

**Field Validation and Demonstration of Zero-NO_x Emission
Hydrogen Bus and Fueling Infrastructure**

Task 2 Report

Prepare Hydrogen Fuel Station and Staff for Demonstration

for:

New Technology Research and Development Program

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Abstract/Executive Summary

The following report is provided to TCEQ by The University of Texas at Austin Center for Electromechanics (UT-CEM) to complete Task 2 of their NTRD project. Task 2 includes preparation of the hydrogen fueling station for the demonstration and training of operator's and first responders. Under this task, UT-CEM, along with project partners, has ensured all Capital Metro fuelers and relevant personnel have been trained to fuel the bus with UT-CEM's hydrogen station. Education and training was also provided to first responders that would respond to an incident on site at the Pickle Research Campus. In addition, operator's and maintenance manuals were provided to UT-CEM by Gas Technology Institute (GTI), and procedures were put in place to have maintenance performed by Greenfield when and as needed.

The overall project will demonstrate two fuel cell technologies, both of which will advance the commercial viability of hydrogen transportation in the next few years and are critical to zero NO_x emissions vehicles. Texas can move to the forefront in commercializing and deploying zero emissions vehicle technologies, creating the foundation for a robust hydrogen economy. Two developed technologies to be demonstrated in this validation project are:

- A “ready for the road”, commercially available heavy-duty hydrogen fuel cell plug-in hybrid transit bus combining the clean energies of hydrogen and electric propulsion
- A cost competitive and commercially available hydrogen fueling station that is being commercialized and supported by Texas-based GreenField, an Atlas-Copco Brand.

Under Task 2, UT-CEM and project partners, have trained personnel and first responders on the second of these two technologies, the hydrogen fueling station. Upgrades to the station were completed in June 2012 and the station has been used to refuel the bus during pre-service trials and testing.

Introduction/Background

There has been significant progress over the past few years in developing more reliable and customer-friendly fuel cell vehicles and the infrastructure to support them. This proposal outlines a project that will demonstrate two such technologies, both of which will advance the commercial viability of hydrogen transportation in the next few years. As a continuation of a previous TCEQ-funded project and in collaboration with the US Department of Transportation's Federal Transit Administration (FTA) National Fuel Cell Bus Program (NFCBP), along with other state and federal agencies, the project partners will demonstrate a turnkey, self-contained, skid-mounted hydrogen fueling station (Figure 1) and an advanced, zero-emissions fuel cell hybrid electric transit bus (Figure 2) that will be operated in Austin, Texas, by Capital Metro for at least one year. The potential for this important national vehicle demonstration program to come to Texas has been made possible only by the ongoing support of the TCEQ and other forward-looking state organizations.

Figure 1. Hydrogen fueling station located at UT-CEM's facility at Pickle Research Campus for the validation project.



Figure 2. Hydrogen fuel cell plug-in hybrid transit bus for the validation project.



While well-publicized financial challenges have slowed fuel cell vehicle development by one or two domestic passenger vehicle original engine manufacturers (OEM), others have continued to develop

vehicles and set market launch projections for full-scale commercialization. For example, government leaders in Europe, Japan, China, Singapore, some US states, the US Department of Defense and the US Department of Transportation have maintained (and in some cases accelerated) research funding for hydrogen technologies. The number of commercial-ready products in the area of buses and industrial trucks (i.e. forklifts) has grown in recent years. There are contracts for over 300 hydrogen fuel cell forklifts to be deployed in Texas in the next two years. Deployment of fuel cell transportation demonstration projects continues to be supported by several state and federal initiatives and increasingly by private industry.

Texas can move to the forefront in commercializing and deploying zero emissions vehicle technologies, creating the foundation for a robust hydrogen economy. Two developed technologies critical to zero NO_x emissions vehicles will be demonstrated in this Field Validation program to further establish viability for full commercial acceptance:

- A “ready for the road”, commercially available heavy-duty hydrogen fuel cell plug-in hybrid transit bus combining the clean energies of hydrogen and electric propulsion, and
- A cost competitive and commercially available hydrogen fueling station that is being commercialized and supported by Texas-based GreenField, an Atlas-Copco Brand.

