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INTERNATIONAL ENERGY AGENCY
HYDROGEN IMPLEMENTING AGREEMENT
TASK 11: INTEGRATED SYSTEMS

Final report of Subtask A:
Case Studies of
Integrated Hydrogen Energy Systems

Chapter 7 of 11

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Chapter 7
CLEAN AIR NOW:
SOLAR HYDROGEN FUELED TRUCKS

1. PROJECT GOALS

Encompassing the second largest city in the United States (Los Angeles), the South Coast Air Quality Management District (SCAQMD) suffers from the most severe air pollution problems in the nation, and its population endures some of the world's worst air quality. This area also offers the greatest potential for development of hydrogen fuel. Ozone, particulate matter (PM10), and carbon monoxide are the most dangerous pollutants identified in the district. Replacing fossil fuels with hydrogen would eliminate both of these pollutants along with the majority of all carbon-based emissions.

Clean Air Now (CAN) has formulated a master plan to develop and demonstrate the hydrogen energy economy. The integrated "Hydrogen Corridor" will extend from the Pacific Ocean at CAN's El Segundo, California solar hydrogen site to the renewable hydrogen and fuel cell program in Palm Desert California. Southern California offers an excellent test bed for the complete infrastructure of a hydrogen economy.

2. GENERAL DESCRIPTION OF PROJECT

Started in August 1994, the CAN Solar Hydrogen Vehicle Project demonstrated a practical application of renewable hydrogen. The demonstration featured a solar energy hydrogen generating system, fueling station, and a small fleet of Ford trucks with internal combustion engines (ICEs) converted to use hydrogen. CAN oversaw, directed and managed the overall project. Other team members included the Xerox Corporation; The Electrolyser Corporation (currently Stuart Energy Systems Inc.); Praxair Incorporated; Solar Engineering Applications Corporation (currently Photovoltaics International, LLC); Kaiser Engineering; City of West Hollywood; W. Hoagland & Associates, Incorporated; Touchstone Technology; the University of California, Riverside, College of Engineering – Center for Environmental Research & Technology (CE-CERT); Matrix Construction and Engineering, Incorporated; and the Energy Technology Engineering Center (ETEC). An aerial view of the facility is shown in Picture 7.1.

The hydrogen-powered utility vehicle fleet was operated by the Xerox Corporation in El Segundo and by the City of West Hollywood. The project was funded by the White House Technology Reinvestment Project (contracted through the U.S. Department of Energy), CAN, SCAQMD, and the rest of the project team.

The goal of the CAN-Xerox project was to demonstrate the use of solar-generated hydrogen as an alternate clean fuel for utility transportation vehicles. This project utilized state of the art, "off-the-shelf" technology including photovoltaic (PV) electricity generation and water electrolysis production of hydrogen.

The hydrogen-fueled CAN Ford Ranger trucks represented a significant advancement in the development of ultra-low emission vehicles (ULEVs). By using hydrogen fuel, these trucks eliminated air pollutant emissions of CO, CO_2, and unburned hydrocarbons, while significantly reducing emissions of nitrogen oxides (up to 90%). Hydrogen produced from electrolysis of water powered by PV electricity, is a clean, practically inexhaustible power source for automobiles.

Picture 7.1: Aerial view of Xerox-Clean Air Now facility

3. DESCRIPTION OF COMPONENTS

3.1 Hydrogen Production System

The intent to produce hydrogen without polluting emission dictated that the hydrogen be produced without aid from the utility grid. Shown in Figure 7.1, the stand-alone system consisted of a PV array, an electrolyzer, and a compressor. The electrolyzer as well as the hydrogen compression system operated directly from the PV array.

Sun tracking Fresnel lens concentrators formed the bulk of the PV array, supplemented by a fixed panel array. The single axis tracker array consisted of forty sub-arrays with 12 tracking concentrators each. Each sub-array had an electronic sun-seeker tracker, which at dusk returned the concentrators to point towards the east overnight to better sense the morning sun.

