in the cost of hydrogen fueling.

- The ultimate target for the cost of dispensed hydrogen is $4/kg, which includes the cost of the H_2 produced at < $2/kg, leaving $2/kg for distribution. The dispensed hydrogen should meet these targets for the FCEVs to be cost competitive against internal combustion engine based vehicles and plug-in hybrid electric vehicles (PHEVs).

Relevance – Project Objectives

Overall Objective

- Develop a smart hydrogen storage tank for fuel cell electric vehicles that incorporates novel designs to eliminate precooling needs in the hydrogen fueling stations.

Specific Objectives

- Keep the hydrogen gas temperature well below the tank design temperature of 85°C (goal ≤ 65°C).
- Provide a higher ending SOC during refueling with 0 and 25°C temperature.
- Completely eliminate the pre-cooling needs of the fueling station.
- Provide a greater than 15% improvement in well-to-power plant efficiency. lowering cost of hydrogen delivered by $0.6/kg.
- Keeping refueling times to 3 minutes or less.
- Providing a higher ending state of charge (SOC) during refueling.

FY 2019-2020

- In Phase I detailed CFD modeling of the novel cooling schemes by GTI and TDA modeled the tank in Solidworks
- TDA has completed the design for a tests unit capable of testing the tank designs up to 620 bar.

Approach: Summary

Project Motivation-smart hydrogen storage tank that incorporates novel cooling schemes to quickly dissipate/absorb the heat of compression and keep the hydrogen gas temperature well below 85° C with minimal impact on the cost, weight, volume, fill time, and well-to-power plant efficiency.

Preliminary Results--We have completed the design for a test unit capable of testing the tank designs up to 350 bar
Detailed CFD modeling of the novel cooling schemes confirmed active gas circulation inside the tank during refueling.

Key Impact

Metric	State of the Art	Expected Advance
Parameter 1	Tank Gas Temp. <85C	65C
Parameter 2	Gas Precooling - 40°C	Gas precooling to 0°C or eliminate it completely
Parameter 3	15% of the station capex goes to pre-cooling equipment that chills the hydrogen to -40°C	save 15-30% of the capital and operating cost of fueling station

Barriers—H_2 gas temperature rise is the major issue in the refilling process, and there are three main constraints: the safe temperature limit, the maximum filling pressure and the state of charge of the tank.

Approach—TDA's smart hydrogen storage tank will incorporates novel cooling schemes with the use of phase change media (PCM) to quickly absorb the heat of compression and keep the hydrogen gas temperature at or under 65C, well below the hydrogen tank's design temperature of 85C.

Partnerships

- TDA will work with Hyper Comp Engineering to fabricate full scale versions of our prototype unit. They specialize in the design, analysis, development, testing, manufacture, and certification of filament wound high pressure composite vessels
- TDA is working with **Gas Technology Insti**tute (GTI) to carry out validation of tank designs
- **National Renewable Energy Laboratory (NREL)** will test full scale e tank models in their hydrogen refueling facility

Approach – Work Plan

Task	Objectives
1. Optimize Tank Design	Continue to optimize tank design; multiple high pressure and temperature cycles with sub-scale prototype.
2. CFD Model Validations	Continue working with GTI and use their CFD models developed in Phase I to further optimize key parameters in our tank design.
3. Fabricate Full Scale prototype Units	After optimization, complete a detailed design of the smart tank, then fabricate full scale prototype units (tanks of volume about 60L similar to those used in FCEV).
4. Prototype Testing at TDA and Design Revisions	Carry out tests with the prototype smart tanks with hydrogen at pressures up to 300 bar (initial shakedown tests).
5. Demonstration at NREL H_2 Refueling Facility	(i) tests at different gas inlet temperatures (-40°C, -20°C, 0°C & 25°C), (ii) tests with different starting pressures (SOC), (iii) multiple fill and discharge cycles at each test conditions.
6. Design Revisions	Based on the demonstration results at NREL, incorporate design revisions as needed and carry out detailed design of the smart hydrogen storage tank for FCEVs.
7. System Analysis (TDA)	Carry out detailed system analysis & evaluate economic viability of the new smart hydrogen storage tank technology; compare our tank designs against the DOE baseline 700 bar system.
8. Reporting (TDA)	Submit a semi-annual & final reports to summarize progress.

