ESTCP
Cost and Performance Report

(WP-200402)

Optimizing Infrastructure for Hydrogen Fuel Cell Vehicles (FCV)

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ESTCP

ENVIRONMENTAL SECURITY
TECHNOLOGY CERTIFICATION PROGRAM

U.S. Department of Defense

COST & PERFORMANCE REPORT
Project: WP-200402

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ACRONYMS AND ABBREVIATIONS

ASME	American Society of Mechanical Engineering
BTU	British Thermal Unit
CH_4	methane
CNG	compressed natural gas
CO	carbon monoxide
CO_2	carbon dioxide
Cr	chromium
CSD	compression storage and dispenser
DLA	Defense Logistics Agency
E-85	Ethanol (85%) Blend in Gasoline (15%)
EA	environmental assessment
ESTCP	Environmental Security Technology Certification Program
EV	electric vehicle
Fe	iron
FCV	fuel cell vehicle
GREET	Greenhouse Gas, Regulated Emissions, and Energy Use in Transportation
H2	hydrogen
HC	hydrocarbons
MCB	Marine Corps Base
MPG	miles per gallon
N_2	nitrogen
NAVFAC EXWC	Naval Facilities Engineering and Expeditionary Warfare Center
NEPA	National Environmental Policy Act
NFPA	National Fire Protection Association
Ni	Nickel
NO_x	Oxides of Nitrogen
PSA	Pressure Swing Adsorption
SAE	Society of Automotive Engineers
SO_x	Oxides of Sulfur
SWRFT	Southwest Region Fleet Transportation
UL	Underwriters Laboratory
VOC	volatile organic compound

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ACKNOWLEDGEMENTS

We want to thank the Environmental Security Technology and Certification Program (ESTCP) for funding this project.

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EXECUTIVE SUMMARY

Environmental Security Technology Certification Program (ESTCP) Office funded the demonstration of an on-site hydrogen production technology for fuel cell vehicle (FCV) applications. Hydrogen production and delivery are key barriers to FCV implementation. Compact steam methane reformer offers advantages due to the abundant supply of natural gas and existing pipeline infrastructure. Naval Facilities Engineering and Expeditionary Warfare Center (NAVFAC EXWC) was principal investigator for the demonstration.

This demonstration project field tested a compact version of a traditional steam methane reformer. The reformer is a sub-component of the larger fuel processor. The reformer converts steam and natural gas into hydrogen (H_2), carbon dioxide (CO_2), and carbon monoxide (CO). Competing variations of the reformer offer quicker startup and improved load following. High energy efficiency remains an advantage of traditional steam methane reformers.

Commencement of the field demonstration began with the manufacturer delivering a new reformer to Marine Corps Base (MCB) Camp Pendleton in January 2010. The project team subsequently took steps to install, commission, and startup the reformer. The team conducted emission testing in February 2010. Permanent system integration efforts followed and included setup of the utility connections, controls, and compressor staging. Integration efforts concluded in June 2010. Startup testing occurred between July 2010 and December 2010.

Reformer testing included intermittent start-up and short term operation. Operating events were at most 3 days, a fraction of the 1000 hour objective. Lack of integrated controls was an underlying factor resulting in shutdowns. Automated feedback controls would have helped extend operating time while minimizing the need for operator attention to achieve emission, efficiency, reliability, and durability objectives. The following paragraphs identify and discuss the results for each performance objective.

Army's Aberdeen Test Center Emission measured emissions while the reformer operated at 25 and 50 percent of full capacity. Emissions at these loads met the objectives for CO_2, nitrogen oxides, and sulfur dioxide. The system failed to meet emission objectives for CO and methane (CH_4). Also, the reformer could not operate for sustained periods necessary to complete 75 and 100 percent load testing.

The team collected pre-commissioning samples from the reformer to evaluate hydrogen quality. Pre-commissioning samples met fuel quality objectives. With the exception of water, contaminants were below the Hydrogen Quality Guidelines in Society of Automotive Engineer (SAE) J2719.(SAE, 2011) The manufacturer hypothesized delivery in rainy weather as the source of water in the samples.

System performance objective was 65 percent reformer efficiency. Efficiency is determined as the ratio of hydrogen energy (output) divided by natural gas energy (input). Efficiency is a primary benefit of on-site reformation relative to competing hydrogen delivery technologies. Reformer test runs were well below the objective loads and duration necessary to draw conclusions on efficiency.

The demonstration objectives included the monitoring of hydrogen leaks to the atmosphere. The team could not evaluate losses from the reformer due to lack of operation. For the balance of station, the compressor was the primary source of leaks, and resulted from component failures. Hydrogen losses from the compressor did not present a safety issue, as the release point was from the elevated vent, above the other equipment. Routine leak checks indicated losses from the piping were very small.

The system failed to meet the performance objective for reliability. The project team executed numerous startups and short term operating events. System operation ranged from several hours to 3 days. The system could not operate steadily for an extended period of time. As a result, the system came nowhere near the 80 percent reliability objective over the 1-year testing period.

As noted above, total operating time for the reformer was minimal, and insufficient to evaluate the durability objective. Durability is of interest as each start up and shut down action expands and contracts the vessel and tubes, which contributes to eventual material failure. Given this, low reliability will shorten the useful life of the reformer.

The reformer fell short of the maintainability objective. Initially, the team envisioned routine service on a quarterly basis for the replacement of consumables. The performance objective was five or fewer trouble calls assuming steady operation over one year. Under actual use, the reformer could not reach steady operating status. This was due to inherent controls design as opposed to system durability.

No significant safety incidents occurred during test period. The quantitative objective included four or fewer hydrogen leaks, all below 10 percent of the lower explosive limit concentration. Personnel noted a potential burn danger near the reformer's stack. Stack insulation, personnel safety gear, and personnel caution will help mitigate the risk of burns. Also, the fire safety panel issued several false alarms. Routine servicing will help avoid false alarms and will help ensure the panel operates to manufacturer specifications.

No trespassing or vandalism occurred during the testing period. As a result, the station met the performance objective for security. Factors promoting security include: (1) routine daily use by the Marine Corps test team; (2) daily contractor occupation of the adjacent maintenance facility; (3) locking of the gate entrance outside normal working hours; and (4) periodic patrols by the military police and railway authority personnel.

Overall, the reformer requires further development to be field ready. From a user perspective, the system did not meet the expectations for modular installation, quick startup, unattended operation, and hydrogen quality. Each aspect requires further engineering and development before the system can be expeditiously installed, commissioned, and operated on a routine basis.

1.0 INTRODUCTION

1.1 BACKGROUND

Use of conventionally fueled automobiles with internal combustion engines continues to pollute the environment and consume resources at an alarming rate. New automotive technologies have reduced emissions of criteria pollutants such as volatile organic compounds (VOC), oxides of nitrogen (NO_x), and carbon monoxide (CO) on a per mile basis. However, as shown in Figure 1, the total miles traveled continues to increase. As a result, many urban areas still suffer from substantial air pollution problems that are directly linked to vehicle emissions. Hydrogen fuel cell vehicles (FCV) are a revolutionary new transportation technology with significant emission reduction benefits over existing internal combustion engine technology. FCVs have zero emissions at the tailpipe. The method for producing and delivering hydrogen to FCVs will determine the feasibility of implementing a FCV program as well as the overall environmental benefits. This project demonstrated a steam methane reformer as one approach to on-site production of hydrogen at a military installation.