The extruded acrylic Fresnel lenses concentrated the sun’s energy ten to fifteen fold onto the single crystal silicon cells, which were mounted on an extruded aluminum heat sink that acted as a heat exchanger to the ambient air. Two sizes of concentrators, 11” and 15” in width, were used in the array. The concentrators were approximately 11.5 feet in length. Each panel (12 modules each) produced 550-750 W.

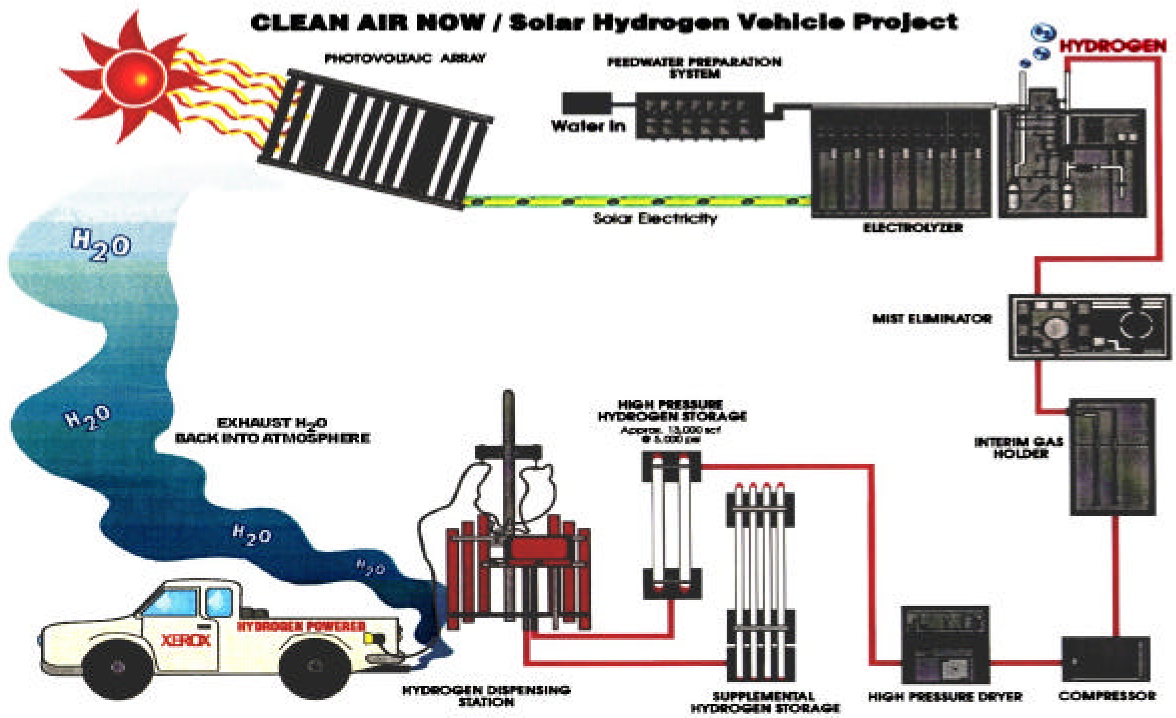

Figure 7.1: Xerox-CAN Solar Hydrogen Production Facility Scheme

Each concentrator yielded several amps at approximately 15 V, and all were connected in parallel. The panels were tied together with cables, and the one adjacent to the bus bar was tied by cable to the bus. The bus was made of ¼” x 6” copper bar, with doubling in the parts that conducted a thousand or more amps.

The PV array power was available to the electrolysis process and to the inverter for the compressor. The inverter required from 500 to 800 A, depending on gas pressure and voltage. The PV array also supplied current to the battery charger to recharge the batteries that maintain the power to the control system at all times.

Water from the city mains was demineralized using a deionizer bed and added to the cell bank to replenish that lost in the electrolysis process. Oxygen and hydrogen are kept separate in the cells by membrane separators. A water seal is used to equalize pressure between the two parts of the cell. The oxygen generated was vented to the atmosphere, while the hydrogen passed through a porous mist eliminator and then to a gas holder that acted as a buffer between the cells and the compressor. The compressor capacity of 404 scf/h was larger than the generating rate of the cells. The compressor ran intermittently, starting when the gas holder was full and stopping when the gas holder was empty. If the compressor was not operational due to a lack of power (i.e., low sun or cloud cover), the hydrogen was vented by the gas holder when full.