Accomplishments

- TDA developed smart H_2 storage tank designs and carried out CFD modeling, demonstrating that re-fueling from ambient temperature conditions is feasible when using TDA's tank designs, thus eliminating the precooling requirements at the station, thereby reducing the cost of dispensed hydrogen by about $0.6/kg

- Inlet H_2 temperature can be increased to 0°C (from -40°C) with 0.25" increase in tank diameter and 5% increase in tank volume

- Inlet hydrogen temperature can be increased to 25°C with 0.5" increase in tank diameter and 9% increase tank in volume

- TDA's smart tank design has minimal impact on the weight, and volume while keeping the same fill time, providing a much higher (> 15%) well-to-power plant efficiency, and increasing the SOC amount of H_2 stored

Progress

Task 1: Optimize Tank Designs– ongoing; expected completion August 2020

- We are optimizing the different aspects of the design.
- Completed the design for a test unit capable of testing to 350 bar.

Task 2: CFD Model Validations– ongoing; expected completion August 2020

- Extended the models to other design cases; carried out 3-D simulations to look at tank orientation.

Task 3: Fabricate Full-scale prototype Units–ongong; expected completion December 2020

- Purchased Type III tank from Vendors.
- Test rig is currently being fabricated.

Task 4: Prototype Testing at TDA and Design Revisions–expected start July 2020

Task 5: Demonstration at NREL H_2 Refueling Facility–expected start Jan 2021

Task 6: Design Revisions–expected start March 2021

Task 7: System Analysis (TDA)–expected start May 2021

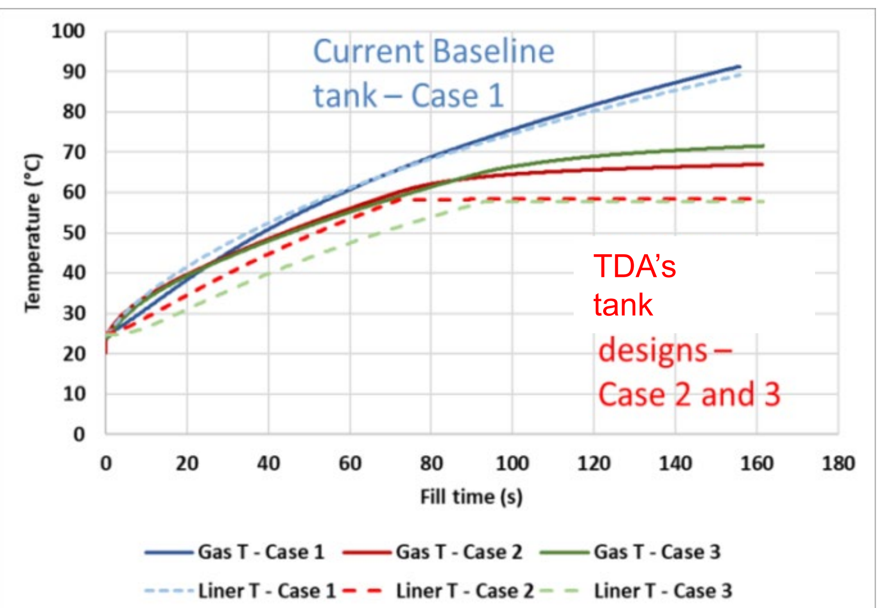
Task 8: Reporting (TDA)–ongoing

TDA

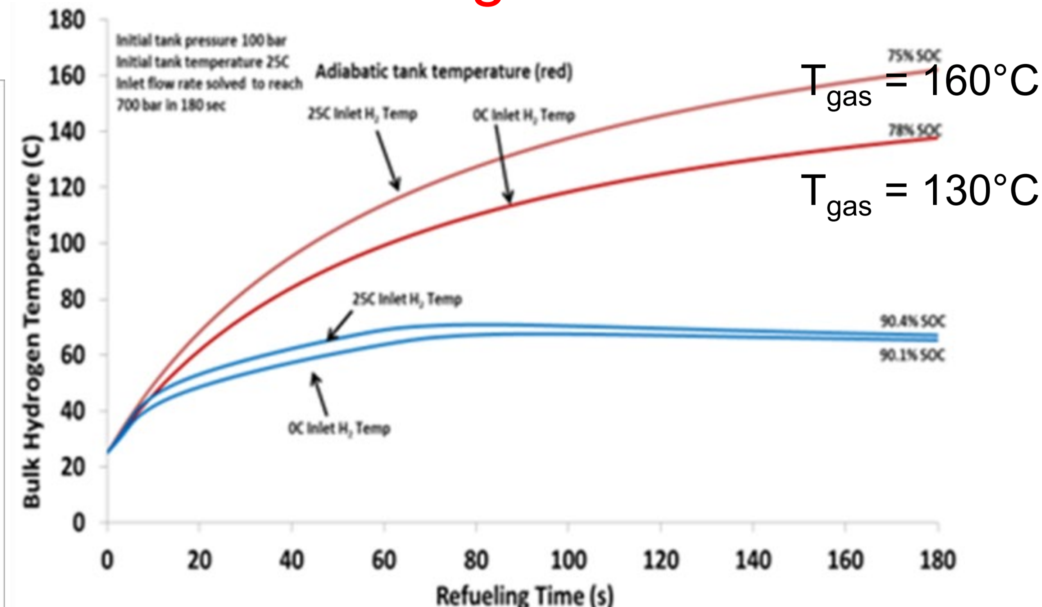
Proof of Concept

- Detailed CFD modeling of the novel cooling schemes by GTI and TDA confirmed the active gas circulation inside the tank during refueling
- This keeps the hydrogen gas temperature at or under 70°C, well below the hydrogen tank's design temperature of 85°C
- The overall SOC also increases by as much as 15.4% compared to adiabatic filling

