Hydrogen Station and Fleet Demonstration at Penn State University

J. Anstrom[1]
Z. Rado[1]

1. The Pennsylvania Transportation Institute, University Park, PA

1. Introduction

A major long term goal of a U.S. hydrogen economy is to incorporate renewable energy sources such as wind, solar, and biomass into the transportation fuel infrastructure. An interim solution promoted by the U.S. Department of Energy (DOE) to support early introduction of hydrogen fueling infrastructure and fuel cell vehicles is to use hydrogen stored on-board the vehicle that has been produced from natural gas at local refueling stations and dispensed at costs and efficiencies competitive with gasoline. However, natural gas for hydrogen production could alternatively be sourced from either domestic wells or renewable sources such as biomass or landfills. This interim solution uses domestic energy resources to meet early hydrogen demand and helps to build a long term market for renewable hydrogen sources by promoting development and deployment of hydrogen vehicles.

The principal objective of a recent cost-shared project between Air Products and Chemicals Inc. (Air Products) and the U.S. DOE was to develop and demonstrate commercial cost viability for a stand-alone, comprehensive hydrogen fueling station that can competitively deliver a hydrogen product stream meeting strict end-use performance requirements in the emerging hydrogen-for-transportation markets. The first commercial unit of this station was installed at the University Park Campus of Penn State in 2005. The station is designed to push the envelope of technologies in the areas of methane steam reforming, dispensing, and hydrogen pressure swing-adsorption purification

Through a partnership with the Penn State Office of Physical Plant (OPP), the Centre Area Transportation Authority (CATA), and Collier Technologies, a fleet of hydrogen fueled vehicles was developed by Penn State's Thomas D. Larson Pennsylvania Transportation Institute (PTI) Hybrid and Hydrogen Vehicle Research Laboratory (HHVRL) to place a significant hydrogen demand on the methane reformer of the new Air Products hydrogen station. Funding for fleet development and demonstration was provided by the Pennsylvania Department of Environmental Protection (PDEP) and the Department of Community and Economic Development (PDCED). The HHVRL developed a hydrogen fuel cell vehicle from a production electric vehicle platform. Collier Technologies modified CNG engines to operate on a blend of 30% hydrogen and 70% natural gas (HCNG) for a CATA 40-ft transit bus and an OPP work van. These first three vehicles are currently in service. Additional funding from PDEP and PDCED is allowing conversion and demonstration of six additional HCNG vans and a hydrogen powered hybrid vehicle. This paper will describe the startup experiences, operational history, and current status of the hydrogen station and vehicle fleet demonstration.

2. Project History and Funding

Air Products designed the commercial hydrogen station shown in Figure 1 with a methane reformer capable of producing 100 kg of hydrogen per day, enough to fill about 25 fuel cell cars. A demand of at least 40 kg per day, or about 10 fuel cell cars, is required to keep the methane reformer in continuous operation and prevent problematic and frequent shutdown and startup of the high temperature reformer components. This is the only operational hydrogen station in Pennsylvania and one of only 66 operational in the US according to the National Hydrogen Association fueling station database. It is only the second installed by Air Products with an on-site methane reformer and the first installed commercial version of this technology.

Figure 1: Air Products Hydrogen Station installed at Penn State University Park Campus near the Office of Physical Plant fleet fueling island just north of Beaver Stadium

Starting in 2003, a partnership including Penn State HHVRL and OPP, Air Products, CATA, Collier Technologies, and Columbia Gas began meeting to explore the possibility of installing the station at Penn State and fielding a hydrogen fleet with sufficient hydrogen demand to place a significant load on the methane reformer. At that time, it was determined infeasible to acquire and operate the number of fuel cell cars and buses necessary to consume 40-100 kg of hydrogen per day. Because of the imperative to consume relatively large quantities of hydrogen, an emphasis was instead placed on obtaining and operating vehicles fueled with a blend of hydrogen and natural gas which had modified natural gas engines. Reasons included:

- These vehicles are currently much less expensive to obtain and maintain than fuel cell vehicles. They are a bridging technology to fuel cell vehicles.
- An extensive fleet of natural gas vehicles already operated at Penn State with the potential to use large quantities of hydrogen if converted, especially the large fleet of CATA CNG buses.
- Collier Technologies could convert the natural gas engines in Penn State work vans and CATA buses to run on HCHG with patented technology allowing 30-50% blends of hydrogen by volume with natural gas. This could be done at low cost per vehicle compared to fuel cells and would be less expensive to maintain.
- HCNG technology would consume much more hydrogen per vehicle than Hythane® technology which is limited to 20% hydrogen by volume.
- Fuel cell vehicle OEMs have tended to place fleet demonstrations in much warmer, larger markets, with more serious air quality issues than University Park. However, the partnership agreed to continue seeking OEM participation.

- Lastly, the PTI Hybrid and Hydrogen Vehicle Research Laboratory (HHVRL) had the capability to integrate our own fuel cell and hydrogen ICE vehicles for demonstration, research, and educational purposes.

In 2003, the partnership proposed a hydrogen fleet demonstration project to the Pennsylvania Department of Environmental Protection (PDEP) under the Energy Harvest Grant requesting funding to complete three HCNG bus conversions, eight HCNG vans, and a fuel cell vehicle and also place the vehicles in operation for a total of three years at a project cost of about $3,200,000. The goals and objectives of this hydrogen station and fleet demonstration became to:

- Deploy a hydrogen vehicle fleet approaching 40 kg/day of hydrogen demand
    - Eight HCNG vans operated by OPP for campus maintenance
    - Three HCNG 40' transit buses operated by CATA on campus routes
    - One HHVRL developed fuel cell vehicle operated on campus
    - One HHVRL developed H_2ICE hybrid vehicle operated on campus
- Demonstrate the Air Products station fueling both hydrogen and HCNG
- Demonstrate fleet efficiency and low emissions
- Operate hydrogen vehicles and the hydrogen station safely and reliably
- Gather and publish long-term data on the hydrogen station and fleet operation
- Perform public outreach on the safe use of hydrogen as a transportation fuel
- Perform technology transfer with regional businesses to develop hydrogen economy infrastructure, advanced vehicles, and products
- Use hydrogen vehicles and infrastructure for undergraduate and engineering graduate education

This proposed fleet was sized to place a realistic load on the station approaching 40 kg of hydrogen per day to keep the reformer in continuous operation. In 2004, a Phase I fleet was funded jointly by PDEP and Department of Community and Economic Development (PDCED). The Phase I fleet consisted of one HCNG bus, one HCNG van, and a fuel cell vehicle with one year of operation for $487,656. Air Products, in a cost matched program with DOE, developed the hydrogen station and began installation at the Penn State Office of Physical Plant in 2004. In 2005, an expanded Phase II fleet was funded by PDEP and PDCED for six additional HCNG van conversions, a hydrogen engine (H_2ICE) hybrid vehicle, and two additional years of operation for $533,324. Table 1 details the partners and their contributions to the Hydrogen Station and Fleet Demonstration at Penn State.