The Electrolyser Corporation constructed the electrolysis system in a 40-foot shipping container. Included therein were:

- Eight electrolysis cells, each rated at up to 4000 A, connected in series in order to provide a system with a 16 V nominal rating. The electrolyzer cells are capable of producing up to 400 scf of hydrogen at 48 kW and 16 V.

- A low-pressure gas handling system which releases the oxygen to the atmosphere and provides a low pressure temporary storage of hydrogen production in a 1.5 m^3 capacity gas-holder.
- A 15 hp [11.2 kW] compressor suitable for operation with hydrogen at pressures to 5000 psi, derated to 4200 psi. A dryer stage reduces the water content to attain dewpoints of -40°C expanded.
- A variable speed inverter (designed for operation from voltages as low as 12 V) to provide a "soft start" of the compressor.
- An electrolyzer control and data logging system which allows operation without an attendant and produces a record of the control and production parameters.
- Battery backup power for the controls, such that the control system continues to operate even on rainy days and at night.

The hydrogen compressor is a Compair Reavell, Model 5409, 4-stage, air-cooled, oil lubricated reciprocating type compressor. The compressor operated at 950 rpm, and had a capacity of 388 ft^3/hr at a discharge pressure of 5000 psig. The compressor was driven by a 15 hp motor that operated at 1450 rpm. The power to operate the compressor was derived from the PV array. To preclude damage to the compressor, each stage of the compressor was protected by a safety relief valve. The exhaust of these relief valves was returned to the top of the moisture separator at the inlet to the compressor.

In addition to the aforementioned safety relief valves, there was an interlock within the compressor system, which was used to protect the hydrogen compressor from damage due to high temperature or low oil pressure. When activated, the interlock initiated a shutdown of the compressor.

3.2 Hydrogen Storage and Dispensing

The hydrogen storage system consisted of twenty-four 2200 psig, 22.5 cubic foot ASME storage vessels (holding ~74,000 scf of hydrogen at 2200 psig) and two 5000 psig, 26.6 cubic feet ASME storage vessels (holding ~14,000 scf of hydrogen at 5,000 psig). The two 5,000 psig vessels were the only vessels filled from the electrolysis system. The 2,200 psig vessels were filled by an external hydrogen supply source, and were only used when hydrogen was not available from the two high-pressure storage vessels. The two high-pressure vessels were protected with two safety relief valves, one valve on each vessel, with each relief valve set to relieve at 4,600 psig.

The hydrogen dispensing system consisted of an Automotive Natural Gas Inc. (ANGI) fueling post, piping, and valving. The ANGI fueling post used a dual-hose rated for operation at 5,000 psig. The system was termed a "fueling post" simply because there were no automatic dispensing or metering functions provided (Pictures 7.2 and 7.3). The piping and valving downstream of the high-pressure storage vessels were all designed to operate to at least 4,600 psig. The dual-hose unit features hose retractors, and the breakaway force was 25 pounds pull on a hose (approximately). These components were protected from overpressure conditions by means of two pressure relief devices installed on the two high-pressure storage vessels. To preclude the overpressurization of the utility vehicle hydrogen storage tanks, a relief valve set to relieve at 3,900 psig was installed on the nozzle side of the dispensing system, with a gas regulator set at 3,500 psig.

Picture 7.2: Refueling the Ballard Fuel Cell Bus at the CAN Solar Hydrogen Refueling Station

Picture 7.3: UCR1 at Solar Hydrogen Refueling Facility

3.3 Balance of System

The power distribution and control system consisted of a battery system, a controller/inverter, and a control panel. The battery system consisted of a 24 V, 265 Ah battery bank, a 1,000 W inverter (nominal 24 V_{DC} to 120 V_{AC}), and a 24 V_{DC}, 30 A battery charger (120 V_{AC} input). Battery capacity was sufficient to power the control functions for 48 hours. Power from the PV array was applied to the inverter through a fusible switch. The inverter supplied regulated 120

V_{AC} power to the battery charger. The battery charger charged the 24 V battery bank with a regulated voltage and current, tapering the charge when the batteries were full. The inverter was remote-controlled from a Programmable Logic Controller (PLC). Only when the PV array current was greater than 200 A would the battery charging system be operated.