This project addresses two immediate needs for lowering emissions in Texas non-attainment and near-non-attainment areas:

- Ultra-low or zero emissions vehicle platforms have not been commercially available for “real” working applications for heavy duty vehicles. Existing vehicles have typically been prototypes that are “test” vehicles not intended for public use. This project will put a zero-emissions bus in regular service with a transit agency to demonstrate that zero-emissions vehicles can and are being used in “real” operating conditions.
- Fueling supply infrastructure is unavailable, making the availability of vehicles irrelevant. This project demonstrates that the existing natural gas supply network can be leveraged to supply hydrogen for zero-emissions vehicles.

Mass transit has long been a transportation option that reduces energy usage and air pollution compared to private automobiles. Transit agencies are on the threshold of revolutionary change.

Transit agencies must find new, more environmentally responsive solutions for expanding their service. In an effort to reduce emissions, transit agencies in Texas are adopting electric rail, compressed natural gas (CNG) buses, liquefied natural gas (LNG) buses, and propane-fueled vehicles as alternatives to diesel. A growing number of transit agencies across the nation are moving toward zero-emission bus technologies for their urban circulator routes. All-electric vehicles are still cost-prohibitive due to the initial vehicle cost, maintenance cost, and the cost associated with the needed on-route electrical charging infrastructure due to limited range capabilities. A potentially lower cost alternative, offered here, is an electric hybrid merging the benefits of electric battery propulsion with the range extension of hydrogen proton exchange membrane (PEM) fuel cells.

This field validation project will help establish full commercial acceptance of a reliable, fuel efficient battery dominant, hydrogen fuel cell transit bus along with its cost-effective, efficient, and reliable onsite

hydrogen fueling station. The program team and partners have come together to demonstrate and promote the future of feasible and cost effective hydrogen transportation technologies.

Escalating petroleum prices and growing concerns with energy security, public health and global climate changes are accelerating technological innovation to continue economic growth while fulfilling environmental stewardship goals. Transportation contributes 27% of the US greenhouse gas emissions (EPA, Greenhouse Gas Emissions from U.S. Transportation, 1990-2003) while diesel exhaust is suspected to be the driving factor in rising childhood asthma and other respiratory complications and cancer. Moving toward a transit agency fleet-wide transition to zero NO_x emission and low greenhouse gas emission vehicle technologies will improve urban air quality.

This zero emission bus combines a lightweight composite chassis with a unique propulsion prime mover approach consisting of two 16 kilowatt (kW) hydrogen PEM fuel cells and 54 kilowatt-hour (kWh) energy storage from advanced Lithium Titanate batteries. The onboard batteries are charged overnight from the grid. This novel vehicle architecture provides a range of 300 miles with a documented fuel economy of about 10 miles per gallon (diesel energy equivalent) which is well over a doubling of fuel efficiency compared to commercial diesel transit buses.

It achieves this high efficiency while also meeting or exceeding performance (e.g. acceleration, gradeability, range, braking distance, etc.) of its diesel counterparts, and emitting no tailpipe pollutants thereby exceeding the 2010 heavy-duty bus emissions standards.

Also, this field validation will further demonstrate and validate increased collective hydrogen fuel cell stack life, reduced fuel cell stack replacement costs, lower operating costs, and increased reliability as well as 'in service' transit performance of a fuel cell powered vehicle.