PTI began conversion of Phase I vehicles in 2004. They are shown in Figures 2 and 3 in front of the completed Air Products Station. PTI managed vehicle conversion and data collection for each vehicle. The HCNG van was the first to become operational in October of 2004. The HyLion fuel cell vehicle began fueling in 2005. Development of the HCNG bus engine began in 2004 and installation in the HCNG bus began in late 2005 at the PTI Bus Test Center. Bus testing and debug began in July 2006 and passenger operation began in June 2007 with HCNG operation beginning in August 2007.

Table 1: Penn State Hydrogen Demonstration Partners and Contribution

Partner	Contribution
PA DCED	Salaries, equipment, materials, services, travel
PA DEP	Salaries, equipment, materials, services, travel
Air Products	50% share of hydrogen station
US DOE	50% share of hydrogen station
CATA	Transit bus base maintenance
	Transit bus base fuel
	Transit bus depreciation
	Insurance
OPP	OPP van base maintenance
	OPP van base fuel
	OPP van depreciation
	OPP station site
	Insurance
PTI	EV1 chassis
	Waiver of project overhead charges
	PTI base fuel
	Insurance
Collier Tech	Contribution of one Daewoo engine
Columbia Gas	Donation of compressed natural gas storage tanks

Figure 2: Penn State HHVRL HyLion Fuel Cell Vehicle and OPP #618 HCNG E250 Van

Figure 3: CATA Bus 85, New Flyer converted to HCNG

Additional positive outcomes from this hydrogen station and fleet demonstration have been realized according to the original goals and objectives listed above. A significant amount of public and educational outreach has been accomplished through public use and visibility of the hydrogen vehicles and station, during special events, tours, and by press coverage. The hydrogen station and vehicles have become an important component in engineering education at Penn State, especially through the DOE funded Graduate Automotive Technology Education (GATE) Program which offers graduate level engineering courses focused on hybrid electric and fuel cell vehicle development. Penn State also participates in DOE sponsored Advanced Vehicle Technology Competitions. In 2007, the Penn State team fielded a hybrid electric SUV with hydrogen assisted bio-Diesel combustion which achieved better emissions than a stock gasoline vehicle in the federal test procedure. A US DOE funded combustion research project at Penn State is investigating the emission benefits of mixing small amounts of hydrogen to assist combustion of gasoline, Diesel, and natural gas. These programs utilize the hydrogen station and vehicles for research and education. The PTI HHVRL is leveraging the hydrogen station and fleet demonstration along with the GATE Program and other resources to form a new advanced vehicle development consortium for research and development of energy efficient advanced automotive products and hydrogen infrastructure in collaboration with regional industry and local government. This consortium will also serve to strengthen industry relationships with Penn State engineering education, become a resource for energy policy makers, and a venue for public outreach on hydrogen technology. The hydrogen demonstration has also helped to raise the profile of Pennsylvania as a hydrogen economy leader in fueling infrastructure and advanced vehicle technology development.

3. Air Products Hydrogen Station

There is broad agreement among government and industry that hydrogen and fuel cell technologies hold great promise for reliable, renewable, zero-emission transportation. This belief is driven by the extremely high efficiency of fuel cells compared to combustion engines and the renewable nature of hydrogen fuel. Conversion to a hydrogen economy will help our country meet objectives for lower emissions, mitigation of greenhouse gas output, and reduction of foreign oil imports. Efforts to achieve our national energy security goals and substantially reduce our energy dependence, however, must begin now and continue with sustained commitment over the next several decades. Early deployment of hydrogen fueling infrastructure and hydrogen fueled vehicles will be necessary to encourage eventual market-driven solutions. Hydrogen vehicles deployed in this early phase will be a mixture of cost-effective internal combustion engines modified for hydrogen as a bridging technology and a limited number of demonstrations of more expensive prototype fuel cell vehicles. This project and others like it are vital to building early hydrogen demand for transportation that will eventually enable mass deployment of renewable production of hydrogen from wind, solar, and biomass along with other clean domestic sources of energy.

As shown in Figure 4, hydrogen as a transportation fuel could be distributed by pipeline, trucked as a gas or liquid, reformed locally from natural gas, or produced locally by electrolysis of water. Hydrogen pipelines are the most economical long term delivery method but will require years of infrastructure investment to be widely available. Trucking hydrogen as a gas is only economical over short distances. Trucking hydrogen as a liquid is more economical but has an energy penalty associated with liquefaction. Local electrolysis of water eliminates the cost of distribution but is not currently the most energy efficient alternative. Natural gas reforming technology is currently the most common and cost effective method of commercial hydrogen production and is widely accepted as the most economical source for the early hydrogen economy. Natural gas is also widely available in North America through an existing pipeline infrastructure to support on-site reformation and distribution of hydrogen fuel. A small natural gas reformer can support a small local fleet of hydrogen vehicles during early phases of an emerging hydrogen economy like the mixed technology fleet at Penn State depicted in Figure 4.