The batteries supplied power to the control system day and night. Most of the equipment and electronics operated directly from the 24 V_{DC}. However, a few devices required 120 V_{AC}, and this is supplied through a 250 W auxiliary inverter. The controller/inverter was a variable speed motor drive for operating the three-phase compressor motor. It operated directly off the photovoltaic array and provided controllable, regulated AC voltage at 208 VAC to the motor. It was comprised of a DC boost converter, followed by a DC to AC inverter, and a control board to provide all run, monitor, and fault operations. The control panel contained two main sections: Control and Data Acquisition. The control panel included the control, annunciation, and instrumentation systems for the plant. It was dedicated to the 24 V_{DC}, 12 V_{DC}, and 120 V_{AC} devices. The PLC controlled the compressor, battery charging system, solenoid valves, and the DC switch. It also performed the annunciator function.

When operated at full capacity, the electrolytic cells consumed approximately 12 liters (3 gallons) of water per hour. The electrolyte feedwater was filtered and demineralized using a system of filters and an ion exchange resin bed. This prevented scaling of the electrolytic cell system and maximized electrolytic cell performance. A conductivity meter and cell were supplied for measuring the conductivity of the water to the plant.

3.4 Vehicles

In 1994, under contract from SCAQMD and CE-CERT, Hydrogen Consultants Inc. (HCI) (Currently Hydrogen Components, Inc.) and Advanced Machining Dynamics (AMD) converted a Ford Ranger truck to use a hydrogen fueled ICE, known as UCR1. UCR1 used a constant volume injection (CVI) system that delivered timed and metered quantities of hydrogen to each cylinder. Fuel metering was controlled fluidically with trimming by an electronic pressure regulator using exhaust oxygen feedback.

The CAN/Xerox project included funding to provide similar truck conversions to be used by the Xerox maintenance staff, and also for a truck to be used by the City of West Hollywood. These trucks were used for short runs around the Xerox buildings, and on local streets. The truck converted for the City of West Hollywood used the freeways to go to El Segundo for fuel. Whereas UCR1 had an automatic transmission, the CAN trucks used manual transmissions – which improved low speed acceleration. These trucks were dubbed CAN1, CAN2, and CAN3. CAN1 and CAN3 are owned by the Xerox Corporation. CAN2 was the property of the City of West Hollywood.

The original vehicles were equipped with a 2.3-liter, 4-cylinder gasoline fueled engine, five speed manual transmission, standard steering, and 3.08:1 rear drive gears. Conversion to hydrogen fuel included cylinder head modification for increased air flow, increasing piston displacement to 2.85 liters, addition of a roots type supercharger and intercooler, 4.10:1 rear drive gears, and a CVI system.

The emissions control system consisted of an electronically trimmed fuel injection system with exhaust oxygen feedback, a positive crankcase ventilation system and an oxidation catalyst. The lean burn engine was held in a closed loop control with a constant fuel-air equivalence ratio of less than 0.45 where oxides of nitrogen are very low. There were no other significant pollution emissions with hydrogen fuel.

At the request of Praxair Corp., the first Xerox truck was fitted with two Comdyne aluminum/fiberglass tanks having an internal volume of 3.70 cu.ft. Subsequently, EDO Canada provided two carbon fiber, 3600 psi tanks having an internal volume of 5.64 ft^3 each, mounted in the bed of each truck. These tanks used approximately 50% of available bed space and allowed a range of about 144 miles. These EDO tanks reduced tank weight by 58% and increased range by 52%.

Using an intercooled supercharger instead of a turbocharger, and increasing engine displacement to 2.85 liters, provided low speed performance at least as good as a standard unit, despite operating at less than 50% of the stoichiometric fuel-air ratio. The compact, lightweight EDO fuel tanks allowed the vehicle to be used as a practical and useful truck. If regulations are changed to permit storage of gaseous fuels on board vehicles at pressures in the range of 5500 psi to 7000 psi, increases in range and payload will make such vehicles very practical low emission transportation modes.

