Hydrogen Fuel-Cell Electric Hybrid Truck Demonstration

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Final Technical Report

Principal Investigator: Andrew J. DeCandis
Business Point of Contact: Sandra Holliday
Houston-Galveston Area Council
3555 Timmons Lane, Suite 120
Houston, TX 77027

Consortium Members:
Gas Technologies Institute
US Hybrid
University of Texas Center for Electromechanics
Environmental Defense Fund

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Preface

In March, 2012 the United States Department of Energy (DOE) National Energy Technology Laboratory (NETL) on behalf of the Office of Energy Efficiency and Renewable Energy (EERE) Office of Vehicle Technologies (OVT) Program issued Funding Opportunity DE-FOA-0000669 for Zero Emission Cargo Transport (ZECT) Demonstrations. In September, 2012 the Houston-Galveston Area Council of Governments (H-GAC) was notified that it had been awarded a grant under this program, pending completion of a project agreement with DOE.

A key objective of the OVT program was to accelerate the development and production of various electric transportation technologies (ETT) to substantially reduce petroleum consumption and related emissions. This specific FOA notice addressed cargo truck applications in US Ports that are located in the following two non-attainment areas: 1) Los Angeles South Coast Air Basin non-attainment area, and 2) Houston-Galveston-Brazoria nonattainment area.

Eligible vehicles included Class 8 trucks, locomotives, and/or rail systems that could be powered by electric batteries, fuel cells using hydrogen fuel, and/or roadbed or rail systems powered by electricity.

In June, 2014 representatives of H-GAC contacted Gas Technology Institute (GTI) to discuss the ongoing viability of the ZECT project. H-GAC expressed that it was unlikely that the project would move forward as originally proposed to DOE. In November, 2014 H-GAC issued a “Call for Projects, TRN 14-10”, specifically calling for either fuel cell or battery-electric Class 8 cargo trucks to be demonstrated under the terms of their DOE grant. GTI formed a technical team and submitted a proposal to H-GAC in January, 2015. In March, 2015 H-GAC notified GTI that its proposal had been accepted and a contract was completed in July, 2015 between H-GAC and GTI to implement the demonstration project with the new project team.

GTI’s project team consisted of US Hybrid Corporation (US Hybrid), Richardson Trucking, the University of Texas, Center for ElectroMechanics (CEM), and Environmental Defense Fund (EDF). The GTI team proposed to manage and support the **Zero-emissions hydrogen fuel cell hybrid drayage cargo truck demonstration (ZECT)** project, consisting of the demonstration of three (3) fully developed, operational, advanced vehicle technology prototypes for ON-ROAD goods movement applications. The major vehicle OEM for this demonstration was Navistar International Trucks, with the fuel cell and power control hybrid technology provided and integrated by the major Electric Transportation System OEM, US Hybrid. CEM was to provide independent data collection and analysis, while EDF was to provide education, outreach, and communication for the project. GTI was to manage the partnership while also providing hydrogen fuel for the demonstration.

1.0 Executive Summary

The purpose of the project was to demonstrate three (3) fully developed, operational, advanced vehicle technology prototypes for ON-ROAD goods movement applications. The major vehicle OEM for this demonstration was Navistar International Trucks, with the fuel cell and power control hybrid technology provided and integrated by US Hybrid. CEM was to provide independent data collection and analysis, while EDF would provide education, outreach, and communication for the project. GTI managed the partnership and arranged for hydrogen fuel for the demonstration.

The drayage truck is used to transfer the cargo container from/to ports in a warehouse or logistic yard. For port facilities in the Port of Houston Area, as well as virtually all other ports, drayage trucks often queue for long periods, inching along at slow speeds to await loading and unloading. During this process, the trucks are essentially idle, with conventional diesel engines continuously running and producing accompanying emissions. The ZECT would essentially power off during idle periods, or at least utilize minimal electric energy. As such, range limitation by using a gaseous fuel would be mitigated by the fact that the vehicle is not using fuel during much of its duty cycle. The project team expected the vehicle range to be about 200 miles which is well within the duty cycle requirements of the original fleet partner, Richardson Trucking.

The project was intended to demonstrate commercialization and production potential, and to clearly illustrate the selected vehicle technology's potential to reduce GHG emissions and petroleum use if implemented widely.

To achieve this, the project team proposed a two-year demonstration project in the Port of Houston area to assess and track vehicle performance, and evaluate fuel savings, petroleum reduction, and emissions reduction benefits of the prototype technology. Additional time at the front end of the project was required for vehicle and support infrastructure preparation.

In June, 2017 the remaining project partners, which now included Air Liquide, agreed that the project would be unlikely to move forward with the vehicle demonstration, primarily due to the lack of a viable cargo truck fleet partner in the Port of Houston area willing to make a sufficient commitment of resources to operate the vehicles for the demonstration.

While several of the project objectives were not met and no meaningful operating data was generated, there were useful learnings to be gained from the project:

- **No Technical Barriers.** No significant technical barriers prevented the project from moving forward. The Project partners went through the planning and design phases for both vehicles and on-site hydrogen fueling infrastructure. Engineering, site preparation, and construction costs presented challenges, however no technical or regulatory barriers were identified during the engineering and design phase of the project. The vehicle technology

development has continued via other projects, validating that zero emissions cargo truck technology can meet the demands of port operations.