Project Objectives/Technical Approach

With its partners in agreement, UT-CEM will increase the hydrogen fuel capacity of an integrated, self-contained, on-site hydrogen generation and fueling station to provide sufficient fueling infrastructure for an advanced hydrogen fuel cell hybrid-electric bus. UT-CEM will contract with the Gas Technology Institute (GTI) to increase the hydrogen fuel capacity of the hydrogen generation and fueling station, complete necessary enhancements for it, and maintain it. The hydrogen generation and fueling station will be located at the University of Texas at Austin's Pickle Research Campus. The Center for Transportation and the Environment (CTE), a partner in agreement with UT-CEM under a Memorandum of Agreement (MOA), is a grant recipient for the FTA's NFCBP. Under the NFCBP grant, CTE contracted with Proterra, Inc. (Proterra) to build the fuel cell bus to be demonstrated under the grant. Using NFCBP grant funds, CTE will coordinate the use of the Proterra bus and will contract with Proterra for on-site labor support and spare parts for non-routine maintenance of the Proterra bus. The Capital Metropolitan Transportation Authority (Capital Metro), a partner in agreement with UT-CEM under a MOA, will operate the Proterra bus on a passenger service route in Austin, Texas, and perform routine bus maintenance. UT-CEM will ensure that data is collected and evaluated to better understand the Proterra bus's and the hydrogen fueling station's operating efficiency, reliability, performance, and maintenance requirements in order to further establish commercial viability.

The objectives for this work are:

- Twelve month demonstration of an advanced hydrogen fuel cell hybrid-electric bus on a public route to validate that the bus can support normal transit operations, and
- Demonstration of an integrated, self-contained, on-site hydrogen generation and fueling station in support of a hydrogen fuel cell bus in normal transit operations.

Tasks

The validation project consists of six tasks, as stated in the Grant Activities (Scope of Work). The first two tasks included upgrades to the hydrogen station and its preparation for the demonstration. Tasks 3 and 4 focus on the bus preparation and training of Capital Metro staff. The demonstration phase occurs in the fifth task where performance data for the bus and fueling station is collected and analyzed. The final task includes monthly reports and a final report deliverable to TCEQ. The project timeline consists of 24 months, ending in May 2013. The demonstration phase occurs over the last 12 months of the project.

For completeness, all tasks from the Grant Activities (Scope of Work) are shown in the following sections; however, this report deliverable focuses on Task 2, which was completed in June 2012.

Task 1: Hydrogen fueling station preparations

From the Grant Activities (Scope of Work), Amendment 03:

"2.1. Task Statement: The PERFORMING PARTY will contract with the Gas Technology Institute (GTI) to prepare the hydrogen fueling station and increase its hydrogen fuel capacity for use with the demonstration Proterra bus."

Under this task, UT-CEM and GTI will perform upgrades to the hydrogen fueling station on the Pickle Research Campus and prepare it for the demonstration where it will be used to refuel the hydrogen hybrid bus operated by Capital Metro. A major part of this upgrade is the installation of additional storage capacity needed to refuel the bus. Other activities include upgrading cooling and exhaust systems and providing a back-up supply of hydrogen. This task was completed in June 2012 and a separate report was submitted in July 2012.

Task 2: Prepare hydrogen fuel station and staff for demonstration

From the Grant Activities (Scope of Work), Amendment 03:

"2.2. Task Statement: The PERFORMING PARTY will prepare the station operations and maintenance manual, train staff in operation of the station, and arrange for station maintenance during the demonstration."

Under this task, UT-CEM and GTI provided operations and maintenance manuals for the hydrogen refueling station on the Pickle Research Campus and train Capital Metro and on-site staff in fueling the

bus and maintaining the station. An additional component of the training was to educate first responders on the use, design, and safety features of the fueling station. This task was completed in June 2012 with this report submitted in July 2012.

Task 2.1

From the Grant Activities (Scope of Work), Amendment 03:

" 2.2.1. The PERFORMING PARTY and GTI will review and update the station operations and maintenance manual and safety plan, and provide copies of the manual and plan to on-site personnel."

The maintenance and operator's manuals for the hydrogen station were updated by GTI and provided to UT-CEM. UT-CEM reviewed the manual and was provided operational training of the hydrogen station by GTI, including serviceable items and emergency procedures. The manuals also provided the basis of the training for Capital Metro fuelers and emergency first responders. Copies of the manuals will be submitted with this report as separate attachments. They are not included in the appendix due to their length but have been submitted with this report.