To accommodate the modified engine, hydrogen fuel system, and CVI system, several modifications to the chassis and body of the trucks were required. A large capacity air-to-air intercooler was fabricated from components by Allied Signal Corp. and mounted in front of the engine-cooling radiator. The single-row radiator was replaced with a two-row Modine radiator, located 1.5” aft of the original location. Engine intake air was routed through a relocated stock throttle body to the supercharger, the intercooler, and a modified stock intake manifold, and into the engine.

All gasoline fuel system components were removed and discarded. Removal of the gasoline fuel system saved weight and offset some of the weight of the new system.

Hydrogen tanks, transversely mounted at the front of the truck bed, were protected by side impact structures. CAN1's Comdyne manufactured aluminum/fiberglass tanks were protected by a tubular steel structure around the valve end of the tanks. The EDO tanks required extensive bed modification. To accommodate the long tanks, it was necessary to truncate the rear wheelhouses and to install 3” square steel beams between the outer skin and the inner bed walls for crash protection. An added benefit of the EDO tanks was a reduction in weight of 130 kg, compared to the Comdyne tanks.

Steel sheet covers were installed over and behind the tanks to protect them from damage by dropped objects or shifting cargo. The fuel pressure gage, primary regulator, and flow control valves located in the bed were also protected by these covers.

4. OPERATIONAL EXPERIENCE AND PERFORMANCE

4.1 Solar-Hydrogen Production Facility Performance Data

From the very beginning of the project, one of the guiding principles was to ensure all parties felt safe with the hydrogen technologies that were implemented. The facility was designed using industry standards and applied accepted practices to all the systems.

ETEC performed assessments of the system. Once ETEC gave the facility "safe to operate" ratings, and the El Segundo (California) Fire Marshal agreed, the Building Department issued the final inspection permit.

The codes & standards applied by ETEC to perform the safety and failure mode assessments include:

- NFPA 50A, Standard for Gaseous Hydrogen Systems at Consumer Sites, 1994 Edition.
- NFPA 52, Standard for Compressed Natural Gas (CNG) Vehicular Fuel Systems, 1992 Edition.
- NFPA 70, National Electrical Code, 1993 Edition.
- ASME/ANSI B31.3-1993, Code for Chemical Plant and Petroleum Refinery Piping.
- ASME Boiler and Pressure Vessel Code - 1986, Section VIII, Rules for the Construction of Pressure Vessels.

The performance of the solar-hydrogen production facility was first measured for three days in November 1996. Production of hydrogen began just before 9 a.m. Five hours of good production were observed on average, with the days' compression being terminated by the coastal haze at 2 p.m. Figure 7.2 shows the gradual increase in pressure from 2950 psi to 3450 psi, in the storage tanks (PressExit). The current in the PV array (I_{array}) follows insolation. The current drawn by the inverter (I_{invert}) indicates when the compression system is running. These results show that in November, about 5 hours of production per day took place, and it is estimated as many as 10 hours of production per day are possible in August. (No hydrogen production data from August are available, though PV output was measured over several months.) The production is thus expected to be over 7 hours per day on average, with approximately three compression cycles per hour. At an average current of 1800 A through the eight cells, the system is expected to generate 225 scf of hydrogen per hour.