- **Key Local Support.** The Houston Port Authority was very supportive of the project and expressed a strong desire to see it implemented. Unfortunately, a key leader of the Houston Port Environmental staff was lost to the project for medical reasons during a critical period when the project partners were searching for a new fleet partner. Continued support from Port Houston will aid in deployment of near-zero and zero emission vehicles in the future.
- **State Financial Support.** The inability to secure local funding from either the City, County, or Texas Commission on Environmental Quality was a significant impediment to moving the project forward. There were minimal, near-term commercial advantages that the project team could offer fleet operators to invest in the ZECT vehicles. This type of demonstration has proven most successful in regions where supplemental funds or regulatory relief can be obtained from state or regional sources to enhance financial incentives for fleet operators.
- **Moderate Fleet Operator Interest.** GTI and the Port of Houston Authority staff spoke with over a dozen separate cargo truck fleet operators and each expressed a willingness to demonstrate the prototype vehicles including "in-kind" cost share in the form of space for fueling the trucks and personnel time for driving and servicing the trucks. Operator interest did not however extend to the financial level that would be required for hydrogen fueling station site preparation and operation. The implication is that fleet operators in the Houston area are ready for low emissions technologies that are also economically viable.
- **Commercial Readiness Environment.** "Customer acceptance" of hydrogen as a fuel was surprisingly positive and broad given the lack of any meaningful fuel cell vehicle operations in the Houston area. Local political support was ambivalent but relevant codes officials offered no significant "push-back" on the project. With stronger commercial or regulatory incentives, Houston is technically prepared for hydrogen as a fuel.

2.0 Project Review

2.1. Project Introduction and Goals

The purpose of this project was to demonstrate three (3) fully developed, operational, advanced vehicle technology prototypes for ON-ROAD goods movement applications. These three vehicles were to be Class 8, zero-emissions cargo trucks (ZECT), powered by hydrogen fuel cells, but also with the capability to operate on limited range with batteries alone. Further, the trucks were to be integrated in commercial operations in the Houston-Galveston-Brazoria (HGB) NAAQS 8-hour non-attainment area.

The project consisted of six (6) primary tasks:

Task 1 – Reporting
To fulfill this task, GTI submitted Financial Reporting documents to H-GAC, including invoices, reimbursement request forms, and cost share documentation. Periodic status updates and monthly activity reporting were required to provide updates on progress with vehicle procurement, delivery, deployment, operation and data collection and analysis as outlined in Task 6.

Task 2 – Vehicle and Infrastructure Design and Build
This task consisted of procuring the vehicles, including design, develop, build, modify, and integrate vehicles to support project objectives; this task included all activities required to verify durability testing, safety testing, environmental testing, etc.

Task 3 – Vehicle Deployment and Demonstration
This task consisted of deploying demonstrating, and collecting operational and maintenance data for vehicles and supporting infrastructure for at least two (2) years following deployment of vehicles into fleet operations. Demonstration activities were to be conducted under real world cargo transport conditions in the HGB ozone nonattainment area.

Task 4 – Vehicle Support and Maintenance
This task included scheduled and unscheduled maintenance on the vehicles under test for the duration of the project period of performance.

Task 5 – Vehicle Testing
This task included the development and execution of a test plan for project vehiclesthat, at a minimum, would test project vehicles under varying usage and electric range scenarios in both loaded and unloaded configurations.

Task 6 – Test Data and Data Collection
This task included the collection of operational and maintenance data for vehicles. Data collected was to include powertrain and battery operational data. It was anticipated that U.S. DOE may provide these data and analyses to DOE/NNSA National Laboratories. The following list outlines the minimum data that was to be collected during testing/route analysis phase and/or data collection phase.

Vehicle Operations

- Daily Mileage
- Operating Time
- Payloads
- Speed
- State of Charge
- Auxiliary Loading
- Maintenance Logs

Charging Operations

- Daily Charge Times
- State of Charge
- Energy Consumption
- Utility Costs
- Maintenance Logs

Data Collected was to be used to calculate a number of analytical factors, including, but not limited to:

- Fuel Efficiency (i.e., $/mile, kWh/mile, etc.)
- Cargo Ton-Miles/Vehicle
- Cargo Ton-Miles/Fleet
- Reduction in Petroleum Consumption
- Reduction of Green House Gas Emissions (Million Metric Tons of Carbon Equivalent (MMTCE)/year)
- Reduction of Criteria Pollutant and Toxic Emissions
- Expected Life Cycle Benefit Analysis

Analysis was to be conducted of the following expected benefits (as compared to a FY12 commercially available similar class vehicle or system):

- Expected Reduction in Petroleum Consumption
- Expected Reduction of Green House Gas Emissions (Million Metric Tons of Carbon Equivalent (MMTCE)/year)
- Expected Reduction of Criteria Pollutant and Toxic Emissions
- Expected Life Cycle Benefit Analysis