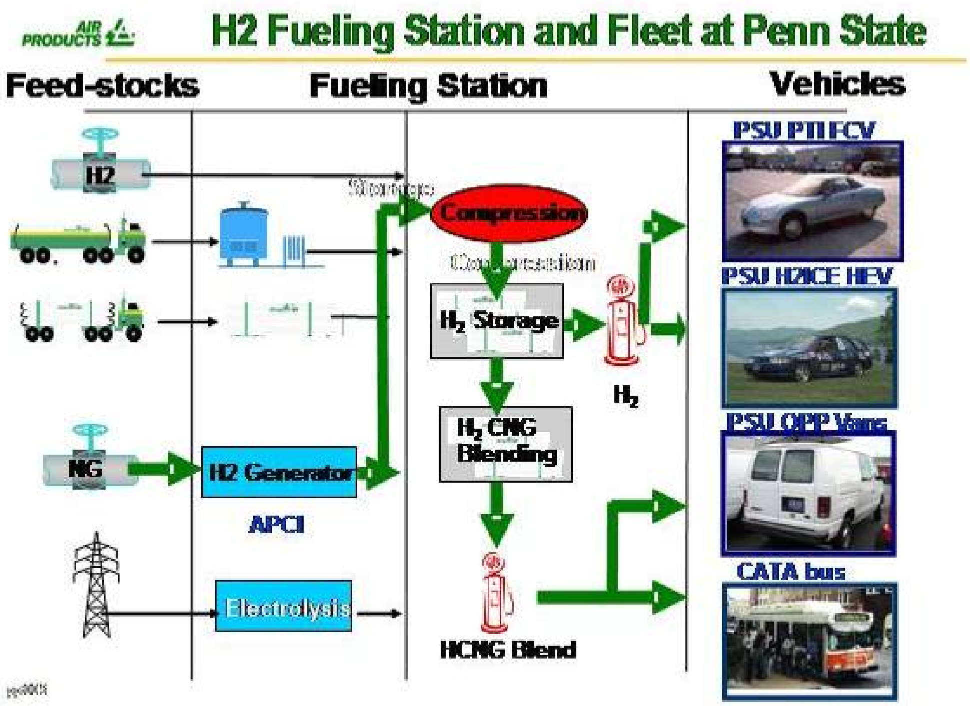

Figure 4: Energy Sourcing for Air Products Hydrogen and HCNG Fueling Station, courtesy of Air Products

Figure 5 shows the Air Products hydrogen station as installed on the Penn State campus, prior to final fencing when major components were still readily visible. The station components include: (1) natural gas reformer, (2) HCNG blend skid, (3) compressor and high pressure storage tanks, (4) hydrogen dispenser, (5) HCNG dispenser, (6) station controller, and (7) back-up liquid hydrogen storage tank. A hydrogen purification unit is out of view behind the reformer. Also out of view is an existing compressed natural gas facility which serves the existing OPP CNG fleet and also supplies CNG to the HCNG blend skid. This CNG compressor has limited capacity and only one HCNG bus can be fueled each day until a second CNG compressor is funded and installed at a cost of about $800,000. A concrete pad is installed in front of the dispenser to provide good static grounding through vehicle tires.

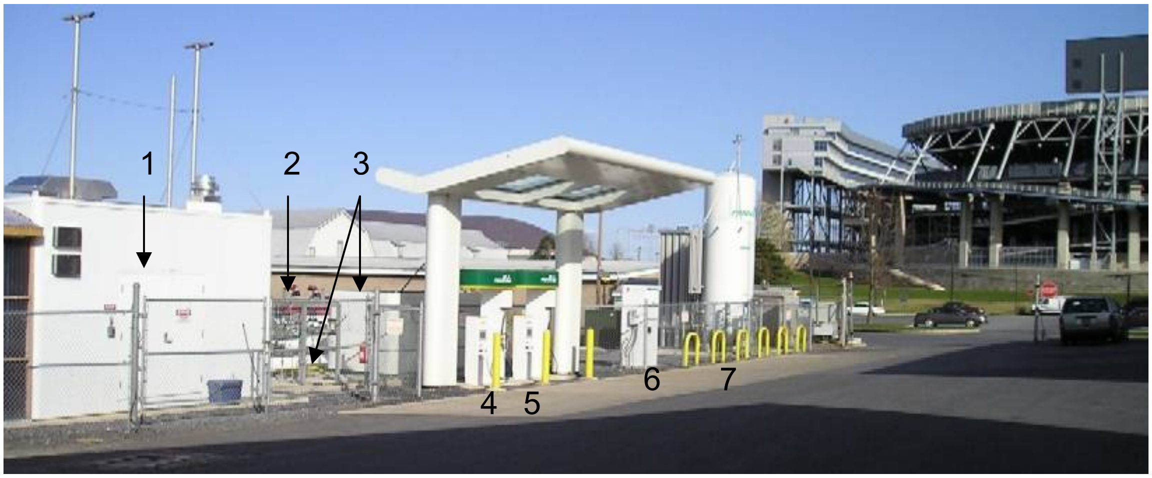

Figure 5: Air Products Hydrogen and HCNG Station Installed at Penn State

Installation of the station began in late 2004. There were no major issues during permitting and installation. The station is installed within a larger fenced complex for Penn State fleet operations just off Park Avenue and north of Beaver Stadium. Access to this area is open on weekdays but restricted by a card activated gate on weekends and holidays. The hydrogen and HCNG dispensers are PIN protected and not open to the general public but request for guest fueling are managed by the HHVRL.

Energy flow follows the process outlined in Figure 4. Low pressure natural gas from the mains is reformed into hydrogen, filtered, and compressed to 7000 psi for storage. Hydrogen is dispensed at 350 bar (5000 psi) according to the California Fuel Cell Partnership fueling interface [1] as shown in Figure 6. The hydrogen dispenser uses an automotive sized fill nozzle and receptacle compatible with SAE J2600 size H35. For the HCNG vehicles, CNG at 5000 psi from storage tanks in the adjacent facility is mixed on demand by the HCNG blend skid with hydrogen from the station storage tanks and dispensed at 250 bar (3600 psi) with a non-communication fill similar to the standard CNG fill procedure as shown in Figure 7. The HCNG dispenser and vehicle receptacles were originally sized for automotive use and compatible with SAE J2600 size H25. These receptacles were installed on both the van and the slow fill nozzle of the HCNG bus. In practice, these smaller nozzles are too restrictive for filling the 1721 liter bus tanks resulting in long fill times, noise, and vibration. Several receptacles have been damaged and experienced leakage over time. As a result, the dispenser nozzle and all HCNG vehicle receptacles are now being replaced with a larger format compatible with Weh TN5 receptacles.