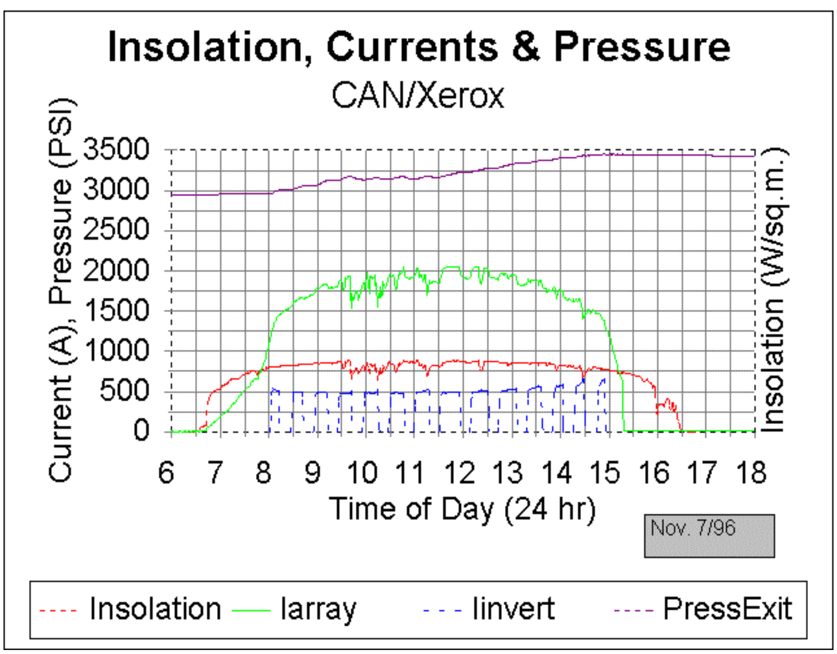

Figure 7.2: Insolation, Currents and Pressure

4.2 Vehicle Performance Data

Since this was a "deployment" project there was no funded R&D. There were, however, ancillary improvements to the original design and some of the component integration specifications: the ICE retrofit (improved low end performance over UCR's truck); the hydrogen generation components (stand-alone capability, data acquisition); and the PV concentrator lens (increased efficiency).

4.2.1 Initial Check-Out

A top-level systems analysis of the CAN1 vehicle retrofit verified that the design was implemented in a safe and skillful manner. Also, the functional readiness of the vehicle and operability of the hydrogen-related safety devices were checked out. CAN1 was inspected by the Energy Technology Engineering Center (ETEC) and was found to meet the general requirements of the retrofit design; however, there were some deviations.

The major problem encountered in the initial checkout tests involved the hydrogen sensors. Neither the H_2 sensor in the truck bed nor the H_2 sensor under the hood in the engine compartment operated properly when the vehicle was delivered. As a result, a design change was made to allow the H_2 sensors to be wired directly to the battery rather than to the ignition. Thus, a hydrogen leak would be detected before the ignition is turned on, which is an improved safety feature.

During the leak check of the high-pressure hydrogen systems, two very small hydrogen leaks were found in the Swagelok joints between the fuel pressure gage and fuel feed valve. In an isolated system, the leaks resulted in an 8% pressure decay during a 24-hour period. It was decided that the two leaks were too small to impact any of the testing to be done at ETEC. These leaks were repaired prior to final vehicle service testing.

4.2.2 Refueling Evaluation

An evaluation was made of the fuel fill modifications necessary to refuel the vehicle with hydrogen. The stock gasoline fill port had been removed and replaced with a CGA-350 fill port for hydrogen service. The other end of this CGA-350 fill port screwed into a ¼-in NPT port that attached to the hydrogen tank lines. The vehicle was always grounded prior to attaching the CGA-350 fill line.

In order to perform the refuel operation, the Rocketdyne H_2 Lab constructed a H_2 fueling station. A total of seven refueling operations were successfully performed by ETEC without any problems or apparent damage and wear to the CGA-350 fitting.

4.2.3 Safety Tests

The objective of the safety tests was to assess safety issues during situations that were expected to be encountered during the life of the vehicle. These included the presence of a mixture of hydrogen and air in the exhaust manifold (such as during vehicle stalling), loss of ignition in one or more cylinders, and oxygen sensor failure. These tests also served as verification of the ECM sequencing for start-up and shutdown. All the safety testing was performed with the vehicle stationary and the hood closed, and the engine running in idling mode.

Fuel starvation-restart safety tests

The objective of the fuel starvation-restart test was to determine if any restart problems existed as a result of the engine running out of fuel. This test also verified the proper ECM sequencing for start-up and shutdown. No safety issues were identified based on these fuel starvation-restart tests.

Stall-Restart Safety Tests

The objective of the stall-restart tests were to determine if any unburned hydrogen that accumulated in either the intake manifold or the exhaust system from an engine stall created a safety hazard when the engine was restarted. The engine ran and idled the same after these tests as it had before the tests were performed.