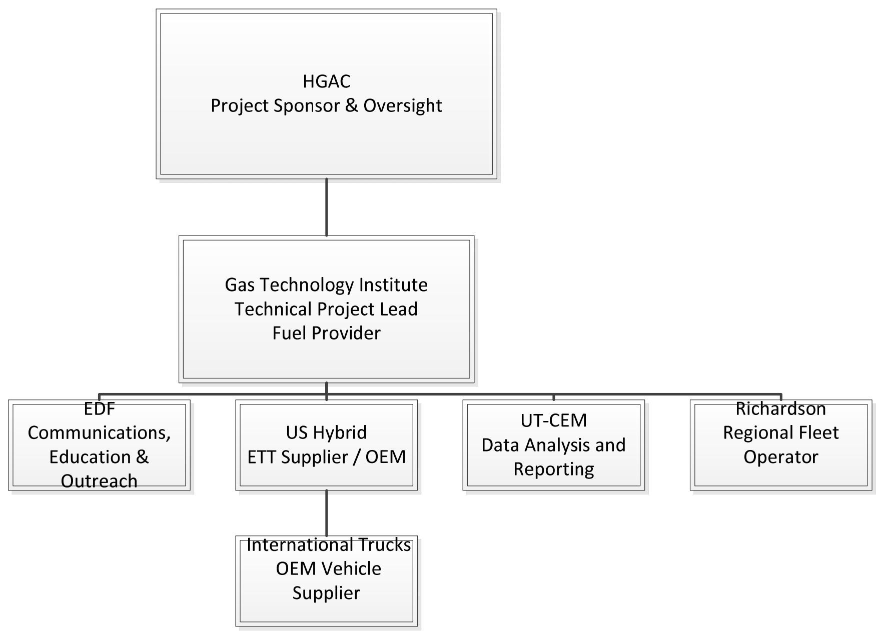
2.2. Project Team and Responsibilities

Gas Technology Institute: GTI was the technical lead for the project. GTI was also the fuel provider for this project.

US Hybrid. US Hybrid is a major supplier of electric transportation technologies and was to be integrating its fuel cell and power control systems with three trucks from major OEM truck supplier Navistar/International.

Richardson Companies. RC is a regional fleet operator and agreed to operate the three fuel cell-electric drayage trucks for 24 months from its newly built barge terminal in the Port of Houston area on Cedar Bayou in Chambers County. RC also agreed to host the hydrogen fueling station at that site, including the site preparation for the fueling station.

Project Organization Chart



UT-CEM. UT-CEM was to provide independent analysis of data collected from the fleet operations. UT-CEM would also assist in the support of the on-site hydrogen fueling station.

EDF. As a leading environmental and science organization, EDF was to provide education and outreach services for the project and planned to communicate project results to interested government and civic organizations.

2.3. Vehicle Engineering Design

2.3.1. Design Discussion

US Hybrid proposed a fuel cell-electric Class 8 drayage truck for port operation. The fuel cell power plant was sized to ensure drayage truck continuous operation based on the most recent Class 8 drayage truck drive cycle data and 80,000 GVWR. The detailed system layout can be seen below (Figure 1).

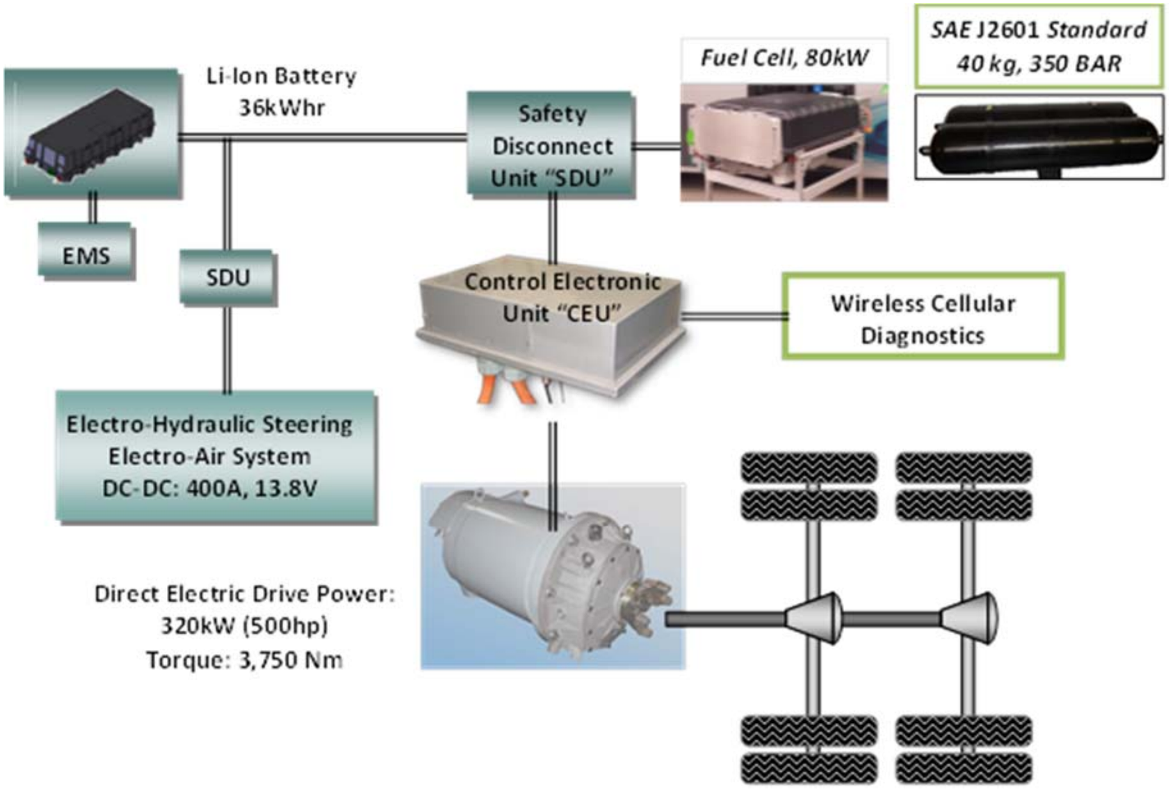


Figure 1: US Hybrid fuel cell-electric Class 8 truck powertrain configuration

Project vehicles were designed to include state-of-the-art technology features, in addition to the permanent magnet motor, advanced digital control, power conversion with high-frequency magnetic, and standard SAE J1939 CAN bus communications and diagnostics.