Figure 6: Steps for filling hydrogen vehicles follows the California Fuel Cell Partnership Protocol shown clockwise from top left: enter PIN, attach communication cable, attach fill nozzle, automatic fill, remove and replace nozzle, remove and replace cable.

Figure 7: Filling HCNG vehicles is a non-communication fill similar to CNG procedure.

The station first became operational in 2005 using liquid hydrogen supplied by the storage tank. The hydrogen reformer became operational in 2006. Some recent station operational statistics from 2007 and early 2008 include:

- H2 Generator production - 54 nm3/hr average for year
- 99.999% H2 purity
- <1 ppm CO in the H2
- H2 generator on-stream 93% overall for year.
    - Some was weather related
    - Some was power quality related
    - Ample stored product (so operator didn't hurry)
- H2 Availability - 100%
- 2007 fuelings = 75
- 2008 fuelings = 23 so far this year

4. Hydrogen Fleet

Figure 8 illustrates the deployment of the hydrogen vehicle fleet superimposed on a CATA route map of the Penn State University Park Campus. The HCNG CATA bus operates most days on the Blue Loop route which travels clockwise around campus. The Blue Loop route is subsidized by Penn State and free to all passengers. It is heavily used by students, staff, and campus visitors making it ideal for outreach. On a typical day it travels 100 miles over 14 hours. The HCNG vans are deployed from OPP for daily maintenance work on campus. On a typical day it travels about ten miles and spends a significant amount of time idling. The HyLion fuel cell vehicle is maintained at PTI as a research vehicle. On a typical day it travels to the hydrogen station in the morning to fuel and returns to PTI where the fuel cell produces power and the electronics export power for 6 to 8 hours. If time allows it travels to the fueling station to fuel for a second time. The H_2ICE hybrid vehicle is also operated from PTI as a research vehicle. It fuels intermittently and is used on the test track and around campus. Table 3 summarizes the estimated hydrogen demand on the station for all vehicles currently planned for the fleet. It also includes the demand of a few researchers on campus who transport portable laboratory tanks between their labs and the hydrogen the station to fill with hydrogen or HCNG. The total demand is estimated at about 13 kg of hydrogen per day. The addition of two more HCNG buses as originally planned would enable the fleet to approach the 40 kg per day goal.

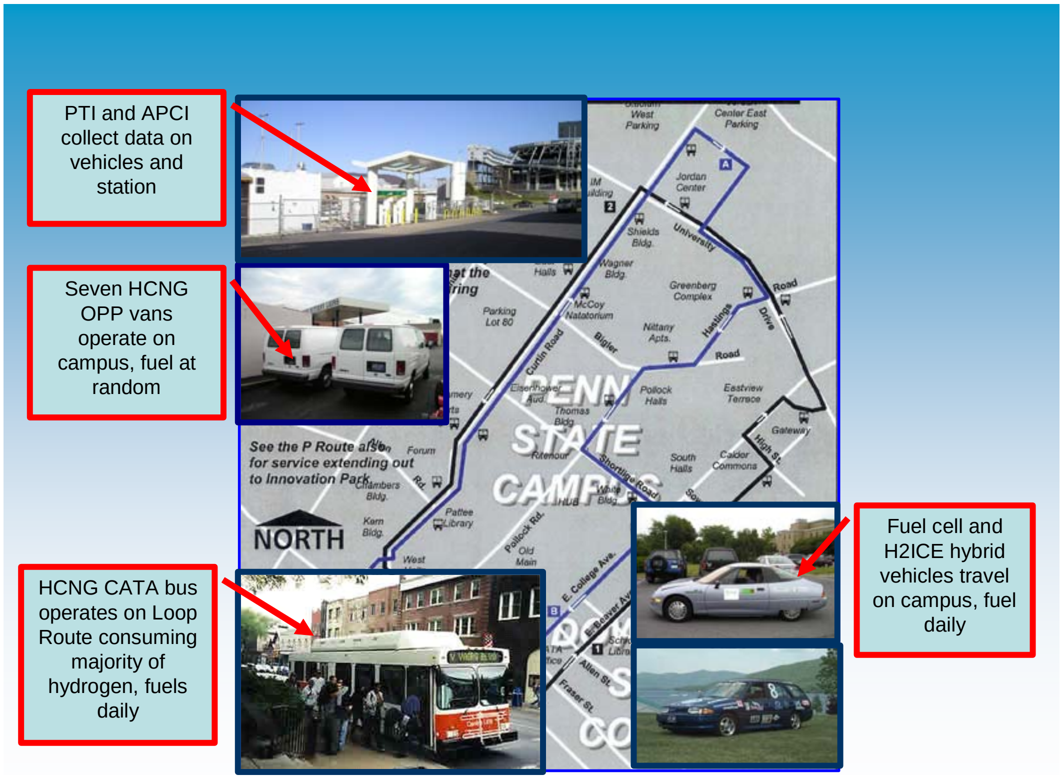

Figure 8: Operation of Penn State Hydrogen Fleet on Penn State Main Campus

Table 3: Estimated Hydrogen Demand of Current and Requested Hydrogen Vehicle Fleet

Vehicle Type	Hydrogen kg/fill	# Vehicles	Vehicle Fills/day	Demand kg/day
HCNG Bus	8.9 kg	1	1	8.9
HCNG van	2	7	0.2	2.8
Fuel Cell	0.62	1	2	1.24
H_2ICE Hybrid	0.62	1	0.5	0.31
Research Tanks	1.0	na	0.2	0.2
Total	-	10	3.9	~13.5

HyLion Fuel Cell Vehicle

During Phase I, the PTI HHVRL developed the HyLion fuel cell vehicle shown in Figure 9 based on a GM EV1 electric vehicle chassis. The HyLion is intended to represent fuel cell vehicles which may be mass produced by 2015-20. The EV1 chassis was donated by GM in 2001. It was donated mechanically intact with complete documentation but without batteries and most of the electronic control modules namely the electric drive ECU, brake ECU, and battery management system. Under this project, the PTI HHVRL has developed our own 70 kW field oriented induction motor inverter, brake ECU, Nickel

Metal Hydride battery pack, battery management system, and a proton exchange membrane (PEM) hydrogen fuel cell system with power converter. This was accomplished by a team of a dozen graduate and undergraduate students and faculty, many of them volunteers. The motor inverter also was designed with vehicle-to-grid (V2G) capability to export AC power when parked. The HyLion serves as case study in engineering classes and as a technology transfer demonstrator with industry and the public.