Failed Oxygen Sensor Safety Tests

These tests were performed to determine if the engine could run safely and be restarted with a failed oxygen sensor. A failed oxygen sensor maintains the electronic pressure regulator in open-loop control of the air/fuel ratio; therefore, the air/fuel ratio is fixed and cannot be adjusted by a signal to the electronically controlled pressure regulator. There was no noticeable difference in how the engine either started or idled with the oxygen sensor either on or off. However, when the engine was idling with the oxygen sensor on and the oxygen sensor was then turned off, the engine stalled. Although the engine stalled when the sensor was turned off (failed oxygen sensor), it did not create a fuel system safety hazard.

4.2.4 Service Tests

Service tests were performed to assess the general operability of the hydrogen fueled vehicle and to get a very preliminary indication of any degradation in performance which could have resulted in subsequent hydrogen safety issues. Initial service testing was performed on a network of mountainous roads with uphill and downhill grades as steep as 12.5% within the ETEC complex.

The following data were gathered during the service tests:

- From the very beginning of the service testing, the vehicle ran very sluggishly during acceleration. Even while accelerating downhill, the engine seemed to cough, causing the vehicle to lunge rather than to accelerate smoothly. At times, the engine made a very strange pinging or clattering sound while the vehicle was being accelerated, regardless of the direction or degree of the road grade. Since the engine did not make this strange sound continuously, it appeared to be caused by the engine not being adjusted and tuned for hydrogen service while under relatively high torque. None of these strange sounds was detected during the safety tests, which were performed while the vehicle was stationary and the engine idling under very low torque. Most of the problems manifested themselves at speeds below 35 mph with the vehicle in the first three gears. The vehicle seemed to run quite well at 36 mph in 3rd gear and 45 mph in 4th gear.
- Because of engine restart concerns due to condensation forming in the combustion chamber and on the spark-plug electrodes, if the engine stopped while it was cold, a series of cold start-restart tests were performed. After the vehicle had been parked outdoors all night after the refueling operation, the cold engine was started and then immediately shut off. This test

was repeated a total of five times and each time the engine started immediately. Even though there was a large amount of condensation formed during these tests, none of the condensation prevented the engine from restarting. Examination of the sparkplugs showed them to be very clean.

- A series of tests was performed to simulate a failed oxygen sensor by turning the oxygen sensor off. With the oxygen sensor off, the engine started immediately; however, when the vehicle was driven, the engine ran very rough and stalled three times. It was determined the vehicle definitely needs the oxygen sensor on and operating in order for the engine to run properly.
- A quart of oil was added to the engine, after only 223 miles of initial service testing. Although there may have been some oil consumption because the engine had just recently been rebored, the loss of oil was probably due to an oil leak at or near the engine/transmission interface.
- A total of 240 miles were driven during the initial service testing. Each time the vehicle was refueled, the trip odometer reading, hydrogen tank pressure, and approximate ambient temperature were recorded. It was assumed that the tank temperature was approximately the same as the ambient air temperature. This information was used to calculate the fuel consumption. During initial service testing, the average mileage rate was 7.04 miles/lb, equivalent to 14.73 miles/gal of gasoline. Contributing factors for this low mileage rate were: engine not properly tuned, mountainous test road, low speeds, and some testing with the oxygen sensor off.

5. ENVIRONMENTAL ASPECTS

A single Federal Test Procedure (FTP) dynamometer was run on the CE-CERT vehicle, showing carbon-based emissions to be extremely low, and average NO_x emissions of 0.37 g/mile. This can be compared to the ULEV standard for NO_x of 0.2 to 0.3 g/mile (over 100,000 miles). Other dynamometer tests gave evidence of the engine control system having operational characteristics prone to high NO_x under certain conditions.

The three CAN trucks, although expected to be identical, operated notably differently. This became evident in constant speed dynamometer tests done in conjunction with CE-CERT. The NO_x tests varied depending on the truck, with the best of these vehicles maintaining below 35 ppm NO_x at full throttle over a range of speeds. This suggests a capability of operating at sub-ULEV emissions under the worst of conditions. The most powerful truck, CAN2, operated with a richer mixture, had higher NO_x test values.