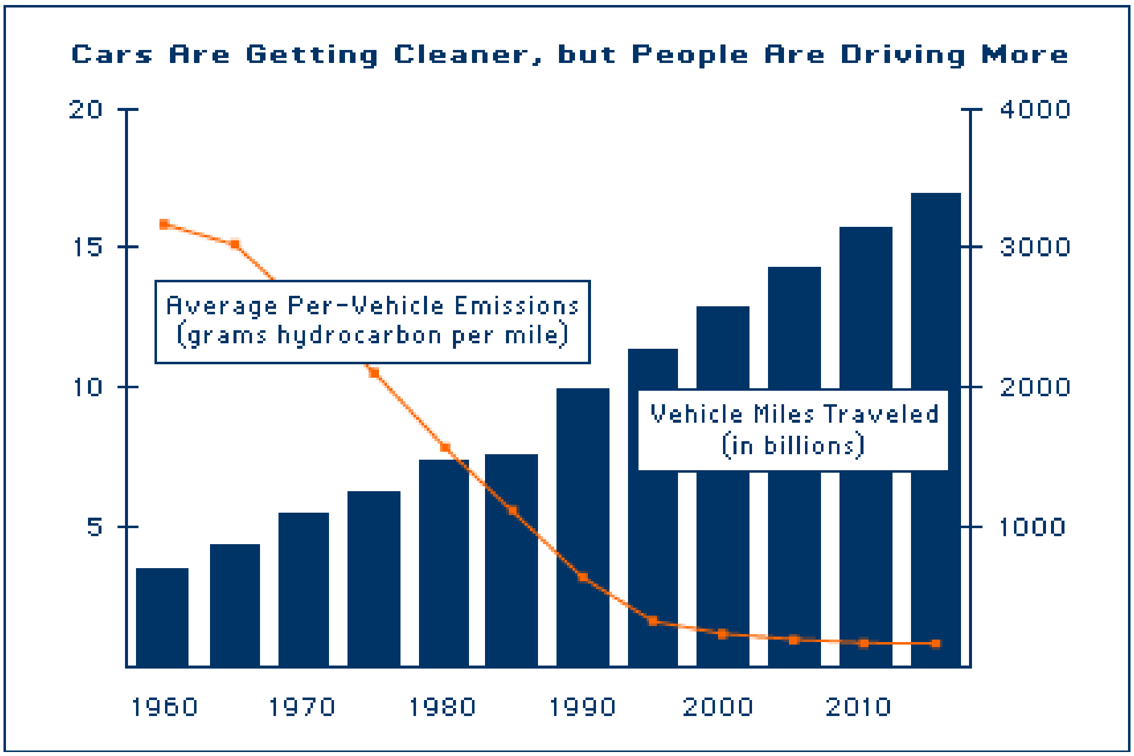

Figure 1. Annual vehicle miles traveled versus annual vehicle emissions. (U.S. Environmental Protection Agency.)

1.2 OBJECTIVES OF THE DEMONSTRATION

Field validation objectives under this project included the station's criteria emission testing and assessment of overall process efficiency. Primary criteria emissions testing included NO_x and CO. Data collection objectives also included monitoring of other solid and hazardous waste streams, durability, reliability, safety issues, efficiency, and hydrogen losses. This type of data allows for comparison with other conventional and alternative fuel vehicles. In addition, the project was to provide hydrogen for initial testing of the demonstration FCVs.

1.3 REGULATORY DRIVERS

Federal, state, and local governments have passed initiatives requiring the use of clean burning alternative transportation fuels. Section 782 of the Energy Policy Act is specific to hydrogen, having directed the Federal agencies to lease and purchase FCVs and hydrogen systems by January 2010 (Energy Policy Act, 2005). Executive Order 13149 required federal agencies to exercise leadership in the reduction of petroleum consumption through the use of alternative fuels and more fuel-efficient vehicles Executive Order 13149, 2000). Navy Environmental Policy Memorandum 98-05 requires that all new vehicles be capable of operating on alternative fuel (U.S. Navy, 1998).

2.0 DEMONSTRATION TECHNOLOGY

2.1 TECHNOLOGY DESCRIPTION

Industrial sized equipment for reforming natural gas has been in use for several decades. Compact reforming equipment is similar in concept to industrial size reformers but has modifications to allow lower cost materials. Primary components include sulfur removal, steam reforming, water gas shift, and pressure swing adsorption (PSA), as shown in Figure 2. The reformer, shift reactor, and PSA are collectively known as the fuel processor. Post processing equipment includes the hydrogen compressor storage and dispenser (CSD). CSD equipment is very similar to that used for compressed natural gas (CNG) vehicle applications, with modifications to compensate for higher pressures and hydrogen's physical effects on certain materials.

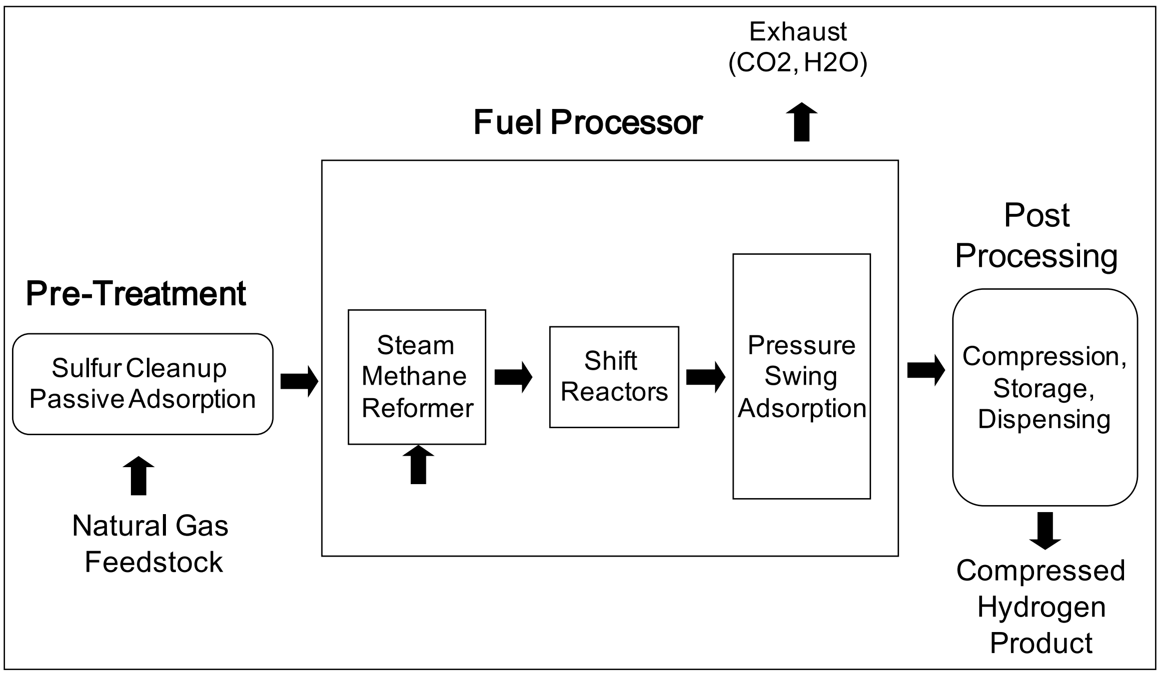

Figure 2. Hydrogen production process flow chart.

The reforming process converts natural gas to syngas. Syngas from the reformer contains primarily hydrogen, carbon dioxide (CO_2), and CO. Industrial reforming chambers react the natural gas and steam in long catalyst-filled tubes. Reaction chambers must be made of temperature and pressure resistant materials such as nickel alloys. Designers have designed compact reformers in stacked plates or concentric cylinders coated with catalyst. The reforming process requires a heater to generate steam. The heater is fueled with natural gas and tail gas from the PSA unit. Low NO_x burners are common in the heater design in order to minimize emissions. Table 1 lists reformer waste streams.

Table 1. Waste generation for reformer-based hydrogen fuel station.

Station Subsystem	Input Stream	Output Stream	Waste Streams
Gas Pretreatment System	Pipeline Natural Gas	Desulfurized Natural Gas	Spent Sulfur Adsorbent, Natural Gas Leaks
Fuel Processor	Natural Gas, Water	Low Pressure Hydrogen	**Exhaust:** CO_2, H_2O, Trace CO, HCs, NO_x, H2 **Leaks:** Natural Gas, H2 **Condensate:** Trace Fe, Ni, Cr, HC
Post Processing	Low Pressure Hydrogen	Compressed Hydrogen	**Leaks**: H_2

This project demonstrated a compact version of a traditional steam methane reformer. Table 2 lists primary design criteria for this demonstration project. Although competing variations offer quicker startup and better load following performance, traditional steam methane reformation is expected to provide higher efficiency. A popular variation is known as Autothermal reforming, and oxidizes a part of the methane in the reformation process in lieu of an external water heater. The downside of Autothermal reforming is nitrogen stream dilution, which burdens the hydrogen separation process. Energy conservation initiatives and the opportunity for integration with a stationary fuel cell favor the steam methane technology.

Table 2. Primary design criteria for compact hydrogen fuel processor (1/10 scale demonstration unit).

Parameter	Design Value
Hydrogen Output	10 kg per day
Hydrogen Purity	99.99 % (minimum)
Natural Gas Consumption (Full Load)	67 cubic feet per hour
Water Requirement	2 gallons per hour
Electrical Requirement	3 Kilowatts
Footprint	8 feet by 12 feet (maximum)

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

Advantages of on-site steam methane reforming include competitive operation and maintenance cost, low criteria emissions, high efficiency, and available distribution infrastructure. Operation and maintenance costs are primarily related to utilities (natural gas and electric) and minor equipment maintenance. There are no costs or emissions associated with truck deliveries. Efficiencies can approach those of a central reformer, especially when considering a combined stationary power project with waste heat recovery. Finally, the extensive natural gas pipeline infrastructure supplies the majority of military installations throughout the continental U.S. Availability of a modular reforming system could allow quick implementation throughout Department of Defense without the need for additional distribution infrastructure or new power plants.