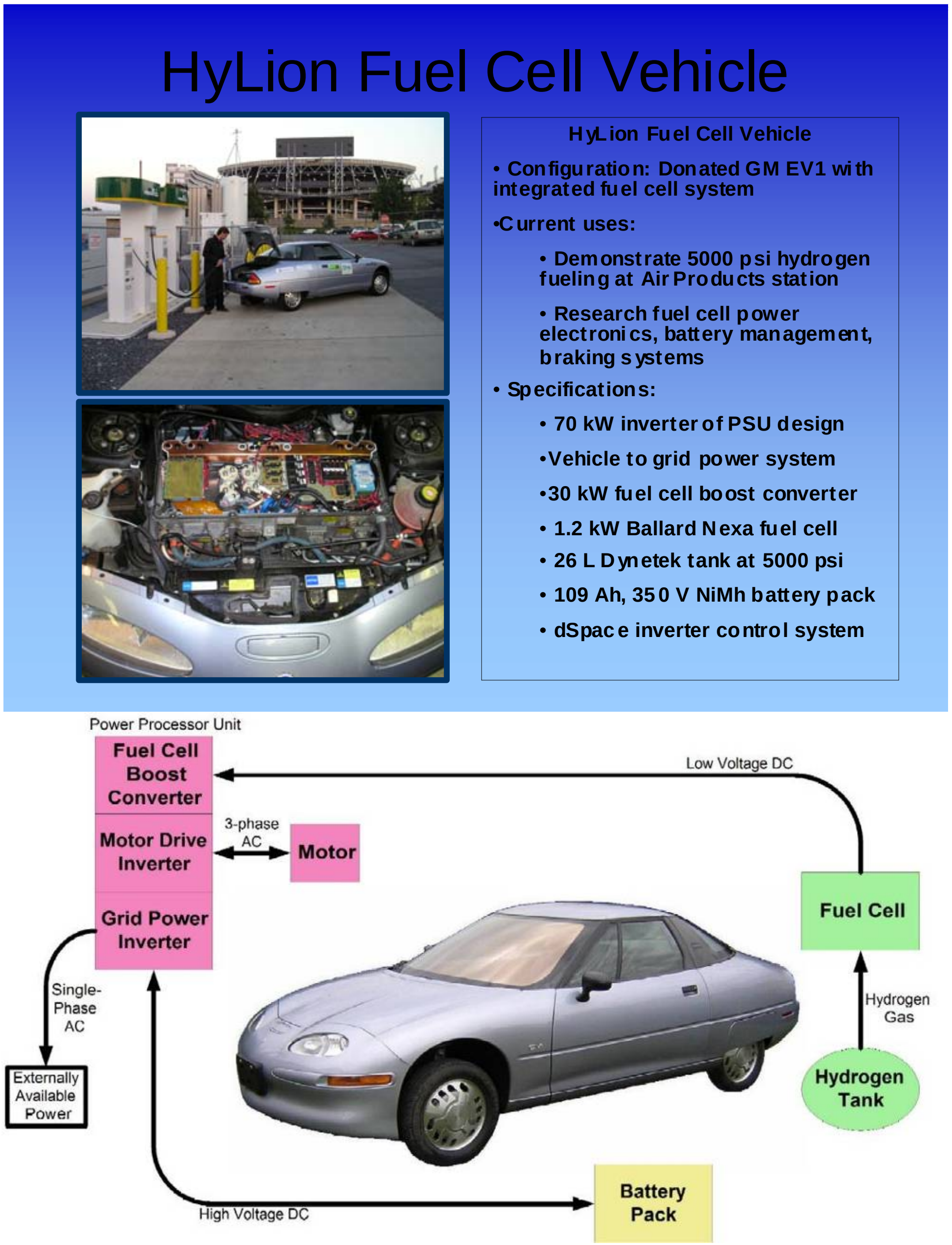

Figure 9: HyLion Fuel Cell Vehicle specifications and schematic showing Vehicle-to-Grid power export capability

HCNG Vans

Figure 10 shows Penn State OPP van #618 which was modified by Collier Technologies in 2004 to run on either HCNG or CNG. The Ford ECU adapts automatically to the fuel blend. This van is used by OPP electricians as a campus work vehicle. Collier Technologies developed a retro-fit kit which included an Eaton supercharger to compensate for the loss of power due to changes in volumetric efficiency from hydrogen in HCNG fuel. The kit also includes a high-volume exhaust gas recirculation (EGR) system to reduce NOx as part of a lean burn strategy. The modified 5.4 liter V8 engine produces stock power on the HCNG mixture, extremely low NOx, and stock fuel efficiency. The original steel CNG tanks, manufactured by Faber, are not hydrogen compatible. They were replaced with composite tanks manufactured by Structural Composites.   Six additional vans are currently undergoing conversion and will be deployed on campus by summer 2008. The six new HCNG vans will be converted without superchargers, which are no longer available. They should have sufficient power for on campus service and better long-term reliability without superchargers. OPP vans fuel at random, several times a week.