A single FTP75 test procedure was run on the high performance truck, CAN2. Total grams per mile results (as compared to the ULEV standard and proposed EZEV standard) are given in Table 7.1. It is evident that the hydrogen-fueled truck handily meets any of the standards for CO and HC, but the NO_x only meets the high mileage ULEV standards.

6. OTHER EXPERIENCES

The hydrogen-fueled trucks were operated from December 1995 to July 1997. Although the trucks, PV system, and electrolyzer performed to expectations, the compressor needed the most maintenance, and in fact was down for three months prior to December 1995.

Table 7.1: Comparison of Emissions in g/mile

	CAN2	ULEV 50,000 mi.	ULEV 100,000 mi.	EZEV
CO	0.052	1.70	2.1	0.170
HC	0.003	0.04	0.055	0.004
NOx	0.299	0.20	0.3	0.020
Total	0.36	1.94	2.455	0.194

The system produced about 1800 scf H_2/day in the summer and roughly 1200 scf H_2/day in the winter months. The solar array generated roughly 34.5 kW (2300 A at 15 V) during the summer months and about 18.2 kW (1300 A at 14 V) during the winter months. CAN1, with the smaller Comdyne storage tank, carried 1500 scf of hydrogen and had a range of 60-65 city miles and 90 highway miles. CAN2 and CAN3 with the larger EDO tanks carried approximately 2300 scf H_2 and had a range of 110 city miles and 140 highway miles. The trucks require 22 scf H_2/city mile and 16.5 scf H_2/highway mile. The solar production facility provided 1800 scf H_2 per day in the summer months, sufficient for 82 city miles, or 109 highway miles.

The greatest trouble spot in the system was the compressor. After causing the three-month delay, the compressor ran without any major problems. It was felt that if the compressor performed a heavier duty cycle, it would have run into more problems.

Another problem was the needle valves used in the high compression lines. The seals didn't hold and minor leaks occurred. Ball valves were then used to replace the needle valves. The ball valves were easier to turn at the correct turning torque. The problem was solved, and it is recommended that ball valves should always be used in high-pressure lines.

7. FUTURE PLANS

Currently, CAN has the opportunity to move from hydrogen energy demonstration to commercialization. They will be splitting the project in two parts, using its assets to enhance the hydrogen infrastructure in Southern California. Xerox Corporation will maintain hydrogen storage tanks and dispensing capability to continue to provide service for their vehicles, as well as to other vehicles that will be operating in the western end of the Los Angeles basin. Hydrogen will be trucked in to supply the facility. The generation portion of the facility, along with a new dispensing station, will be installed at Sunline Transit in the Coachella Valley to provide hydrogen and hydrogen/natural gas blends for buses planned to operate on public transit routes.

Sunline Transit of Thousand Palms has stated that they "are committed to the alternative fuels area, and we want to get to the fuel cells and the use of hydrogen as fast as we can."

The lessons learned by Clean Air Now and the rest of the project partners from the Xerox facility will be used to provide Sunline with a viable and non-polluting source of hydrogen. Clean Air Now and Sunline Transit will be ushering in the hydrogen age within the public transit sector in California.

8. CONCLUSIONS

The Clean Air Now Solar Hydrogen Vehicle Project, at Xerox Corporation, El Segundo, California, represents the first fully permitted, commercially dedicated facility of its kind in the United States. Greater public exposure to the clean energy technologies of tomorrow was effected by the project and all its participants. All aspects of the renewable hydrogen economy were incorporated into the facility by design; from renewable hydrogen generation and hydrogen storage and dispensing, to end-use technology practically applied at a private corporation. The facility demonstrated fully independent hydrogen fuel production and use, creating a virtually pollution-free transportation system.

Clean Air Now continues to work so that someday its facility will no longer be the largest of its kind in America. CAN has entertained thousands of students and other people at the facility, fostering a greater understanding of the benefits of hydrogen energy and cultivating additional efforts.