3.0 PERFORMANCE OBJECTIVES

3.1 PERFORMANCE OBJECTIVES

Table 3 lists the performance objectives for the hydrogen refueling station based on the steam methane reformer. Actual performance results are indicated in the table and briefly discussed in the paragraphs below.

Table 3. Performance objectives.

Type of Performance Objective	Primary Performance Criteria	Expected Performance (Metric)	Actual Performance
Quantitative	1. Air emissions	CO < 20 ppm NO_x < 20 ppm SO_x < 10 ppm HCs < 250 ppm H2 < 10 ppm CH_4 < 200 ppm CO_2 < (10 lbs/ lb H2)	CO < 1000 ppm NO_x < 14 ppm SO_x < 3.5 ppm HCs < 45 ppm ND CH_4 < 2511 ppm ND
	2. Hydrogen Purity	99.99% CO < 2 ppm S < 2 ppm High MW HCs < 40 ppm Diluents <1000ppm	> 99.995% CO < 0.001 ppm S < 0.001 ppm HCs < 0.06 ppm Diluents < 20 ppm
	3. Efficiency	> 65%	No Long-Term Operating Data
	4. Hydrogen Losses	< 3% H_2 (110 kilograms/year, assuming 3600 kilograms/year hydrogen production)	No Long-Term Operating Data
	5. Reliability	>80%	No Long-Term Operating Data
	6. Durability (Vehicles) Fuel Cell Stack Life Span	>60,000 miles <2 cell failures per year	*Specific Data Not Available
	7. Durability (Station)	Two or fewer unscheduled equipment failures, maintain catalyst over dem/val period.	No Long-Term Operating Data
	9. Maintenance	Less than five user trouble calls over dem/val period.	12 trouble calls
	10. Safety	Leaks: <1 per quarter, All Leaks < 1/10 lower explosive limit of hydrogen, No fires or safety incidents	11 minor leaks detected using bubble solution and hydrogen leak detector. There were no station safety incidents
Qualitative	1. Security and Site Control	Prevent Unauthorized Access and Vandalism	No Unauthorized Access Noted
	2. Solid and Hazardous Waste	< 1 kilogram spent adsorbents per 100 kilogram fuel produced No waste disposal issues	No Long-Term Operating Data

*The fuel cell vehicle manufacturer was directly in-charge of the vehicle maintenance.

3.2 SUMMARY OF ACTUAL PERFORMANCE

Inability to achieve continuous steady operation over the objective test period impacted the overall demonstration. This factor prevented full assessment of parameters related to on-going operation, namely reliability, durability, and efficiency. The shortcoming related to "start-ability" was not represented in the table as a performance factor.

Air Emissions: This objective evaluates: (1) compliance with local air permitting requirements, and (2) benefits relative to the baseline technology. Measured emissions for CH_4 and CO exceeded the performance objectives for all loads. Importantly, the reformer was not in its final steady operation configuration during the testing. Lack of warm-up time and greater levels of reformate being directed to the heater are potential factors that contributed to the higher emissions.

Hydrogen Purity: Output hydrogen product must be ultra-high purity to prevent damage to vehicle fuel cell systems. Threshold values are based on the automotive industry's interim specification (SAE, 2011) J2719.[6] Initial laboratory testing confirmed the hydrogen product complied with SAE J2719. This result includes the first of four on-site samples collected from the reformer. The final three samples were not collected as the system did not reach steady operation.

Efficiency: Efficiency determines the economic and environmental benefits of the steam methane reformer relative to competing hydrogen fuel production and delivery technologies. Efficiency is defined as the ratio of hydrogen energy (output) divided by natural gas fuel (input). Objective efficiency was 65 percent, and was selected based on a combination of Department of Energy Technology Targets and manufacturer claims. Due to the limited testing, data is insufficient to draw conclusions regarding efficiency of the steam methane reformer.

Hydrogen Losses: Hydrogen losses factor into system efficiency and safety. For system efficiency, losses determine whether enhanced materials or revised operating procedures would benefit the overall efficiency. Data was insufficient to draw conclusions quantifying the hydrogen losses. Leaks in the piping were very small. Larger leaks were detected during compressor system failure that resulted in excess hydrogen venting.

Reliability: This performance objective measures system uptime and availability, and is critical from the user perspective. The reformer's limited operation was insufficient to draw conclusions for long-term reliability. The system experienced issues during start-up, testing, and commissioning. This suggests that the system, in its current state, requires daily attention to operate and maintain.

Durability (Vehicles): System durability characterizes tendency of aggregate parts and components to operate without wear, failure, or malfunction. The manufacturer maintained the test vehicles under the lease arrangement, including close monitoring, observation, and servicing in the event of a failure. The generation of the fuel cells required periodic servicing and repairs.

Durability (Station): Data is insufficient to make a determination for the entire station (i.e., including the reformer). While the compressor exhibited operational problems during the testing period, the project team later contracted a hydrogen company for monthly inspection and service visits. These routine visits helped identify impending maintenance issues and prevented unexpected failures and related trouble-calls. Data is insufficient to evaluate durability of the reformer.

Maintainability: This determines servicing required to keep the system in operation, and is indicative of long-term operation cost and reliability. Due to a lack of continuous operation, data was insufficient to assess long term durability of the reformer. The hydrogen compressor was responsible for the majority of trouble calls and downtime. Once establishing a monthly maintenance contract, the station maintained an acceptable level of reliability. Without the maintenance, the system failed or malfunctioned approximately once per quarter.

Safety Incidents: Safety issues are defined as incidents where there was a fire or equipment accident, including hydrogen leaks greater than one-tenth the lower explosive concentration limit for hydrogen. No related incidents occurred while the station operated independent of the reformer, or during reformer testing. The project team noted dangers involving the reformer high temperature stack, which must be insulated or otherwise protected to avoid accidental burns.

Security and Site Control: This objective evaluates whether the station fencing, access, and monitoring were sufficient to prevent any intrusions or vandalism. No noted issues related to trespassing or vandalism occurred during the testing period. Based on this result, the station met this performance objective.

Solid and Hazardous Waste: Testing was to monitor waste streams to quantify management and disposal cost. The performance metric selected is based upon manufacturer estimates and user perspective of acceptable levels. Operating data were insufficient to evaluate conformance with the performance objective.

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4.0 SITE/PLATFORM DESCRIPTION

4.1 TEST PLATFORM/FACILITIES

The U.S. Department of Defense (DoD) facility selected for this dem/val project was Marine Corps Base (MCB) Camp Pendleton. At the outset of the demonstration, the site had 1561 non-deployable vehicles. Vehicle types included light and heavy vehicles supporting a range of industrial and administrative applications. Host command, Southwest Region Fleet Transportation (SWRFT) has extensive experience with alternative fuels, and just under two decades of CNG vehicle operations. Approximately one-half the fleet operated on CNG or biodiesel. Partnerships with the local gas supplier led to the installation of five CNG stations that supply 379 vehicles on-base. Recent developments include an on-post E-85-dispensing facility operated by the Navy Exchange, and deployment of full size battery-electric and diesel hybrid trucks. One advantage of this experience is that fuel systems on-board the vehicles and at the compressor stations are similar to those required for hydrogen. Both are gaseous fuels at ambient conditions and their dispensing systems are also very similar.

4.2 PRESENT OPERATIONS

FCVs in this demonstration fall under the light duty vehicle class (i.e., 8500 pound gross vehicle weight or less). Liquid fuels (i.e., gasoline and ethanol/gasoline blends) power the majority of Camp Pendleton's light fleet vehicles in this weight category as shown in Figure 3. Natural gas powers a smaller legacy fleet that is experiencing a downward trend due to automaker focus on flex-fuel and hybrid electric models. Approximately 13% of the light vehicle fleet is capable of operating on an ethanol blend (i.e., E-85, or an 85% ethanol and 15% gasoline). The E-85 fleet has expanded due to continued vehicle model availability and low incremental costs.