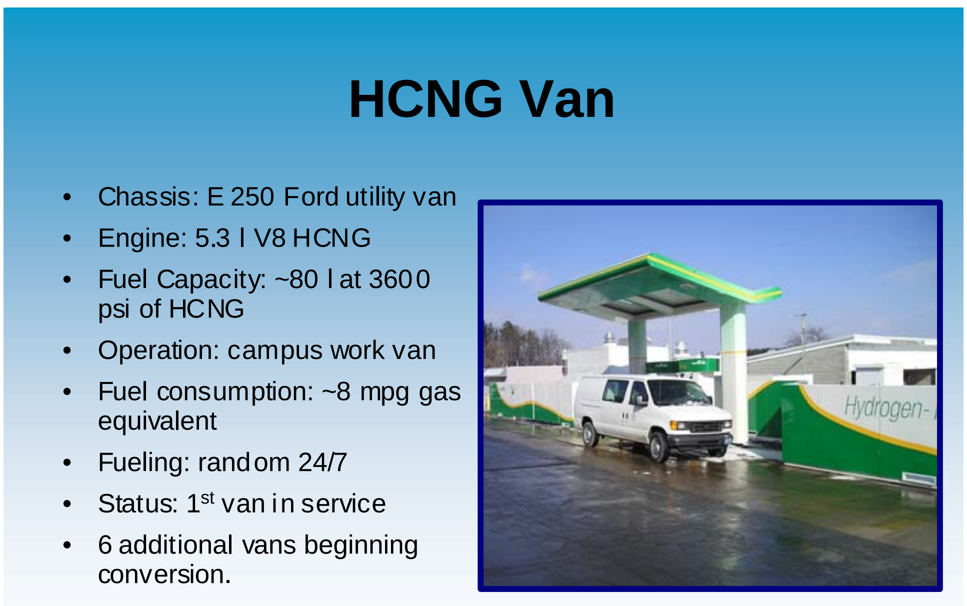

Figure 10: HCNG converted Ford E250 utility van used by OPP on Campus

HCNG Transit Bus

Figure 11 shows the CATA transit bus converted to HCNG by Collier Technologies during Phase I. Collier replaced the stock four cylinder Detroit Diesel 8.5 liter CNG engine in this 40 foot New Flyer bus with a specially adapted six cylinder Daewoo 11 liter HCNG engine also shown installed in Figure 11. The CATA bus stock fuel tanks were a hydrogen compatible composite design from Lincoln Composites and did not require replacement. Collier calibrated the Woodward engine controller for HCNG lean burn operation. It must be reprogrammed to switch between CNG and HCNG. The additional 2.5 liters of engine displacement compensates for loss of volumetric efficiency and power because of hydrogen in the HCNG fuel. Instead of extra EGR, this engine uses a lean burn strategy to reduce NOx and runs smoothly at equivalence ratios as low as 0.54 due to the wide flammability limit of hydrogen. In limited testing to date, the HCNG bus has demonstrated about 15% better fuel economy on the Blue Loop route than the stock CNG bus fuel economy of about 3.25 mpg gasoline equivalent (mpgge). Additional data collection on route and dynamometer testing are needed to gain a complete picture of HCNG engine performance. Doosan Infracore is establishing a new plant in Sparks Nevada to build a production version of this engine for the US market. The production engine will be CNG and HCNG capable. They plan to provide three sample engines to CATA for field trials in 2008. Each HCNG fueling of the bus requires about 9 kg of hydrogen. If three CATA HCNG buses are eventually fielded then they could consume 30 kg of hydrogen a day. This would require a second CNG compressor and more storage tanks to be installed at OPP.

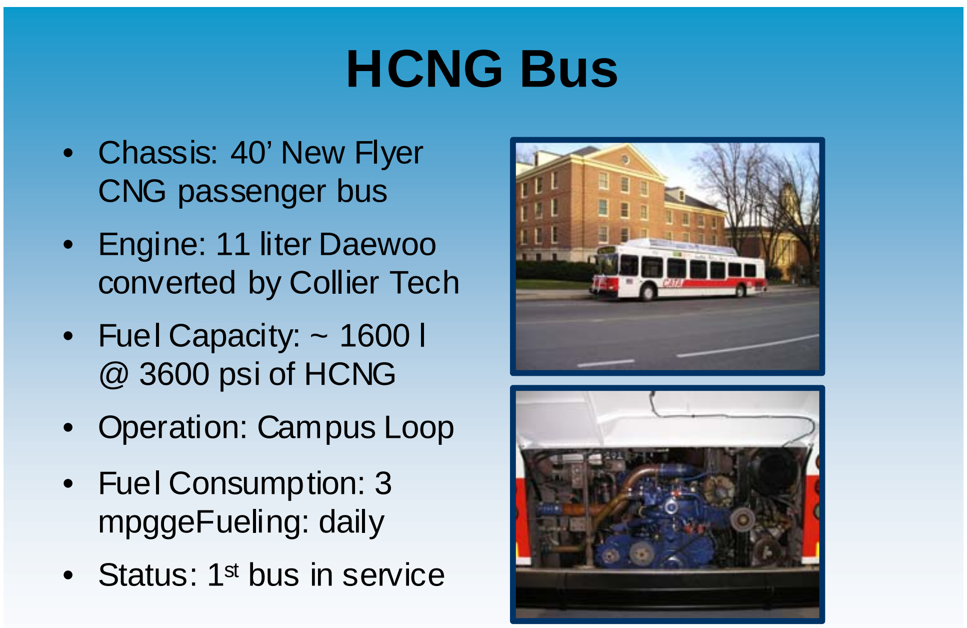

Figure 11: CATA New Flyer 40-ft Transit Bus

H_2ICE Hybrid Electric Vehicle

Hydrogen fueled internal combustion engines (H_2ICE) have demonstrated high efficiency and lower emissions. Ford Motor Company claims its hydrogen engine technology is about 25% more efficient [2] than gasoline. HHVRL faculty and graduate students are collaborating with Collier Technologies to adapt a Kawasaki utility engine, like the 90 degree V-twin engine shown in Figure 12, to run on hydrogen. A similar engine serves as the auxiliary power unit (APU) in the Penn State Electric Lion hybrid electric vehicle. This engine currently operates on propane. The Electric Lion is configured as a range extending series hybrid much like the GM Volt [3] concept vehicle. Electric Lion achieved 52 mpgge on a mixed highway/city course while placing first in the 1999

American Tour de Sol Range Event. An H_2ICE, Nickel Metal Hydride battery pack, and hydrogen fuel systems are currently being developed for the Electric Lion. Some of the engine modifications include a capacitive ignition system and modified propane induction mixer. Assuming a 10-20% increase in fuel efficiency with lean-burning hydrogen, the Electric Lion should demonstrate fuel efficiencies in the range of 58-65 mpgge.