Modeling at GTI

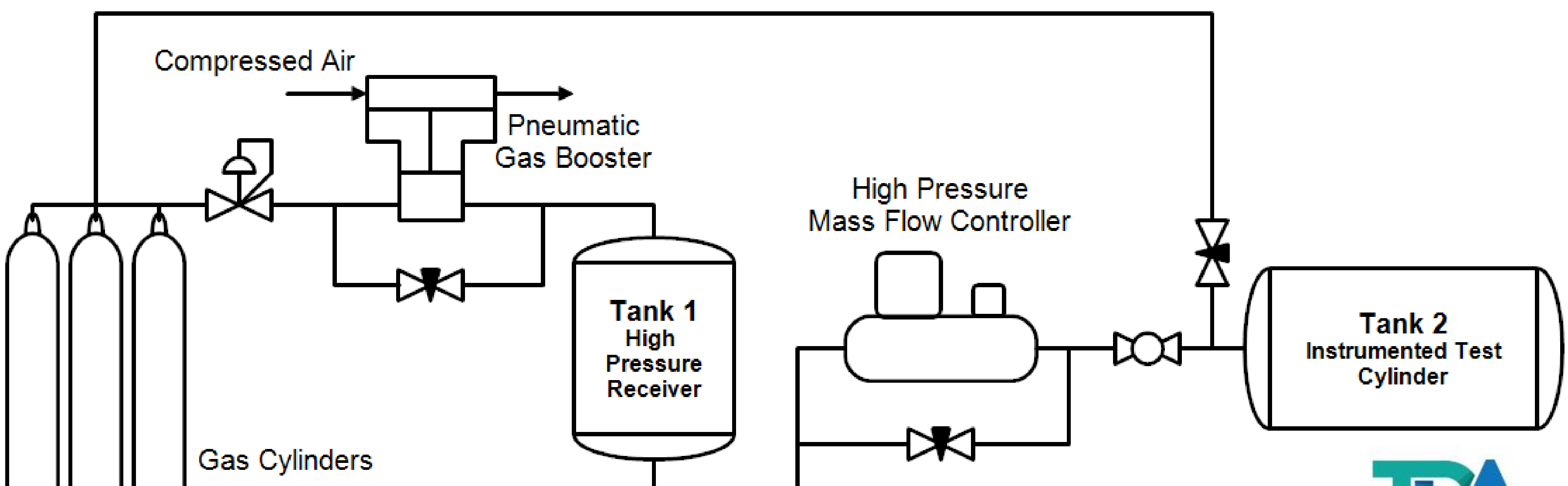


Modeling at TDA



CFD Model Validation Testing

- We will fabricate sub-scale prototype units and perform sub-scale tests at TDA to validate the design
- We have completed the design for a tests unit capable of testing the tank designs up to 350 bar (later can be expanded to 620 bar)
- Gas will be supplied from a 3 or 6 pack of High Pressure H_2 cylinders
- Tank 2 will contain the PCM and be instrumented to measure temperature and flow



Sub-scale Tank Fabrication

- For the sub-scale tank fabrications we have been in discussion with a local composite overwrapped pressure vessel (COPV) manufacturer
- Type III COPVs with large threaded port openings are used in sub-scale testing.
- Full scale prototype units will be Type IV COPV with polymer liner

Proposed Future Work

Prototype Testing at TDA and Design Revisions–testing with the prototype smart tanks with hydrogen at pressures up to 300 bar. These initial shakedown tests and evaluations at pressures up to 300 bar at TDA will allow us to make sure our tests at NREL are successful.

Demonstration at NREL H_2 Refueling Facility–work with NREL to demonstrate the full scale prototype units with their hydrogen refueling infrastructure in Golden, CO using hydrogen available at 0°C and ambient temperatures. Test up to three prototype units.

Design Revisions–(i) identify the optimum tank design; (ii) identify the initial temperature for the gas (any pre-cooling needs); (iii) thickness of the vessels and material of construction of the shell.

System Analysis–detailed system analysis and evaluate economic viability of the new smart hydrogen storage tank technology. We will compare our tank designs against the DOE baseline 700 bar system and quantify the impact on the cost, weight, volume, fill time, and well-to-power plant efficiency.