Task 2.2

From the Grant Activities (Scope of Work), Amendment 03:

" 2.2.2. The PERFORMING PARTY and GTI will provide training for bus personnel, fueling personnel, and on-site personnel for both routine and emergency activities that may need to be performed during the demonstration period."

Throughout the month of May 2013, UT-CEM and project partners conducted several training sessions for Capital Metro staff and emergency first responders. Fueling operators at Capital Metro were trained on operation of the dispenser and safety features of the station. Training was also provided for Proterra service engineers and technicians who would need to refuel the bus while performing maintenance and testing.

Three separate training sessions were also provided for emergency first responders, such as the Austin Fire Department and EMS crews. These training sessions were held at the hydrogen fueling station for all shifts and crews of the nearby fire station in North Austin. Figure 8 shows the first responder training at the hydrogen station. A list of key personnel and contacts will be provided at the station for Capital Metro operators and first responders.

Maintenance training was also provided to UT-CEM staff by GTI. In general, UT-CEM staff are not required to repair or maintain the hydrogen station. GTI and GreenField will perform all major servicing during the demonstration. However, UT-CEM was trainee in operation of the station, its safety features, and routine maintenance items.

Figure 3. Capital Metro bus operator training at fueling station.



Figure 4. Emergency first responder training at the hydrogen fueling station.



Task 2.3

From the Grant Activities (Scope of Work), Amendment 03:

" 2.2.3. GTI will contract with Greenfield Compression to perform routine maintenance on some station major components including the dispensing system and hydrogen compressor."

During commissioning of the hydrogen station, GTI contracted with Greenfield on two separate occasions. The first was to service the compressor prior to initial start-up. The second was to diagnose and correct start-up errors with the dispenser. This work was completed successfully and GTI will

continue to contract Greenfield during the demonstration for maintenance items as needed. A copy of the service order with Greenfield was submitted as part of financial reporting for the grant.

Task 2.4

From the Grant Activities (Scope of Work), Amendment 03:

" 2.2.4. Schedule: The PERFORMING PARTY shall complete this task within 13 months of the signed Notice to Proceed Date as issued by TCEQ."

This task was completed in June 2012, which is 13 months after the TCEQ signed Notice to Proceed Date of May 26, 2013.

Task 2.5

From the Grant Activities (Scope of Work), Amendment 03:

" 2.2.5. Deliverables: The PERFORMING PARTY shall submit a report to the TCEQ upon completion of this task. This report will include but is not limited to the status of the updated station operations and maintenance manual, the status of the updated station safety plan, description of all training sessions, and a copy of the maintenance contract with Greenfield Compression."

This report satisfies the report deliverable for Task 2.

Task 3: Hydrogen fuel cell hybrid-electric bus preparation

From the Grant Activities (Scope of Work), Amendment 03:

" 2.3. Task Statement: The PERFORMING PARTY will ensure that the Proterra bus, Capital Metro personnel, and support materials are prepared for the demonstration."

Under this task, UT-CEM worked with Proterra and Capital Metro in preparing the bus and all support materials for the demonstration. This included the installation of the bus overnight electrical charger, as well as preparation of operator and maintenance manuals and spare parts inventory list. This task was complete in May 2012, and a separate report deliverable was submitted in June 2012.

Task 4: Complete bus pre-service trials and general operation and maintenance training

From the Grant Activities (Scope of Work), Amendment 03:

"2.4. Task Statement: The PERFORMING PARTY will complete pre-service trials with the Proterra bus and ensure that all Capital Metro personnel are trained in the bus's operation and maintenance."

Under this task, UT-CEM ensured that Capital Metro was provided with bus operational and maintenance manuals and are adequately trained on the operation of the bus prior to the demonstration. In addition,

UT-CEM oversaw pre-service trials of the bus which aided the selection of bus routes for the demonstration. This task was complete in May 2012, and a separate report deliverable was submitted in June 2012.