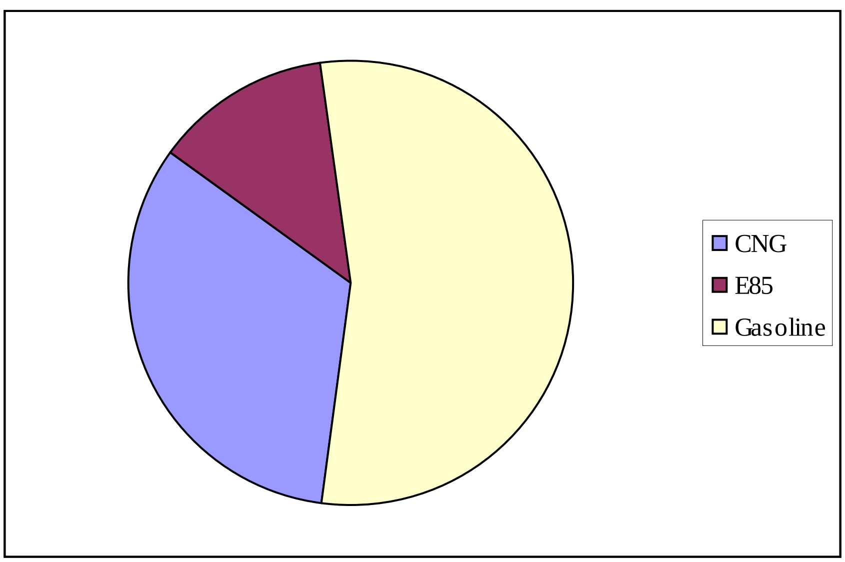

Figure 3. Light vehicle fleet composition at MCB Camp Pendleton.

4.3 SITE-RELATED PERMITS AND REGULATIONS

National Environmental Policy Act (NEPA) is the overarching requirement for new projects on a federal installation (NEPA, 2011). The designated level of NEPA study is contingent upon the potential impact to operations or existing land use on the facility. After several working meetings, MCB Camp Pendleton environmental determined an environmental assessment (EA) was necessary. The basis for the EA determination included: (1) the project set a precedent for future activities; (2) the project site differed from existing land use; and (3) the project required full assessment of impact on public safety.

Naval Facilities Engineering and Expeditionary Warfare Center (NAVFAC EXWC) contracted for EA study support and held a kickoff meeting with the MCB installation working group in December 2004. The EA focus areas included safety, security, utility connections, land use, maintenance, and signature authority. The Base Commanding General approved the final EA document and signed a Finding of No Significant Impact letter in September 2005. Based on stakeholder input, the EA included the following required actions resulting from focus area discussions.

- **Safety:** In order to maintain a conservative setback distance from nearby buildings, the EA specified that maximum on-site hydrogen storage not exceed 60 kilograms. The basis for this determination assumed a single storage vessel at or above 7500 psi (525 megapascal [MPa]). This threshold was selected to minimize risk to personnel in nearby occupied buildings.
- **Security:** In order to support future public access initiatives, the permitted site is beyond the controlled area of the base. Environmental Impact Review Board members requested video camera monitoring to supplement security patrols. Monitoring provisions included cameras at the maintenance facility aimed at the front gate and parking area and toward the hydrogen station.
- **Excavation:** All trenching and excavation must have oversite of a qualified archeological personnel. The archeological personnel observed and monitored trenching for any potential archeological remains or significant artifacts.
- **Maintenance:** The Environmental Impact Review Board members requested the Cooperative Research and Development Agreement include station maintenance provisions to minimize downtime and to promote safe operation.
- **Public Access:** The transition to California Hydrogen Highway operation requires partners to further coordinate and develop a real estate agreement, safety procedures, and site access provisions with MCB Camp Pendleton stakeholders.

NEPA review evaluated the gaseous, liquid, and solid waste streams resulting from the station. No permits were required due to the low levels anticipated.

Vendor claims indicated criteria air pollutant emissions to be very low. However, new host sites must be sure to confirm exhaust levels through emission testing. Based on manufacturer suggested maintenance, the water deionization and natural gas desulfurization systems produce a small amount of solid and hazardous wastes. Product water from the reformer system will have been treated and is expected to be cleaner than the inlet potable water stream. For this reformer, the manufacturer modified the system so that water recycles back into the system. Installation of this system has considered the following environmental regulations:

Clean Air Act.

Air Permit. Coordination with environmental and facilities personnel at the host site identified no specific permitting requirements outside of installation procedures. Meetings with the MCB Camp Pendleton's air quality officials and San Diego Air Pollution Control District concluded the demonstration unit did not require an air permit based on vendor emission estimates. The Air Pollution Control District personnel suggested the team apply for a certificate of exemption to avoid possible questions during compliance inspections.

Risk Management Plan. Host site air quality officials also investigated Risk Management Plan requirements for hydrogen storage. The accidental release prevention program approved under Section 112 (r) of the Clean Air Act mandated under California's Accidental Release Prevention program dictate federal and state Risk Management Plan requirements based on "threshold quantity." Proposed maximum hydrogen storage for this project (i.e., 220 pounds or 100 kilograms), as well as mass storage requirements for full-scale implementation, are well below the hydrogen threshold quantity of 10,000 pounds (4536 kilograms).

Clean Water Act.

Storm Drain Impacts. With the actual amount dependent on climate conditions, an estimated one-half liter of water vapor condenses and drips from the reformer each day. The dripping amount might increase to more than a gallon with a full scale system, depending on climate conditions. Though the condensate is cleaner than the potable feed water, base environmental personnel requested a control or a sewer connection. For this demonstration, the project team opted to reuse the condensate as discussed under the environmental checklist. Sending condensate to the sewer would require pumping of the condensate 800 feet to the nearest sewer drain. Other options considered were evaporation and container plant irrigation.

Resource Conservation and Recovery Act. Solid waste streams include adsorbents from the sulfur removal and water treatment systems. Under the current project scope, site technicians would return saturated adsorbent to the manufacturer for recharging.

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5.0 TEST DESIGN

Table 4 lists the methodology used to test the hydrogen fueling station and the steam methane reformer. Objectives of the testing included an evaluation of emissions depicted in Figure 4. Note that due to the reformer not reaching steady operation, the demonstration fell short of collecting data indicated for several categories in the test design. Additional discussion is provided below the table.

Table 4. Performance confirmation methods.

Performance Criteria	Performance Objective	Methodology
Air Emissions	CO Emissions < 20 ppm NO_x Emissions < 20 ppm SO_x Emissions < 10 ppm HC Emissions < 250 ppm	Emission Test (On-site source testing with real-time On-road vehicle emissions reporter system)
Hydrogen Purity	Diluents (Ar, CO_2, CH_4, C2H6, N_2, O_2) less than 1000 ppm Helium CO concentration < 2 ppm High MW HCs < 40 ppm Sulfur concentration < 2 ppm Formaldehyde, Formic Acid, Ammonia Halogenates	Analytical Laboratory Testing
Reliability	>80% Operation	Maintenance Log
Durability	< 2 or fewer mechanical failures Maintain catalyst over dem/val	Maintenance Log (CSD data only; reformer did not reach steady operating state)
Maintainability	<5 trouble calls over dem/val	Maintenance Log
Losses	< 3% losses	Fuel Metering: (No data; reformer did not reach steady operating state).
Efficiency	System Efficiency > 65%	Estimation only for comparison with other technologies. (No data; reformer did not reach steady operation)
Safety	Fuel Leaks Identified < 1 per qrtr All Leaks < 1/10 Lower Explosive Limit H2 No Safety Incidents	Safety Log
Site Security	Prevent Unauthorized Access and Vandalism	Maintenance Log
Solid and Hazardous Waste	< 1 kg spent adsorbents per 100 kg fuel produced No waste disposal issues	Maintenance Log (No data; reformer did not reach steady operation)