Project Summary

Project Partners

TDA Research, Gas Technology Institute
NREL and HyperComp Engineering

Dr. Ambal Jayaraman, PI

Award #	DE-SC0018757
Start/End Date	07/02/2018 – 08/18/2020
Total Project Value* Cost Share %	$1.15 M Cost Share 0%

Project Vision

TDA Research is developing a smart hydrogen storage tank that quickly dissipates/removes the heat of compression and keep the hydrogen gas temperature well below the hydrogen tank design temperature of 85° C. TDA's design maximizes the heat transfer area and the heat transfer coefficients to quickly dissipate the heat throughout the refueling process.

Project Impact

Reducing precooling needs or eliminating pre-cooling equipment will significantly reduce the cost of delivered hydrogen and promote the commercial success of the Fuel Cell Electric Vehicles.

TDA

Publications and Presentations

- Jayaraman, A., Bonnema, M., Sishtla, C. “Highly Efficient Smart tanks for Hydrogen Storage”, presentation at the Hydrogen Storage Tech Team Meeting, 8th August 2019, Southfield, MI.
- Liszka, M., Fridlyand, A., Sishtla, C., Jayaraman A., Bonnema, M. “CFD Modeling of the Hydrogen Fast Filling Process for Type 3 Cylinders and Cylinders Lined with Phase Change Material”, Proceedings of the ASME 2019 International Mechanical Engineering Congress and Exposition (IMECE2019-11449), November 11-14, 2019, Salt Lake City, UT, USA.
- Liszka, M., Fridlyand, A., Jayaraman A., Bonnema, M., Sishtla, C. “Hydrogen Fast Fill Modeling and Optimization of Cylinders Lined with Phase Change Material”, Proceedings of the ASME 2020 International Mechanical Engineering Congress and Exposition (IMECE2020-22475), November 15-19, 2020, Portland, OR, USA (in press)