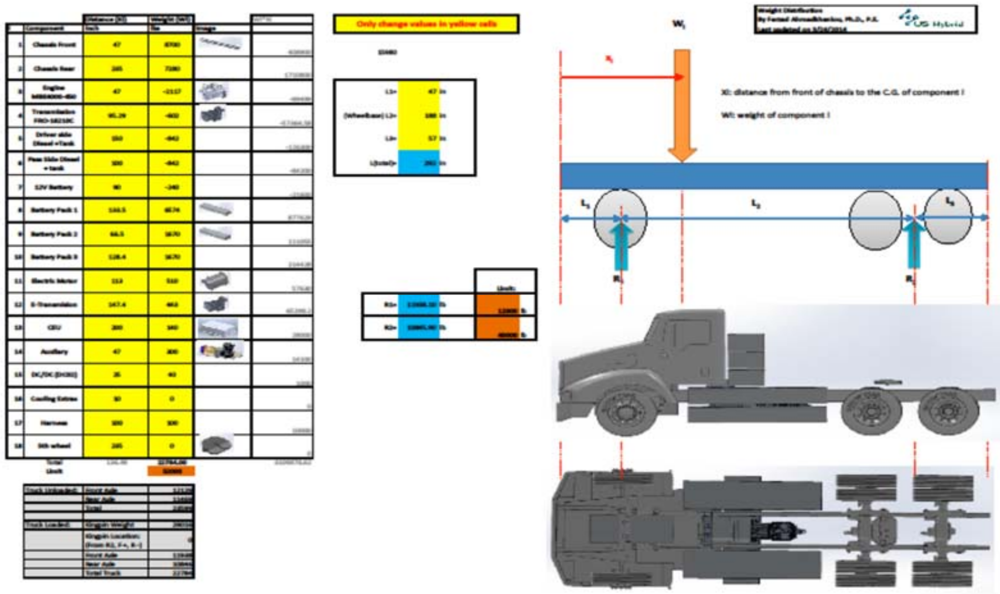
The vehicle chosen for prototyping is International's ProStar Day Cab. The vehicle image can be seen in *Figure 2* and vehicle specifications are shown on Table 1 on the following page.

Figure 2. ProStar Truck

Table 1 US Hybrid fuel cell-electric Class 8 Drayage Truck Specifications

Drayage Class 8 Truck Specifications	
GVWR	80,000lbs
Wheel Base	189" Minimum
OEM Manufacturer and Model	International, ProStar Day Cab
Front Axle Rating	13,200lbs
Rear Axle Rating	40,000lbs Tandem
Suspension	Air
Truck Performance	
Range H2 and Battery	320km/200 miles
Range Battery Electric	8km/5 miles
Top Speed	97 KPH/60 MPH
Acceleration 0-40 MPH	10 sec
Fuel Cell System Specifications	
Fuel Cell Supplier	US FuelCell PC80™
Model and Type	PC80™, PEM Fuel Cell
Fuel Cell Voltage, Current, and Power	140-300, 600A, 80kW
DC-DC Converter	85kW rated, PCM600™
Hydrogen Storage System Specifications	
Weight of Storage Tanks	734kg/1618lbs
Storage Capacity	38.56kg of H2
Max Pressure- Min Pressure	350 BAR/5076 PSI - 13.8 BAR/200 PSI
Fueling Time	< 15 minutes, Communication Port (90% capacity)
Energy Storage Specifications	
Battery Type	Li-Ion
Battery Max Power	300kW
Battery Energy	36kWhr
Direct Electric Traction Drive System Specifications	
Motor Type	Internal Permanent Magnet
Traction Drive Power	320kW/ 429HP
Motor with Integrated Gear Unit Weight	1496lbs
Integrated Traction Inverter Power	320kW
Integrated Traction Inverter Weight	127lbs
Charger- Integrated	J1772, 6.6kW, for Service
Control, Communication and Diagnostics	J1939, CAN
Auxiliary Systems Specifications	
DC/DC Converter	27.8, 400A
Air Conditioning	Electric
Power Steering	Electro-hydraulic
Air Compressor	Integrated Electric, Oil-less

Figure 3 US Hybrid Custom Weight Balance Simulation Tool



US Hybrid engineered a custom weight balance simulation tool (illustrated above), to analyze the effect of adding and removing components from the vehicle. Due to the lighter weight of the 80kW fuel cell compared to that of a diesel engine, the vehicle weight balance is maintained. The front axle rating is not exceeded and the payload is comparable to that of the diesel configuration.

The selection of this system configuration was based on the duty cycle of the target application and end user preference. These are based on operating similar trucks in their fleets, which include those in the congested ports, those in construction and distribution to central business areas for pick-ups and drop-offs and those that operate on highways. Thus, the driving cycle of the truck is a combination of low average speed stop-and-go events with extended idling periods and high speed driving. For the purpose of energy efficiency, the drayage port drive cycle was used for the modeling and sizing of components.