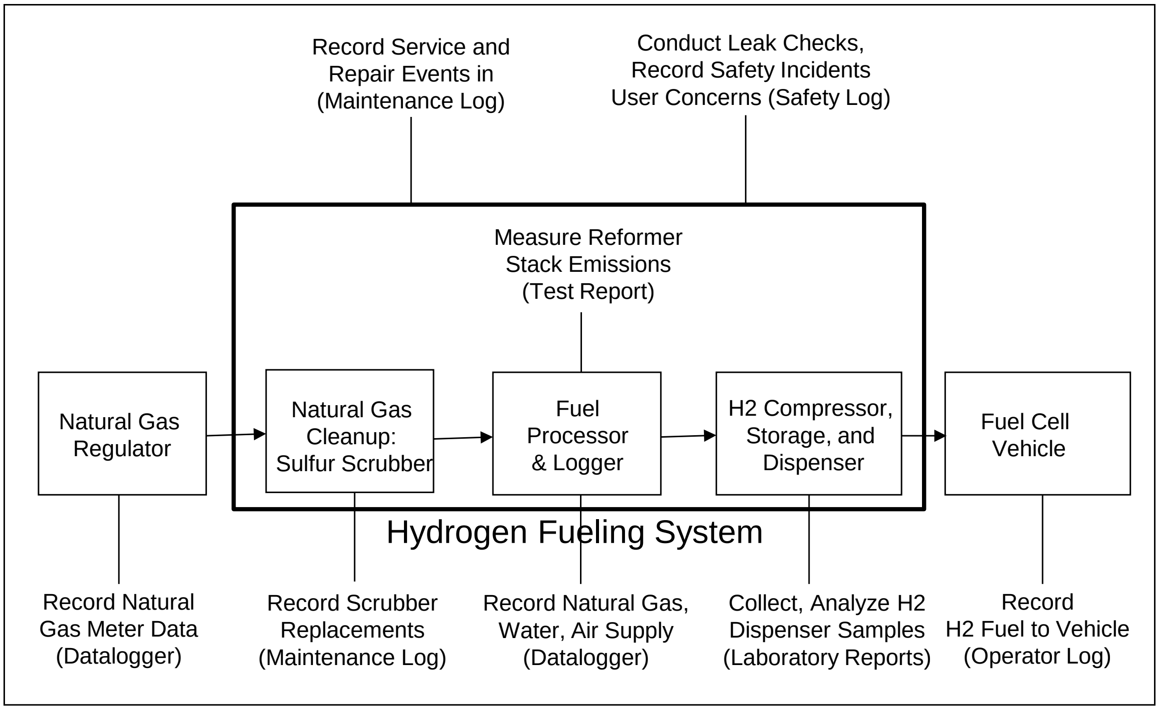

Figure 4. Experimental design.

Air Emissions

A team from the Army's Aberdeen Test Center Emission deployed emission analysis instrumentation and personnel to Camp Pendleton to conduct emission testing. Testing included three 30-minute sample collection runs from the reformer's exhaust stack each while the system operated at 25, 50, 75 , and 100 percent.

Hydrogen Purity

The project team conducted both baseline and initial production samples. Baseline purity testing included validation of the cleanliness of the hydrogen CSD and interconnecting piping. Local gas suppliers provided baseline hydrogen (i.e., ultra-high purity quality) in six-pack carriages. The project team also sampled initial product hydrogen from the reformer. Reference hydrogen standard was SAE Interim Specification SAE-J2719: Hydrogen Quality Guidelines for Fuel Cell Vehicles. Table 5 lists procedures for analyzing and reporting on the collected hydrogen samples.

Table 5. Hydrogen quality testing methods.

Constituent	SAE J2719 Limits µg/Mol	American Society of Testing & Materials Method
Water	5	D7649[8]
Total Hydrocarbons	2	D5466[9]
Oxygen	5	D7649
Helium	300	D7649
Nitrogen, Argon	100	D7649
Carbon Dioxide	1	D7649
Carbon Monoxide	0.2	D7649
Total Sulfur	0.004	D7652[10]
Formaldehyde	0.01	D5466
Formic Acid	0.2	D5466
Ammonia	0.1	D5466
Total Halogenates	0.05	WK34574[11]

Hydrogen Losses

Determination of losses through pipeline leaks is accomplished by conducting a mass balance on hydrogen exiting the reformer and hydrogen dispensed to the vehicles. Data from the meters is not available given the reformer did not reach steady operation.

Reliability, Durability, and Maintenance

Operational monitoring enables the assessment of maintainability of the reformer. NAVFAC EXWC kept records of maintenance activity conducted at the station in the on-site log book. This includes date, time, and work description. The team also kept records of the contractor labor cost for the on-going maintenance.

Efficiency

Demonstration plan for assessment of the reformer and overall fuel cycle efficiency required measurements on consumption of natural gas, electricity, hydrogen dispensed, and miles driven. The measurements were not captured as the station did not reach steady operation.

Safety

The project team monitored safety concerns through on-site evaluations and logging of incidents in the on-site logbook. An independent consultant conducted a safety review of processes for the reformer and balance of station. In addition to the safety review, Los Alamos National Laboratory conducted an independent audit of the station's equipment and piping to determine compliance with regulatory codes.

Security and Site Control

This aspect of the testing included monitoring and observations by the project team. Data of interest includes any unauthorized access or vandalism reports. This was accomplished through periodic discussions with the FCV operation and maintenance team (i.e., SWRFT and the FCV manufacturer) and logging of any incidents observed or reported.

Solid and Hazardous Waste

The reformer waste generation includes the sulfur adsorbent for the natural gas cleanup and water deionization. There was no data to collect on waste generation, as the reformer did not reach continuous operation.

Reformer Integration

Following initial emission testing, the team worked to fully integrate the reformer at the site. This included permanent utility connections required by National Fire Protection Association (NFPA) 70. This requirement limited quick start-up, and necessitated moving the switch controls outside the National Electric Code Class 1 Division 2 Zone (NFPA, 2008). The zone includes the area within 10 feet horizontally from the hydrogen reformer. All equipment within this zone must be non-arcing and explosion proof given the presence of hydrogen gas in the operations.

Well-to-Wheels Assessment

Investigators will compare emissions from FCVs with emissions from other alternative fuels by a conventional model. The analysis assumes a fully commercial and optimized reformer. Emission estimates for the natural gas feedstock were from the Greenhouse Gas, Regulated Emissions, and Energy Use in Transportation (GREET) model (Wang, 2010). The model enabled calculation of total fuel cycle emissions on a gram per mile basis.

6.0 PERFORMANCE ASSESSMENT

Testing Summary
Initial testing focused on the hydrogen station dispensing into vehicles using off-site hydrogen. Testing occurred with the dispenser configured for Type II communication fills to avoid overheating. The FCV manufacturer established the appropriate Type II setting as 1.4 kg/min. The testing included filling the vehicles with the dispenser nozzle and communication cables connected to the FCV. Figure 5 shows both the hydrogen fill and the communication connections.

Figure 5. Hydrogen fill and communication connections. Shows the hydrogen fill connector (left) and the Type II communication connection (right).

Under the objective commissioning plans, the manufacturer delivered the reformer to Camp Pendleton for 5 days of initial operational testing. The initial effort included load observations and emission measurements. The team subsequently connected the reformer to permanent utility lines, and followed with numerous startups.

Following initial testing, the team worked to fully integrate the reformer at the site. This included permanent utility connections required by NFPA 70. The requirement delayed the commissioning effort by eight months as a result of moving the switch controls 10 feet from the equipment pad. The controls movement required an additional concrete pad, overhead 2-inch intermediate metallic conduit for electrical and communication cables, 0.5 inch copper water pipe, and 1.5 inch black iron pipe runs from the reformer to the controls and utility concrete pads, respectively.

Air Emissions Testing
Emissions were within performance objectives for CO_2, nitrogen oxides, and sulfur dioxide for 25%, 50%, and 75% loads as presented in Figure 6. The exhaust failed to meet performance objectives for CO and methane at the expected exhaust flow rate. The testing fell short of two objective test runs at 75 load and all objective runs at 100 percent load. System shut-downs at these loads were possibly due to out-of-range natural gas and/or water pressures.

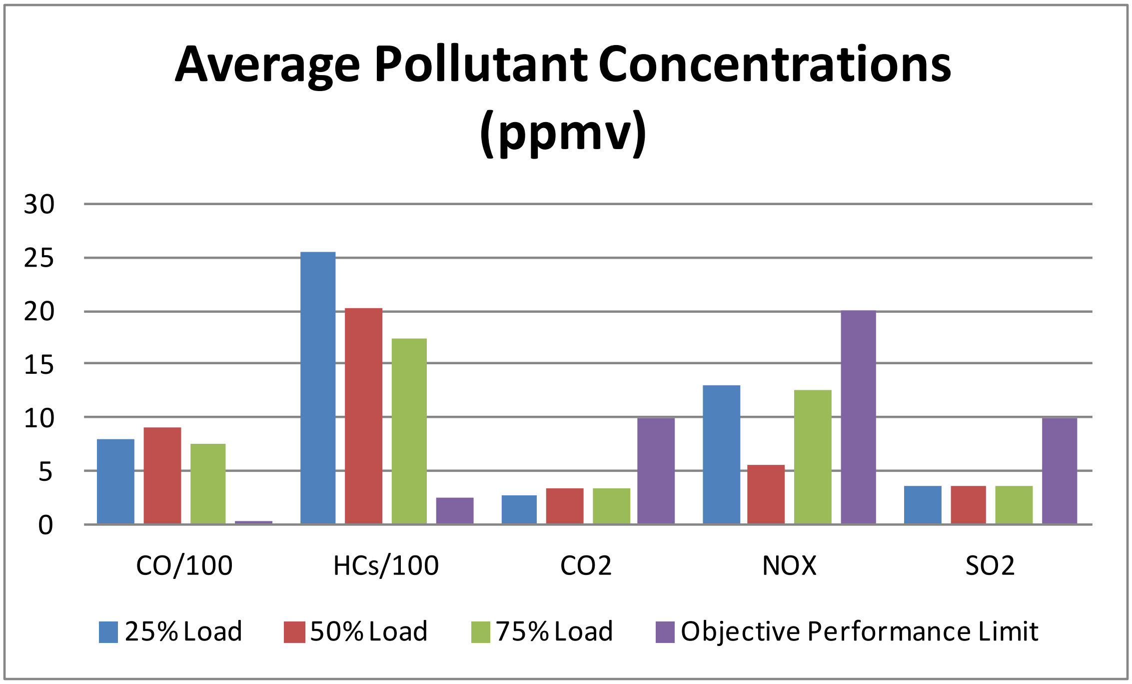

Figure 6. Average pollutant levels in reformer exhaust emissions.