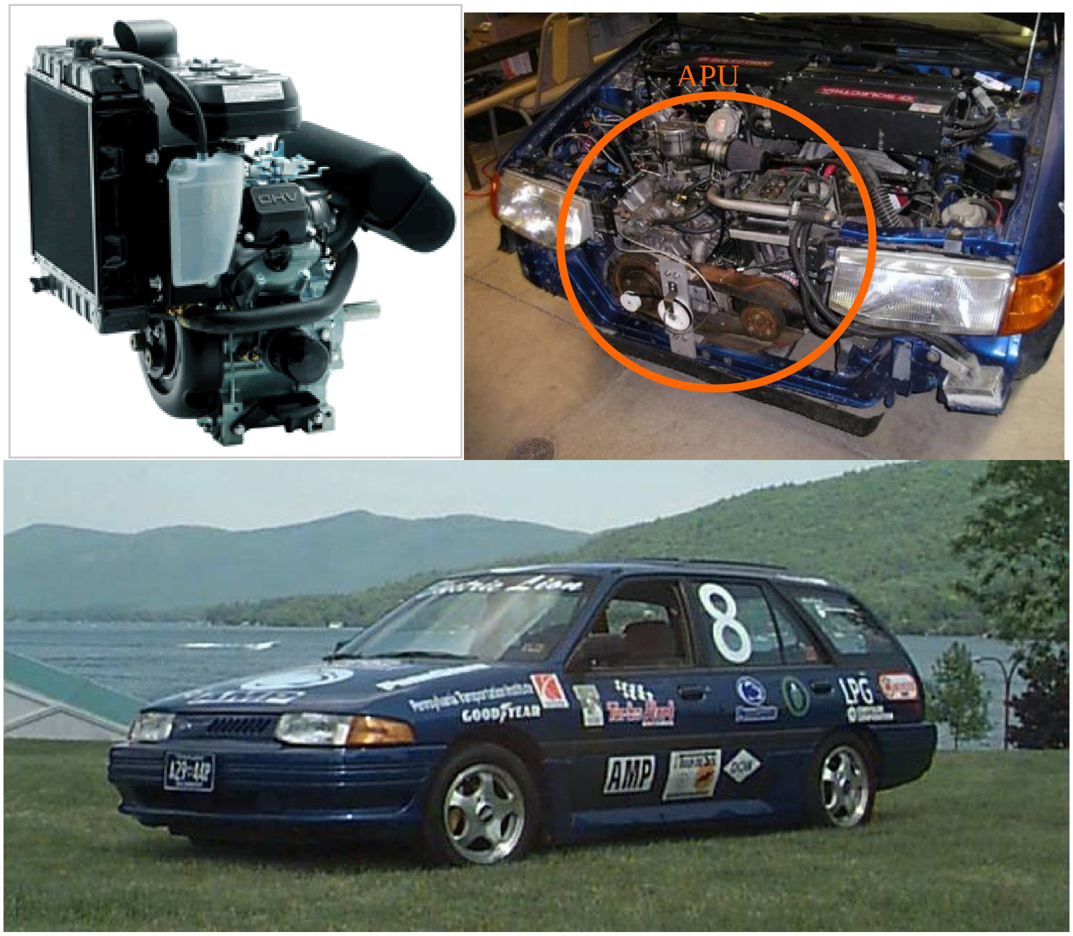

Figure 12: Kawasaki FD620D Engine (top left), series hybrid electric power-train (top right), Penn State Electric Lion Hybrid Vehicle (bottom)

Penn State Hydrogen Assisted Bio-Diesel Parallel Hybrid and Other Vehicles

Penn State competes in DOE Advanced Vehicle Technology Competitions. Their most recent entry in DOE Challenge X competition is a modified Chevrolet Equinox with a parallel hybrid electric power-train. The 1.3 liter TDI engine runs on bio-Diesel. The Penn State team developed a hydrogen assisted combustion system which mixes about 4% hydrogen (energy content) with induction air to improve emissions. This vehicle, shown in Figure 13, can fuel at the Penn State station as needed for development.

Figure 13: Penn State Challenge X Hybrid Vehicle

Other vehicles which have fueled at the Air Products hydrogen station while visiting Penn State include a Ford Focus FCV and hydrogen fueled Hummer® H2 Conversion built by Intergalactic Hydrogen.

Operating Experience of the Air Products Hydrogen Station

The hydrogen station has been in operation now since July 2005 and provided valuable field experience for both Air Products and Penn State. It has been very reliable and most problems have been solved quickly. The most common reason for shutdown has been electric power quality tripping station alarms. Early in the demonstration, winter temperatures caused moisture trapped in compressed air pilot lines to freeze. This led to installing a liquid nitrogen source for dry control gas and wrapping vulnerable lines and components with insulation and heaters. Dispenser touch screens have had brightness and clarity issues in direct sunlight and processor failures have resulted in upgrades. The most serious problem has been with vehicle receptacles. The HCNG vehicles have been using a 3600 psi hydrogen receptacle sized for passenger cars. The CATA bus has 1721 liter (453 gallon) tank capacity which results in long fill times that created significant frost and vibration damage within the receptacles. This has led to receptacle leakage and failure to seal when the fill nozzle is removed. Air Products and the HHVRL are in the process of switching the HCNG dispenser and all HCNG vehicles to a larger format dispenser nozzle and receptacle designed for hydrogen fuel cell buses.

Operating Experience of the HyLion FCV

The fuel cell and tank was the first system developed and installed in the HyLion and allowed test fueling of hydrogen at 350 bar as soon as the station became operational. As expected, other fuel cell vehicle systems have proven more complex and challenging, especially the field oriented three phase induction motor inverter. Our inverter is now operational but other systems are still under development. The battery management system and fuel cell voltage converter are designed but not yet installed. The EV1 brake controller is complex with both hydraulic ABS and regenerative braking on the front wheels and electric brakes on the rear wheels. We plan to have all these systems operational by summer 2008 which will allow the HyLion to safely drive on campus streets to the fueling station up to twice a day. It is currently transported by tow dolly to the fueling station. The real value to this hydrogen demonstration of developing such a complex system is that it lets engineering students and the visiting public peek under the hood at technology that may become common in fuel cell vehicles they may design and purchase in a decade or two.