The fuel cell power plant was designed to provide the average power to ensure charge sustaining operation, while the energy storage system (battery pack) is sized such that the vehicle can operate in pure electric mode for 5 miles and provide the transient power required by the powertrain. The fuel cell electric vehicles require some battery on board to provide the transients and most importantly, be able to recover the regen energy, especially for drayage applications. This serves to enhance fuel economy. Therefore, the fuel cell powertrains are of the hybrid type and utilize battery storage. US Hybrid's proposed design will allow charge sustaining fuel cell operation, with need for only hydrogen infrastructure. *With this configuration, there is no need to separately charge the batteries on the trucks with an external electric charger.*

Based on the ZECT configuration, vehicle performance was estimated by simulation in the "'Vehicle Performance Prediction" table below. From the vehicle dynamic performance indexes such as the maximum gradability, the acceleration time, and the maximum speed, the vehicle will be able to climb freeway ramps to merge quickly into freeway traffic.

Table 2. Vehicle Performance Prediction

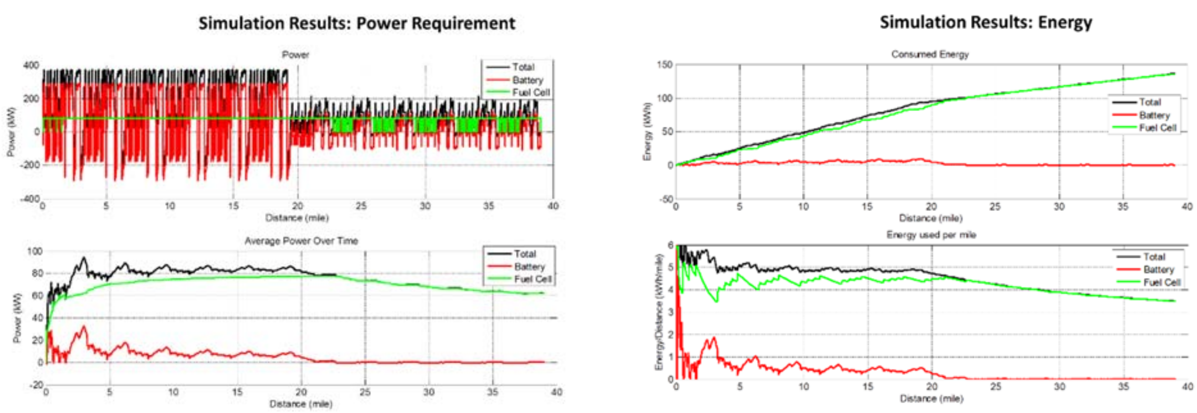
Maximum Speed	60 mph
Maximum Gradability	26%
Accel. time (0 to 50mph)	41s
Fuel economy	8.7 miles/kg of H_2
Electric Range	5 miles (Battery SOC from 100% to 20%)

Fuel economy is evaluated from the combination of drayage port cycles. Data was to be collected through a wireless transceiver using US Hybrid's proprietary iDrive technology for the planned 24-month data collection duration. The drayage port cycle features a low speed stop-and-go pattern, which is also a legitimate representation of downtown or central business area driving behavior.

Proposed vehicle's performance for the intended fleet application for this project

The charts following are included to illustrate a sampling of the modeling tools that were used to predict the vehicle performance and to select components for this port drayage truck application.