Hydrogen Quality Testing

Table 6 presents results of hydrogen sample testing conducted at the station. The Figure 7 bar chart compares levels of contaminants from the on-site reformer sample with the SAE J2719. Analytical results of baseline CSD tests indicated high levels of hydrocarbons and halides. The suspected source of these compounds were the compressor seals, which may contain fluorinated polymer compounds. Also, results of initial pre-delivery testing on a hydrogen sample from the reformer indicated high levels of water. The vehicle manufacturer team reviewed all results were acceptable for supplying the FCV test vehicles.

Table 6. Hydrogen quality test results.

Constituent	SAE J2719 Limits µg/Mol	CSD System Baseline: Ultra-High Purity Bottle Gas	Reformer System Factory Test	Reformer System Upon Delivery
Water	5	4.6	<1	21
Total Hydrocarbons	2			
Methane		0.015	<0.005	0.014
Ethane, Ethene, Ethyne		<0.6	<0.6	<0.6
Isopropyl Alcohol		0.0053	ND	ND
Ethylbenzene		0.0043	ND	ND
Xylene		0.0055	ND	ND
Other Hydrocarbons		0.038	<0.07	0.038
Oxygen	5	<2	4.7	<0.3
Helium	300	149	<10	<10
Nitrogen, Argon	100	<5, <1	7.3, <1	<5, <1
Carbon Dioxide	1	<0.5	<0.5	<0.5
Carbon Monoxide	0.2	<0.001	<0.5	<0.001
Total Sulfur	0.004	<0.001	<0.001	<0.001
Formaldehyde	0.01	<0.001	<0.005	<0.005
Formic Acid	0.2	<0.005	<0.02	<0.003
Ammonia	0.1	<0.04	0.08	<0.08
Total Halogenates	0.05	0.6		
• Chlorine		<0.003	<0.03	<0.02
• Hydrogen Chloride		<0.005	<0.03	<0.02
• Hydrogen Bromide		<0.02	<0.03	<0.02
• Butane, 1,1,3,4-tetrachloro-1,2,2,3,4,4-hexafluoro-		0.5	ND	ND
• Butane, 1,1,2,3,4,4-hexachloro-1,2,3,4-tetrafluoro-		0.1	ND	ND
• Other Halogenates		ND	<0.08	<0.05
Particulate	1 µg/L	0.00090	NM	NM
Particulate Size	< 10 µm	1 @ 80 µm	NM	NM

Note:
ND = Dot Detected
NM = Not Measured

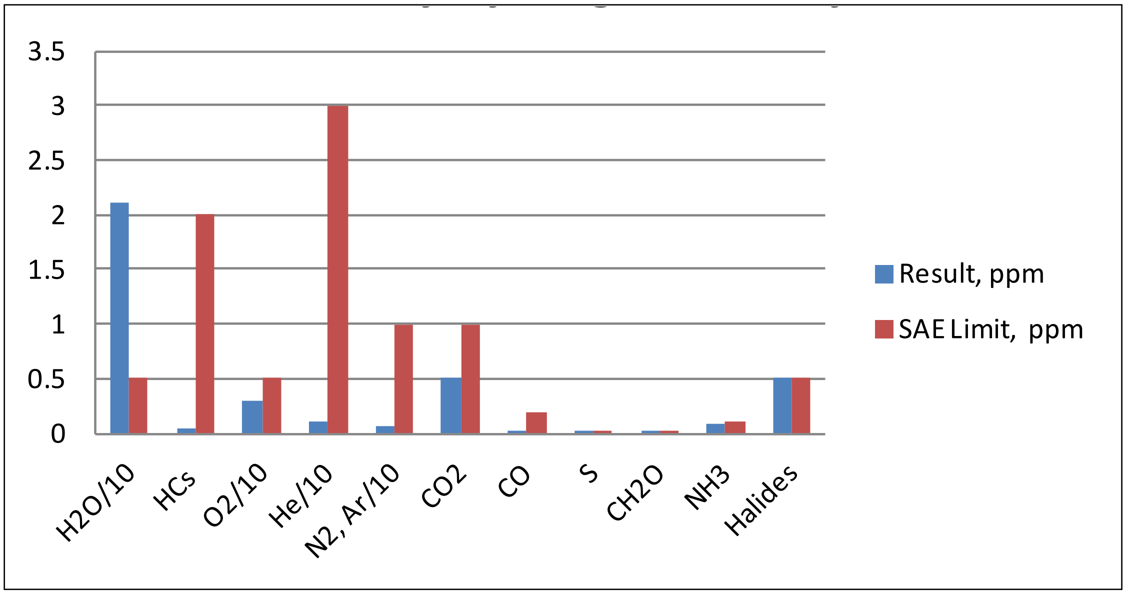

Figure 7. Comparison of hydrogen fuel sample contaminants with the SAE J2719 limits.

Reliability
The project team, along with the supplier, executed numerous startups and operated the system for short periods of time for up to three days. The system could not operate steadily for an extended period of time. A major factor contributing to shutdowns was the lack of comprehensive system controls. Given the performance objective of 80 percent operation, the system did not meet the reliability performance objective.

Durability
The reformer did not undergo extended durability testing as planned for the one-year demonstration period.

Maintainability
In its current state, the system would require daily service to maintain steady operation. Given the attempts at startup the system ran for no more than two to three days. Clearly, the system fell short of the performance criteria established for this demonstration. For the balance of station, compressor and safety systems require service calls on a monthly basis. During the demonstration, both systems experienced failures every six to 10 weeks before service was provided.

Hydrogen Losses
Comprehensive loss monitoring on the reformer in accordance with the test design could not occur. The system did not reach steady operation, and there was insufficient operating data to conduct a mass balance. While compressor malfunctions lead to substantial loss, leaks from hydrogen piping and dispenser were minimal. A relatively large amount of hydrogen is returned to the burner in order to achieve the low levels of contaminants required by SAE J2719. This is a process loss that impacts efficiency, and not an atmospheric release due to lack of system sealed integrity.

Safety

On-site safety events were minimal. The one event involving the reformer involved a second degree burn from contact with the reformer stack. This is considered a design deficiency. Applying proper insulation in and around the stacks, and the reformer vessel tubes would substantially reduce the chance for personnel burns. Among the more safety related concerns is the exchange of the six pack carriages. This requires a ground based observer to guide the fork lift operator in order to avoid collisions and ensure careful placement of the six packs.

Security

No trespassing or vandalism occurred during the testing period. Factors supporting security and station vigilance included: (1) occupation of the adjacent maintenance facility by government contractors; (2) locking of the gate entrance to the compound outside normal working hours; and (3) periodic patrols by the railway authority.

Solid and Hazardous Waste

Solid and hazardous waste include the deionization tanks, and sulfur clean-up cartridges. The project did not generate related data as the system did not operate for an extended period of time. The project did not generate local solid or hazardous waste.

Vehicles

Close monitoring and quick response to repairs ensured the four test vehicles were available for daily operations at Camp Pendleton. This early commercial real world testing allowed the monitoring of the vehicle fuel cell system durability in order to identify failure rates and components requiring further optimization. On average, the vehicles achieved 50 miles or more per day of operation over the demonstration period. The industry objective is 50,000 mile durability with no failures. Automakers estimate that this durability will be reached with the generation of FCVs coming in the 2015 timeframe.