Operating Experience of the HCNG vans

The HCNG van, in operation since October 2004, has proven to be very reliable. Van #618 has logged only 1200 miles to date on its on campus service route. The only significant maintenance problem has been occasional sticking of the EGR butterfly valve which has caused hard starting and engine stumbling. Collier Technologies is upgrading this design for the next six vans. Fixing this problem just requires occasional lubrication of the valve. A problem with engine knocking turned out to be high hydrogen concentration in the HCNG mixture caused by frozen moisture in the station HCNG blend skid controls. HCNG fleet vans could be a very cost effective and low risk option compared to fuel cell vehicles and or HCNG bus conversions for organizations considering their own hydrogen demonstrations.

Operating Experience of the HCNG Bus

CATA bus #85 has logged about 24,000 miles to date on the HCNG engine. After a long debug period, it began passenger service in June 2007 on CNG and August 2007 on HCNG fuel. Safety issues with the current HCNG receptacles have kept filling under direct engineering supervision. Therefore, the majority of service has been on CNG with HCNG service about once a week. This CNG service has been vital, however, to completely debug all vehicle systems. Transit service is an extremely demanding, harsh, and highly visible operating environment. A lot of time and effort was directed at achieving high reliability of the mechanical accessories (alternator, radiator fan, air compressors, air conditioning) and their belt drives which were unique to this prototype installation. A recurring problem has been failure of the fuel shutoff solenoid valves located on the engine fuel manifold. During debug, one of these solenoid valves failed partially open and created symptoms which indicated a problem with the engine controller or calibration parameters. Several valves have failed since. The engine has proven to be very reliable once these problems were resolved and well liked by the drivers for its extra power and quiet operation. HCNG it appears to run “smoother” and with less vibration and noise than CNG. A prototype engine installation on a transit bus or other heavy vehicle requires a longer development period than light vehicles because of the high reliability and severe service environment.

Data Collection

The scope of the data collection and distribution portion of the project was to develop and install on board the converted bus a system equipped with all necessary special communication hardware and protocol capabilities to communicate with the vehicle’s automotive subsystems. The system also needed to be able to filter, collect, store and communicate the accumulated vehicle information through a variety of wireless and wired communication channels off-board the vehicle in real-time or in batch operation mode. The schematic concept is depicted in Figure 14.

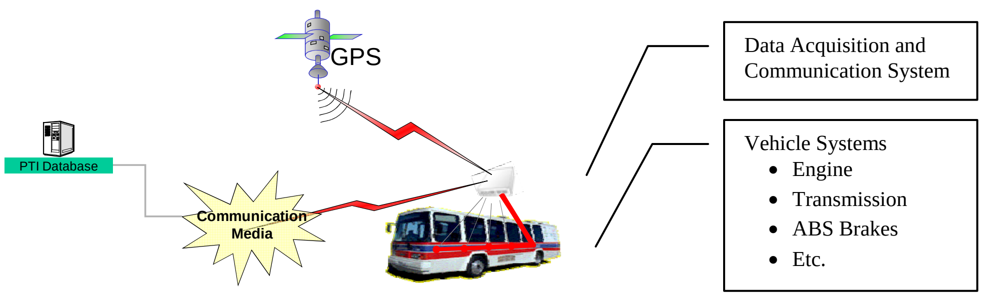

Figure 14: System Schematic

The developed Data Acquisition and Communication System consists of four basic modules:

- An integrated industrial I/O module for data gathering and control of the diverse modular CAN subsystems (J1939 and J1587).
- A wireless communication module. A GSM/GPRS mobile digital telephone with internet capability.
- A WLAN with Ethernet wireless communication module with 802.11b protocol capability.
- A small form factor industrial computer with powerful processing capacity and adequate infrastructure.

The system is packaged into a single rugged and small industrial package operating with voltages between 9V and 36V that is easy to power and install in vehicle. (see Figure 15)

Figure 15:. Data Acquisition and Communication System

The Data Acquisition and Communication System in Figure 15 is currently deployed in the HCNG bus and is collecting data. The system uses the available digital vehicle network data buses J1939 and J1587 and additional installed performance sensors like temperature together with GPS-location to collect performance data onboard the bus during in-service operation. The system was tested in relaying data through Wi-Fi (802.11b) communication and wired Ethernet channels and is undergoing testing in delivering collected data through it's built in GSM – GPRS communication interface. The use of the Wi-Fi and GPRS communication means it will enable real-time or near real-time data transfer from the in-service vehicle. This system will gather extensive operational data during 2008 under various operating conditions for analysis in the final demonstration report.

6. Conclusions and Future Work

The hydrogen station and fleet demonstration at Penn State has succeeded due the strong cooperation among its partners and the community at large. Outcomes to date include:

- Several types of hydrogen vehicles deployed including fuel cell, HCNG, H_2ICE
- Unique field experience gained with on-site methane reformer and HCNG mixing
- Large hydrogen vehicles do require large format receptacles for frequent fueling
- HCNG appears to be a reliable, fuel efficient, safe, clean, and cost effective bridging technology for hydrogen vehicle and infrastructure market penetration
- Universities are excellent venues for hydrogen demonstrations encompassing research, education, outreach, technology transfer, transit and fleet operations

With an operating station and small fleet established, future work includes deployment of larger numbers of hydrogen vehicles along with gathering and reporting long-term data on hydrogen station and fleet performance. Funding will be sought to continue and expand the hydrogen fleet along with industry participation to demonstrate production fuel cell vehicles and collaborate on related research.

7. References

1. Fueling Interface Details Information, California Fuel Cell Partnership, IOSpecRev_010203_Public to Send.doc, August 5, 2002.
2. H2RV – Ford Hydrogen Hybrid Research Vehicle, www.Ford.Media.com, August 10, 2003.
3. http://www.chevrolet.com/electriccar/