Figure 4. Performance information



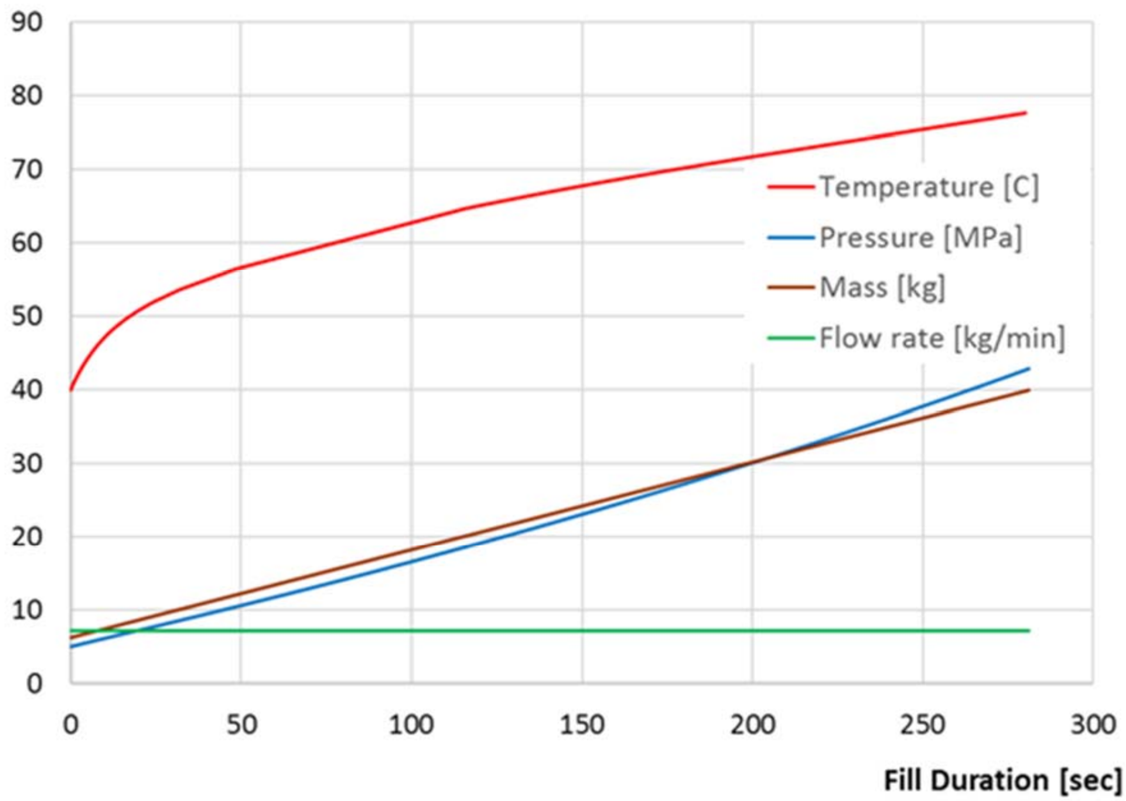
Fuel Cell Power plant sizing

Based on the simulation models and the actual power measurements of the fuel cell power plant, the minimum fuel cell power to ensure a sustainable drayage truck operation and to meet the drayage truck drive cycle and 65,000 GVWR is 76kW. US Hybrid planned to use the PureMotion 80, which is a 80 kW continuously rated fuel cell power plant. This PEM fuel cell technology was originally designed by UTC and is now licensed by US Hybrid for exclusive use in its vehicle systems.

2.3.1.1. *Vehicle Storage Fast Fill Modeling*

A limited amount of data and documented experience with large volume 350 bar rapid fueling of hydrogen heavy-duty trucks exists. One potential barrier that the team investigated was the possibility for excessive heat gain within the hydrogen storage system on-board the truck during a fast fill dispensing event. GTI performed modeling and then conferred with Argonne National Labs to confirm that a sufficient high flow rate could be maintained during a large volume fill event without the upper temperature limit of the storage cylinders being exceeded. Higher pressure 700 bar dispensing must make use of pre-cooling equipment to condition the hydrogen in order to stay below the upper temperature limit of commercial hydrogen type 3 and type 4 cylinders of 85C.

The chart below shows the results of the modeling performed for a 7.2 kg per minute fill rate into a storage system during a 40 kg fill event. As indicated, the maximum temperature anticipated inside the cylinders is below 80C at the conclusion of the fill. This confirmed that a large hydrogen mass transfers into a heavy-duty vehicle representative of the ZECT truck targeting a temperature compensated 350 bar fill can be accomplished safely without the need for precooling of the dispensed hydrogen.



Modeling results of high flow, large volume, dispensing event

2.4. Fleet Operator and Site Preparation

2.4.1. Fleet Operator #1

Richardson Trucking offered to provide cost-share and to be the fleet operator for the demonstration phase of the ZECT project. Richardson Companies (RC) is a major trucking company operating in the Port of Houston area. RC was founded and established at the Port of Houston by Mr. Nolan Richardson in 1969. Since the company's inception 46 years ago, the company continues to be owned and operated by the Richardson family and grown into a diversified fully integrated service provider for the Port of Houston cadre of import and export customers. While trucking continues to represent the largest portion of the groups' activities, Richardson has since expanded into additional cargo service offerings which include stevedoring, freight-handling, container trans-loading operations and barging. The Richardson Companies perform these operations at the Port of Houston and other terminal sites listed below:

Port of Houston Terminal/Facility Name	*Services performed by Richardson Companies*
Port of Houston Turning Basin/City Dock	Drayage Trucking, Stevedoring, Storage, Barging
Greensport Industrial Terminal	Drayage Trucking, Stevedoring, Storage, Barging
Port of Houston Barbours Cut Terminal	Drayage Trucking, Container Trans-loading
Port of Houston Bayport Terminal	Drayage Trucking, Container Trans-loading

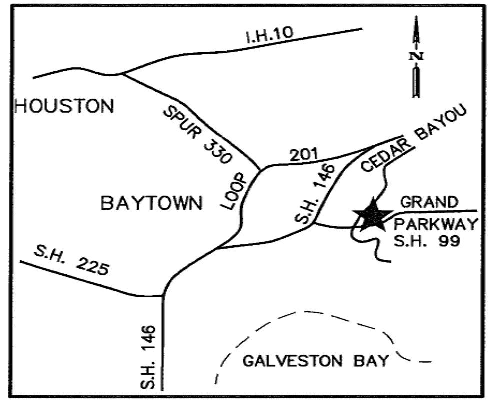
Figure 4: Richardson Company Port of Houston Operations

They operate a fleet of 158 trucks dedicated to the Port of Houston area and the 8-county region and serves a wide array of importers/exporters, all with varying types of commodities and cargo originating from or destined to the Port of Houston shipping terminals. RC is categorized as a local/8-county drayage trucking provider and is a major tenant/operator at the Port of Houston. RC has also participated in TERP and H-GAC grants and to date has converted a total of 35 trucks to cleaner burning diesel engines.

While Houston is the hub and center of the Richardson Companies' operations, the group also has significant holdings and activities in Mobile, Alabama where Richardson is the exclusive trucking service provider for inbound shipments of cargo destined for the Hyundai and Kia Motors Automobile Assembly Plants.

Richardson's new "GreenTransport" terminal was selected as the host site for the project and for the location of the hydrogen fueling station equipment.