Task 5: Proterra bus and fueling station demonstration

From the Grant Activities (Scope of Work), Amendment 03:

"2.5. Task Statement: The PERFORMING PARTY will operate the hydrogen fuel cell hybrid-electric bus in a realistic working environment over a twelve month period, including using the hydrogen generation and fueling station as the bus's primary fuel source."

Under this task, UT-CEM and project partners will operate the bus and fueling station for 12 months. The bus will be operated by Capital Metro as part of their UT Shuttle passenger service. Capital Metro operators will refuel the bus using the Pickle Research Campus hydrogen fueling station. During the demonstration, UT-CEM will collect data to assess the performance of the fueling station and the bus. This task will be completed in May 2013.

Task 6: Reporting

From the Grant Activities (Scope of Work), Amendment 03:

"2.6. Task statement: The PERFORMING PARTY will prepare and submit monthly detailed project reports and a comprehensive final report while ensuring compliance with all TCEQ program requirements"

Under this task, UT-CEM will submit monthly progress reports and billing statements to TCEQ. The monthly reports are on-going. Upon completion of the project, UT-CEM will submit a final project report summarizing the results of the project. All reports are to be submitted on time and within budget per NTRD program requirements. The final report will be completed following the end of the project in May 2013.

Discussion/Observations

Objectives vs. Results

Accomplishment of Task 2 was an additional step towards meeting the project's first goal of demonstrating a hydrogen hybrid fuel cell bus in Austin, Texas. Training sessions were held on hydrogen station operations for all Capital Metro personnel and emergency first responders prior to beginning in-passenger service for the demonstration. During pre-service trials of the bus, the hydrogen station was able to produce, compress, store, and dispense hydrogen to the bus at 350 bar.

Delivery of the bus was delayed multiple times during the project and caused the team to amend the Grant Activities Statement of Work twice to realign task deliverables.

Critical issues

UT-CEM has identified the following critical issues for performance of the hydrogen station during the demonstration based on the pre-service trials:

Communications

During the upgrade and commissioning tasks for the hydrogen station, several communication modules for the station computer control system failed. The modules were replaced relatively quickly and easily, but communication outages at times hampered start-up and operation of the station. GTI has spare modules in-house for quick turn around on any future failures.

Thermal limits

The station struggles to maintain temperatures in electronics cabinets during warm days above 100-F. An external blower was installed to help mitigate this issues, and has improved operations by allowing the electronics to operate at ambient temperatures up to 110-F. Thermal limits are continually monitored by the station's control system and the team will closely watch the station's performance during warm summer months.

With these two known issues, UT-CEM and GTI will operate the station in a partially manual mode, in which hydrogen production is not done automatically when the storage tanks become low. UT-CEM and GTI will start the process themselves so that temperatures and communications can be monitored closely during the summer. As more confidence is gained throughout the demonstration, fully automated operation may be implemented.

Technical and commercial viability of the proposed approach

The accomplishment of Task 2 has not shown any large technical barriers that cannot be overcome and would limit commercial viability of the hydrogen station. A higher capacity cooling system would allow more reliable operation during warm summer months.

Scope for future work

Future work related to lessons learned during Task 2, could include upgrading the station's cooling capacity within the hydrogen station.

Intellectual Properties/Publications/Presentations

Proterra and GTI have both previously filed patents on their technologies prior to this project. No new IP has been generated during the project.

Summary/Conclusions

This report completes Task 2 of the Grant Activities SOW. The hydrogen station upgrades have been completed and all training of Capital Metro personnel and emergency first responders has been completed. The station is ready to begin fueling the bus during the demonstration period.

Completion of this task has the hydrogen station and personnel ready for the demonstration of an advanced hydrogen fuel cell hybrid-electric bus on a public route to validate that the bus can support normal transit operations.

Acknowledgements

UT-CEM would like to acknowledge the following project partners:

- Gas Technology Institute - hydrogen station implementation
- Capital Metro Transit Authority - in-service passenger demonstration
- Proterra, Inc - bus manufacturer
- Federal Transit Administration - funding source through the National Fuel Cell Bus Program
- Center for Transportation and the Environment - program management under the FTA funding

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