Emissions and Fuel Economy Comparison

NAVFAC EXWC used GREET to calculate well to wheel emissions for comparison vehicles of similar body style. Federal emission and economy standards were based on 2008 to 2010 model year vehicles. Table 7 compares emission components for each vehicle. Energy consumption, also a primary objective, is included in the analysis and is based on Environmental Protection Agency fuel economy for comparable vehicles. Figure 8 shows the emissions comparison in bar chart format. FCVs offer significant emission reduction potential for CO, NO_x, and VOCs.

Table 7. Format for emissions comparison of alternative transportation technologies[1] (grams per mile)

	CO	CO_2	GHGs	NO_x	PM	SO_x	VOCs
CNG	3.961	323	401	0.376	0.073	0.135	0.194
E-85	4.047	522	362	0.651	0.167	0.278	0.428
Battery Electric	3.960	323	401	3.960	0.073	0.135	0.194
Gasoline	3.974	442	465	0.456	0.069	0.134	0.344
Hybrid Electric	3.962	327	345	0.361	0.059	0.098	0.244
FCV	0.060	236	283	0.165	0.105	0.168	0.027

[1] Values based on data from Argonne National Laboratories GREET.

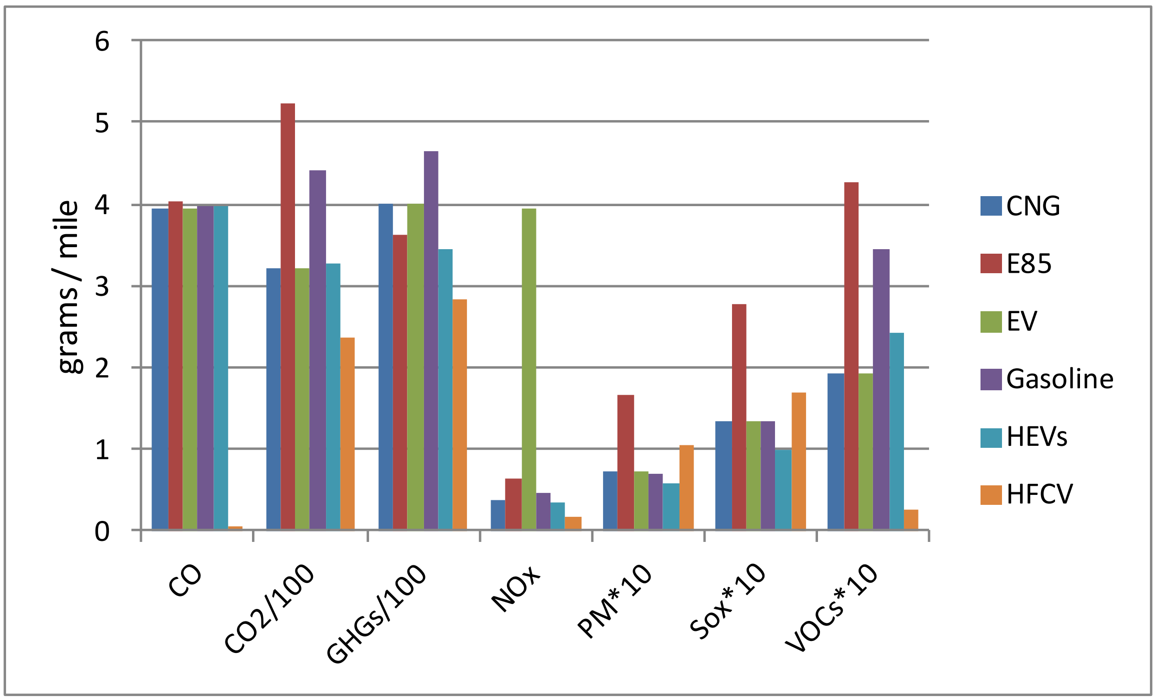

Figure 8. Comparison of fuel cycle emissions from hydrogen FCVs with other alternative transportation technologies.

7.0 COST ASSESSMENT

7.1 COST MODEL

NAVFAC EXWC used Environmental Cost Analysis Methodology as a basis for cost analysis P2/Finance, 1996). This analysis assumes a fully commercialized reformer system. The analysis considers Department of Energy performance metrics and manufacturer estimates. Costs are analyzed to a Level II Environmental Cost Analysis Methodology. Consumer price indexes are adjusted to 2012 costs. The cost analysis covers two components: (1)competing hydrogen fueling methods and (2) competing alternative fuel vehicle technologies.

Table 8 lists basis for the cost model. The comparison of the FCV technology assumes production and delivery required to support 100 light duty vehicles based on a truck platform (i.e., pickup trucks, vans, and utility vehicles), each weighing 5000 pounds or less gross vehicle weight rating, and each operating 10,000 miles per year. Fleet size basis of 100 vehicles is the upper range FCV fleet size expected in the next 10 years. Mileage basis is the average for light duty vehicles operating at MCB Camp Pendleton.

Table 8. Fleet model assumption for cost analysis.

Vehicle Type	Fleet Size	Weight Category	Duty Cycle	Fuel Economy
Light Truck	100	6000 lbs gross vehicle weight rating	10,000 miles/year	Combined City/Highway

Table 9 lists the competing hydrogen production scenarios evaluated in Environmental Cost Analysis Methodology. Baseline scenario is hydrogen delivery by truck. Alternative 1 is on-site production by steam methane reformation. Alternative 2 is on-site production by Polymer Electrolyte Membrane electrolysis powered by grid electricity.

Table 9. Hydrogen delivery options.

Option	Technology	Description
Hydrogen Baseline	Tube Trailer Delivery	150 kg Department of Transportation storage at 2400 psi
Hydrogen Alternative 1	Steam Methane Reformer	100 kg/day on-site production
Hydrogen Alternative 2	Electrolyzer	100 kg/day on-site production

Note: All hydrogen options assume 60 kg ASME Storage, 3-stage compressor, 5,000 psi dispenser 35 feet by 45 feet equipment pad, 8-foot chain link security fence, and fire safety panel with flame detectors.

As a secondary cost analysis, NAVFAC EXWC compared FCV operating costs with other available transportation technologies (i.e., CNG, E-85, EV, gasoline). A major assumption in this analysis relies on an estimated cost for the FCVs. Existing FCVs are limited production and available as a commercial lease only. As such, NAVFAC EXWC considers both initial lease rates and manufacturer projections for the FCVs and power trains. The existing test vehicles are built in low volumes and are still in the pre-commercialization phase.

Table 10 lists competing alternative fuel technologies. Costs for competing conventional alternative fueling technologies are adapted from existing cost data as follows. CNG is from the installation of CNG stations between 1995 and 1999 by NAVFAC Southwest. These projects were the result of a dual effort with the Air Force in Southern California executed under utility contracts in partnership with the local distribution companies. E-85 system costs are based on several recent construction projects of several E-85 stations between 2007 and 2012. EV charging station costs are based on projections. These costs are highly dependent on the utility connections. The costs assessment assumes an average cost based on a single Level 2 charger. As with the hydrogen fuel alternatives, alternative fueling systems are sized to support the same reference fleet operation: 100 light duty trucks each running 10,000 miles per year.

Table 10. Scale of alternative fuel technology for cost comparison.

Option	Fuel Technology Description	Vehicle Technology Description
CNG	Natural Gas Compressor Station, 15,000 ASME Storage	Compressed Natural Gas Vehicle
E-85	7000 gal. UL 2085, Integrated Above Ground Tank and Dispenser	Flexible Fuel Vehicle
Battery Electric	50 Level II Chargers, Dual Plug, 208V, 3-Phase Power	Lithium Ion Battery Electric Vehicle
Conventional	Regular Gasoline, Oxygenated, Use Existing Station	Conventional Spark Ignition Engine
Hybrid Electric	Regular Gasoline, Oxygenated, Use Existing Station	Hybrid Electric Vehicle, No-Plug-in

Table 11 lists vehicle comparison platforms for the cost analysis. Platform selection is based on comparable light trucks that are 6,000 lbs, front wheel drive, and automatic transmission. Annual use assumption is 10,000 miles per year. Fuel economy is assumed a combined city and highway average. Reference data source is Department of Energy's website: http://www.fueleconomy.gov/. Standard fleet vehicle assumptions are necessary as efficiencies will vary widely depending on specific engine, transmission, and duty cycle. Although the demonstration vehicles have real world data, the fuel economy in the test may not provide valid comparison as the FCVs were subject to different duty cycle applications than the other vehicles.

Table 11. Fuel economy assumptions for vehicles.