GREENTRANSPORT FACILITY
2301 E GRAND PARKWAY S
BAYTOWN TX 77523



VICINITY MAP

Green Transport ZECT Host Site Location

Photos from Richardson Green Transport Barge Terminal near Baytown, TX

The Richardson Green Transport Barge Terminal location was considered an excellent choice for the site demonstration for multiple reasons:

- As a “greenfield” location that was under construction, equipment, utilities, concrete, and associated trades labor was on-hand, making site preparation for the hydrogen station theoretically less expensive and less disruptive to port operations than modifying an existing site.
- The primary cargo for the Green Transport barge terminal is steel and other dry cargo. Liquid cargo – especially for flammable liquids could raise questions from permitting officials for the trucks since they used hydrogen fuel.
- The fleet operator, Richardson Companies was interested in concentrating their cleanest emissions vehicles at the new barge terminal, and felt that the project

would enhance their local reputation as a leader in clean-emissions fleet operations.

- While well within the Port of Houston area, the Green Transport terminal was somewhat isolated from other Port operations. If ZECT trucks needed maintenance or encountered significant downtime, repair work would not disrupt other cargo operations.
- Strong support for the project came from the owner and leadership of the company during the proposal and contracting phases of the project.

2.4.2. Station Equipment and Layout

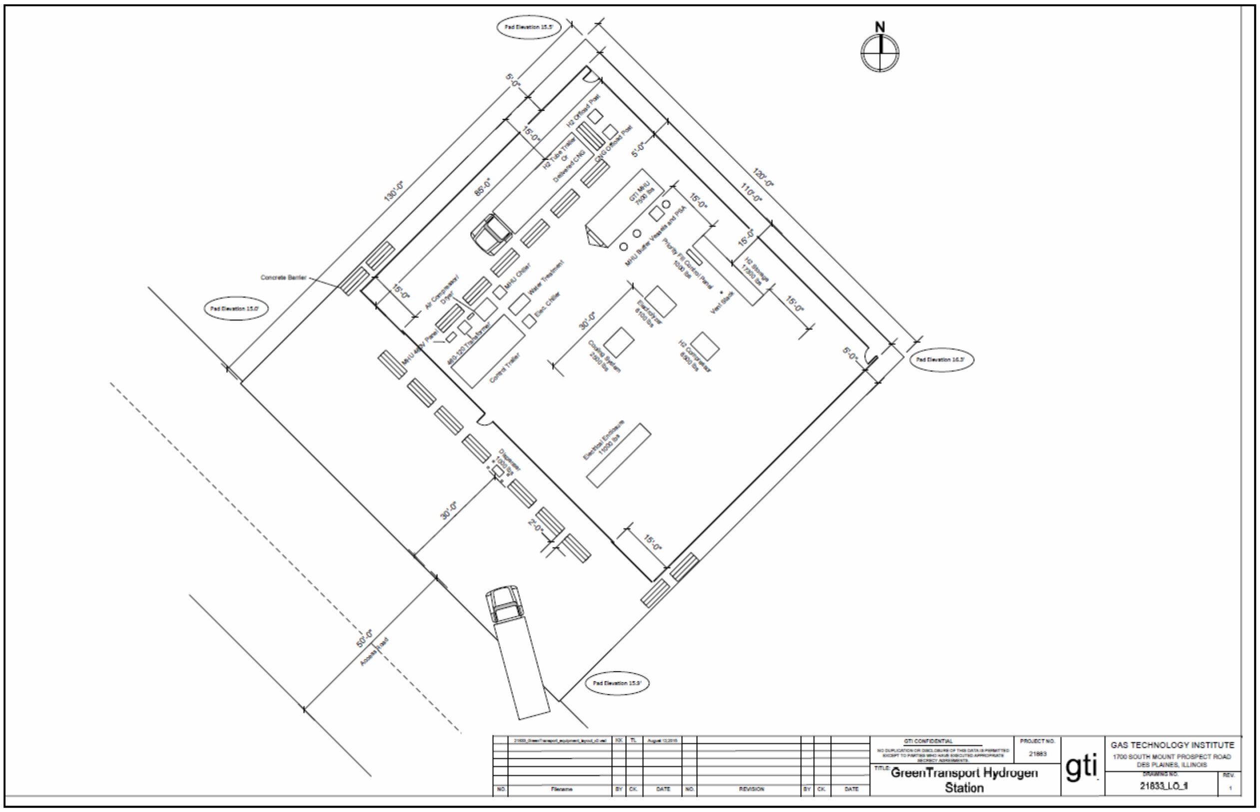
The hydrogen station design consisted of GTI's Mobile Hydrogen Unit (MHU) paired with a 30 kg/day Hydrogenics HyStat electrolyzer. The two hydrogen generation systems were to be used for on-site generation. The reformer and the electrolyzer were designed to be operated with shared on-site compression, storage, and dispensing. GTI provided both the MHU unit and the electrolyzer unit (which was purchased from Shell, which had previously used it at their Santa Monica station in California).

Generally, a station would not be designed to use on-site generation from multiple sources however there were strong reasons for this station design:

- Each of these systems had already been used for other applications and their operational capabilities were well known.
- Neither system had the capacity to fully supply the ZECT fleet alone (the expected daily use was 40-50 kg/day).
- Having two systems provided some redundancy in case one of the generation systems went down for maintenance.
- H-GAC expressed a strong desire to see natural gas utilized as the hydrogen supply source believing that a natural gas connection would gain more local support for hydrogen as a fuel.
- By using existing equipment, GTI could keep the overall cost of the project low.
- Since the demonstration was expected to only last for two years, it was expected that a permanent hydrogen supply would be found once the DOE project was completed.