Vehicle Alternatives	Assumed Economy (mpg)	Vehicle Category
Fuel Cell Vehicle	38	Compact Sport Utility Vehicle
Flex-Fuel Vehicle	18	Compact Sport Utility Vehicle
Electric Vehicle	62	Pick-up and Delivery Truck
Conventional Spark Ignition Engine	24	Compact Sport Utility Vehicle
Hybrid Electric Vehicle (non-plug-in)[1]	31	Compact Sport Utility Vehicle
Compressed Natural Gas[2]	25	See Note 1.

[1] Mileage estimate is based on an extrapolation estimate for a 2008 model year sedan as there are no comparable fuel economy ratings for compact sport utility vehicles or comparable light truck models.

[2] Assumptions use 2008 vehicle models for consistency. MPG rating is based on user input on combined city and highway driving at fueleconomy.gov

7.2 COST ANALYSIS AND COMPARISON

This section presents both capital purchase and operating costs for the infrastructure options.

Capital Cost

All alternative fuel system scenarios include the upfront cost for a fueling station capable of supplying 100 light duty vehicles. Baseline scenario (gasoline) assumes access to existing nearby stations, and includes no capital cost. Capital cost of alternative fuel stations include engineering and planning, permitting, equipment, construction, training, and startup. Costs are based on estimates from prior CNG projects, and recent E-85 and EV charging projects.

Hydrogen fueling options include site preparation and facility equipment. Site preparation includes utilities, equipment pads, access road, fire safety equipment, security fencing, and station lighting. Hydrogen equipment falls under three options, including a mobile tube trailer for off-site delivery (Baseline), a steam methane reformer for on-site production (Alternative 1), and an electrolyzer for on-site production (Alternative 2).

Operating Cost

Table 12 includes estimated incremental costs for alternative fuel vehicle technologies. Estimates assume vehicle leasing from the General Service Administration, a seven-year life cycle, and upfront payment of the incremental cost for the alternative fuel vehicle. Costs are normalized to a 12-year life cycle for combination with the fueling technologies.

Table 12. Incremental cost of alternative fuel vehicle technologies.

Vehicle Technology	Fuel Technology	Per Vehicle[1]	Fleet Aggregate, 12-Year Cycle [2]
Conventional Engine	reformulated gasoline	Baseline	Baseline
Hybrid Electric	reformulated gasoline	$8600	$1,474,300
Plug-In Electric	lithium battery	$25,000	$4,285,700
Natural Gas Engine	CNG	$10,000	$1,714,300
Flex-Fuel Engine	E-85	$1800	$308,600
FCV	compressed hydrogen	$25,000	$4,285,700

[1] Unit incremental cost is the per vehicle premium for the alternative technology.
[2] Assumes 7-year replacement cycle. Fleet size is 100 vehicles.

Table 13 and Table 14 present cost assumptions for delivered fuels and utilities, respectively, used for the fuel station cost analysis. Rates in Table 14 are based on data from the Navy's Comprehensive Utilities Information Tracking System.

Table 13. Cost assumptions for delivered fuels.

Fuel	Natural Unit	Cost per Natural Unit	Gasoline Gallon Equivalent[1]	Cost	Reference[2]
Ethanol Blend (E-85)	Volumetric Gallons	3.73	1.29	5.18	DLA Pricing[2]
Regular Unleaded Gasoline	Volumetric Gallons	3.73	1.00	3.73 (volumetric gallon)	DLA Pricing[2]
Hydrogen (tube trailer)[3]	Kilogram	61.83	1.01	Delivered Hydrogen Product	Camp Pendleton Supply Contract[3]

1 Conversion Factors from Department of Energy, Alternative Fuel Data Center.(AFDC,

2 Fuel prices are from Defense Logistics Agency (DLA).(DLA, 2012)

3 Bulk Delivery of 40,000 standard cubic feet by Tube Trailer. Monthly cost includes $2200 (trailer rental), bulk hydrogen product ($2415), Hazmat fee ($4), fuel Surcharge ($10), pickup and delivery ($200). Note only 90 percent of the tube trailer hydrogen is usable considering 10 remains upon return for refill.

Table 14. Cost assumptions for station utilities.

Utility	Unit	Cost/Unit	Source
Pipeline Natural Gas	million BTU	$5.13	
Electricity	mega-watt hour	$10.27	Navy FY10 Costs, Domestic [1]
Water	kilo-gallon	$4.00	

1 Cost estimates are based on figures from the Navy's Comprehensive Utilities Information Tracking System.

7.3 COST SUMMARY

Table 15 summarizes the costs for the hydrogen fueling system comparison assuming a full commercialization of the reformation technology. This cost outcome is only realistic with further development of the steam methane reformer. It relies upon 2010 utility costs, full scale operation assuming the reference fleet size, and a reliable reformer with low maintenance requirements. For smaller fleet operations in the near-term, the baseline tube trailer appears to be the most cost effective option. If power is readily available at very low cost, the electrolysis system will be a competitive system for a larger fleet application.

Table 15. Summary of life cycle costs for competing hydrogen fueling options.

	Up-Front Capital Cost	12-Year Operating Cost [1]	Projected Station Life Cycle Cost
Tube Trailer Delivery	$1,648,500	$2,039,900	$3,688,400
Steam Methane Reformer	$2,105,000	$1,391,400	$3,496,900
Grid Electrolysis	$2,130,400	$4,307,600	$6,438,000

1 FCV cost is not included, and is equivalent for each option.

Table 16 provides a comparison of the competing alternative fuel technologies with the hydrogen FCVs. Capital cost for the vehicles is the primary factor placing FCVs and EVs in the highest priced scenarios. This assumes 2010 pricing of competing conventional and alternative fuels, which could change over the next 10 to 20 years. Both FCVs and EVs have the greatest flexibility in terms of energy source, suggesting the cost of these options could decrease with technology advances in materials and manufacturing techniques.

Table 16. Alternative fuel technology cost comparison.

Vehicle Technology	Fuel/Energy Storage	Station Capital Cost	12-Year Fuel & Station Operations Cost	12-Year Fleet Incremental Cost	12-Year Life Cycle Cost
Internal Combustion Engine	reformulated gasoline	Existing	$2,029,200	Baseline	$2,029,200
Hybrid-Electric	reformulated gasoline	Existing	$1,525,200	$1,474,300	$2,999,500
Plug-in Electric	lithium battery	$1,400,000	$665,500	$4,285,700	$6,351,200
Internal Combustion	CNG	$1,075,100	$991,800	$1,714,500	$3,781,400
Flex-Fuel	E-85	$550,000	$2,694,600	$308,600	$3,553,200
FCV	hydrogen, (steam methane reformer)	$2,105,500	$1,391,400	$4,285,700	$7,782,600

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8.0 IMPLEMENTATION ISSUES

Primary stakeholders of the hydrogen FCV technology include fleet managers. As end users, the fleet leadership is ultimately responsible for the program planning and development of alternative transportation technologies and fueling infrastructure.

The early stage of the technology presents challenges for system load matching. While reformer manufacturers have developed larger units capable of supporting a commercial fleet, demand at most sites is well below production output. This is largely due to lack of available FCVs. As a result, reformer systems typically cycle between production and idle modes. This variable production not only reduces efficiency, but also demands further attention to hydrogen quality. To address these issues, stations must have excess hydrogen storage and an adjacent consumer to ensure steady hydrogen usage.

New hydrogen fueling projects will require substantial environment planning. NEPA review is required for evaluation of the various impacts to the environment, personnel, and existing operations. Drivers for the EA at Camp Pendleton included: (1) the project sets a precedent for future activities, (2) the project site differs from existing land use, and (3) the project requires full assessment of impact on public safety. This same level of NEPA study could very well be a requirement at other sites.

Siting considerations resulted in moving the site, impacts to launch schedule, and increased cost. Stakeholders may face similar challenges at new locations. Base security stakeholders established station setbacks from surrounding buildings, roads, utilities to address anti-terrorism force protection initiatives, and worse-case scenario. Security initiatives also raised concerns with public access to the fueling facility. Most hydrogen storage is aboveground, and will require fencing, lighting, and security patrols.

Contracting for hydrogen station construction also complicates implementation. Local construction contracts are optimized for common buildings such as administrative offices and housing. Use of these same contracts for specialized systems such as hydrogen fueling stations adds cost and incurs risk due to the lack of specialized knowledge. This approach requires clear contract language and performance based controls for effective execution. For the best efficiency, the resultant contract must include a single general contractor, and sub-contractors that specialize in the installation of hydrogen fueling equipment.

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9.0 REFERENCES

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APPENDIX A

POINTS OF CONTACT

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