2.4.3. Station Design and Deployment Results

The hydrogen station design was completed for the Richardson Companies site and site preparation began. The figure below shows the overall layout of the site. A complete set of construction drawings were prepared for the necessary civil, mechanical, electrical, grading, fencing, and pavement improvements for the site. Richardson Companies, as part of their cost share commitment to the project, performed the grading and preparation of the equipment pad location to ready it for the concrete pour. In addition, electric utilities extension from power distribution panel were arranged for.



Green Transport Hydrogen Station Layout

In order for the fueling station to be designed and ready to dispense in coordination with the delivery of the vehicles, the fueling station equipment was delivered to the site for design and layout purposes. The equipment was made ready for setting into place upon completion of the equipment pad installation. The photo below shows the equipment stored at the Green Transport Barge Terminal.

H_2 Fueling equipment ready for setting in place on-site at Green Transport Barge Terminal

2.4.4. Fleet Operator #2

In October, 2016, Richardson Trucking informed the other project partners that it no longer was able to be the fleet operator for the project and could not continue to support the preparation for the demonstration. Hydrogen fueling station site preparation cost estimates, combined with Richardson's declining fleet operations (coinciding with general energy industry economic lulls during this time frame) were partly responsible for Richardson's decision.

At this point, the remaining project partners asked the Port of Houston to assist in locating an alternative fleet operator. This effort met with a high degree of interest from over a dozen different fleet operators in the Port of Houston area. While each of the operators was willing to devote "in-kind" cost share in the form of personnel and space to locate equipment, none were able to provide the resources necessary for site-preparation for equipment installation.

At that time, the project team considered a number of different options for fueling the trucks, but none were considered economically viable.

Throughout the search, the team had kept representatives from Air Liquide informed of the project, in case delivered hydrogen (from tube trailers) was used as a back-up fuel supply option or a more cost-effective approach to allow the truck demonstrations to move forward with an alternate fleet operator. In January 2017, Air Liquide offered its hydrogen plant site in La Porte, Texas (also in the Port of Houston area) and its fleet of industrial gas delivery trucks (Class 8, used to haul industrial gases, including hydrogen) as an alternative fleet operator and station site.

Air Liquide's offer was contingent upon its management team's approval. This was complicated by a recent merger and operations reorganization due to the acquisition of AirGas. Air Liquide was considered an excellent replacement fleet operator for several reasons:

- Hydrogen is a core business for Air Liquide and Air Liquide could justify the cost-share required for the project as an investment in its future business.
- Air Liquide has a strong technical competency with hydrogen and would require little to no education on basic hydrogen safety for operations of the trucks and fueling station equipment.
- Supplies of hydrogen were readily available at the Air Liquide facility, so the station installation could be scaled back to include only compression, storage, and dispensing.
- While the Air Liquide fleet did not technically operate at the Port of Houston, it was well within the Houston-Galveston-Brazoria non-attainment area and its operations closely resembled those of drayage truck operators.

Air Liquide's Gas Plant in La Porte, Texas

Selected location for fueling station at Air Liquide site

Preliminary design layouts were developed and reviewed with local Air Liquide site personnel resulting in the selection of the equipment pad and associated utilities to support the deployment of the GTI equipment.

In June, 2017 Air Liquide informed the project partners that it would not be able to host the ZECT project and would not be a fleet operator for the ZECT trucks. Shortly thereafter, H-GAC decided not to move forward with pursuing any other fleet options and the other project partners agreed.

2.5. Conclusion

The learnings from this project can be used to enhance the chances of successful technology development and demonstration research projects going forward. In particular, the knowledge gained from the project include:

- No significant technical barriers prevented the project from moving forward. The Project partners completed the planning and design phases for both the vehicles and the on-site hydrogen fueling infrastructure. No technical or regulatory barriers were identified during the engineering and design phase of the project and the vehicle builds and station construction successfully began before the demonstration fleet exited the project.
- Business decisions cannot always be anticipated, and honoring cost share commitments are viewed by commercial partners much like any other business decision. This project's initial host fleet was enthusiastically supportive and eager to demonstrate the new technologies at the start of the project, however unforeseen economic changes in their industry made them unable to move forward. Contingencies and risk mitigation strategies need to continue to be part of these types of projects even though this project demonstrated that all influencing factors can never be anticipated.
- Technology advancements in the hydrogen fuel cell vehicle space are occurring rapidly, largely in part thanks to the government investments in projects such as this one. As delays are introduced the risk of project objectives and goals becoming less relevant needs to be considered and the overall value of the project reevaluated. This project's value began to shift from the technological advancements of the vehicles to the experiences gained in real world deployments of unfamiliar technologies into a region outside of California and the user experiences that would inform future advancement objectives.

Attachment: Products Produced for Technology Transfer

a. *Publications* – none to date
b. *Internet Sites* – none to date
c. *Networks / Collaborations Fostered* – none to date
d. *Technologies / Techniques* –
   - *Fueling station engineering drawings* – complete with general site layout, equipment pad dimensioned design, utility layout, conduit and piping schedules, excavation and civil design drawings, equipment specifications, and site lighting and protection designs.
   - *Class 8 Truck Hybrid Design* – proprietary design to integrate hydrogen fuel cell and battery storage specific to intermodal high weight carrying applications.
e. *Inventions / Patent Applications* – none to date
f. *Other Products (data, audio, video, education aid, instruments, equipment)* –