Solar Powered Hydrogen Generating Facility and Hydrogen Powered Vehicle Fleet

DOE/GO/10039--T2

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Final Technical Report

Project End Date: January 6, 1997

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April, 1997

PREPARED FOR THE UNITED STATES DEPARTMENT OF ENERGY

Under Contract No. DE-FC36-94GO10039

Final Technical Report

1. **INSTRUMENT NO.:** DE-FC36-94GO10039

2. **PROJECT TITLE:** Solar Powered Hydrogen Generating Facility and Hydrogen Powered Vehicle Fleet

3. **REPORTING PERIOD:** August 11, 1994 through January 6, 1997

4. **NAME AND ADDRESS:** **Clean Air Now**

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5. **PROJECT START DATE:** August 11, 1994

6. **COMPLETION DATE:** January 6, 1997

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7. APPROACH CHANGES:

Technical approach and scope remained consistent, once the project partners were finalized early in the timeline. This was reported earlier, and remained essentially unchanged. The only project non-critical "Scope of Work" deviation is outlined in attached cover letter to Golden Field Office personnel.

8. PERFORMANCE VARIANCES, ACCOMPLISHMENTS, OR PROBLEMS:

Outlined below are summaries of project critical deliverables (please see referenced attachments for body of report and supporting documentation).

- *"Design and Operation of the PV Powered "Stand-Alone" Electrolyzer System" technical data and discussion is included in sections 8.0-8.4 of separate numbered pages 1-12, to allow for greater depth and clarity. Proceeding the technical paper are two system *actual* output and performance charts (attachments 1 &2), contrasting a typical "cloudy" day performance with a "sunny" day "ideal" system performance scenario.

- Attachment 3 "Abstract" provides a project scope and approach overview and technical brief.

- **Please see attachment #14, Final Inspection & Building Permit, dated February 14, 1996.** Clean Air Now is proud to report that its Solar Hydrogen Generation and Refueling Facility has become the *first* "renewable hydrogen" plant to be fully permitted for operation in the U.S. The facility is also the largest of its kind in the country and the third largest in the world (Germany has the two largest solar hydrogen facilities in existence). Facility as-built blue prints are available from Clean Air Now upon request.

- Attachment 15 is ETEC' final safety assessment report "**Safety Assessment of the Clean Air Now Solar Photovoltaic Hydrogen Generation and Dispensing System**". Energy Technology Engineering Center has rated the Clean Air Now facility "**safe-to-operate**" and determined that the facility is within applicable codes and standards.

- Attachment 16 is Praxair's design detail of the "partial fill" hydrogen fueling system installed at the Xerox site in December 1994. Subsequent upgrades to support high pressure dispensing for on-board storage of 3,600 psi (DOT regulation) were made, once the solar generation and compression system was installed.

- Attachment 18 is the issuance of the California Air Resources Board's "Experimental Permit". As far as Clean Air Now knows, this is the first such permits pertaining to hydrogen powered vehicles used in a private practical application by a third party. These permits allow us to drive our hydrogen trucks legally on California roads.

- Attachments 20-22 include ETEC's deliverables on the safety assessments of the converted hydrogen trucks. These studies indicate that the trucks are "safe under normal operating conditions" and the tested vehicle "performed similarly to a gasoline fueled vehicle".

- Attachment 24 is CE-CERT's Final Report "Evaluation of Supercharged Hydrogen Fueled Ford Ranger Trucks" on emissions and performance. These studies, including an FTP-75 test, indicate the trucks perform well, even exceeding some performance parameters of the gasoline stock version. Total emissions are well with those of CARB's classification of an Ultra-Low Emission Vehicle. Carbon monoxide (CO), hydrocarbons & non-methane organic gases (HC/NMOG) gram/mile levels are substantially less those of even an Equivalent Zero Emission Vehicle. Nitrous oxides (NO_x) levels fluctuate during operation, throwing that emission level above ULEV levels at times. This is an area for improvement for hydrogen combustion technology related to the current configuration. As indicated by CARB's letter dated 9-3-93, we are confident that when fuel production is taken into consideration, our trucks, powered by renewable hydrogen, will meet EZEV emission standards.

- Please see attachment 25, "Xerox-CAN! Hydrogen Fueled Lean Burn – Supercharged Ford Ranger Pickup Trucks", for an in-depth discussion on the configuration and areas of concern related to Clean Air Now's hydrogen trucks.

- Attachment 39 is Clean Air Now's Media and Public Outreach Kit. It includes a layperson's explanation of the Solar Hydrogen Vehicle Project and related hydrogen energy technologies and issues. Also included are Congressional statements related to the project, news clippings, newsletters, photos, graphics, articles, brochures, a press release, and events attended by Clean Air Now personnel.

- We have provided tours to schools, dignitaries, and most notably the International Energy Agency. Some of the public events we have attended and participated in include: -The 1995 U.S. DOE Clean Air Road Rally on March 30 and April 1, 1995 at the Los Angeles Zoo. Then Assistant Secretary Christine Ervin was personally briefed on Clean Air Now's Solar Hydrogen Vehicle Project and viewed the hydrogen-powered truck. -Secrets of the Sun with U.S. Department of Energy, - four ECO-EXPOs in Los Angeles, -Xerox and Manhattan Beach EarthDays, -South Bay Business Environmental Council Science Fair, -MTA Transportation Awareness Week, -SAE conferences in Southern CA, -two RETSIE conferences (Golden, CO, and Los Angeles), -Alternative fueled Fleets conferences, -Automotive Educators Conference at Rio Hondo College, Whittier, California (11/95). – "Element One" video production, -NHA U.S. Hydrogen Meetings, -two World Hydrogen Conferences (Florida and Germany), -two World Hydrogen Summits ('96 and '97), -2000 school children, -IEA, -AQMD, -BMW, -FORD, - German government, -Taiwan, celebrities, and numerous others have been exposed to hydrogen energy technologies and their benefits to society.

9. OPEN ITEMS: 2

1) Final invoice reimbursement. 2) Property Inventory Certificate-Assistance and Patent Certification.

10. STATUS ASSESSMENT AND FORECAST:

All contract objectives and purpose have either been met or surpassed. Additional monies and commitments have been obtained for enhancement of project programming and continuance of facility operation.

11. DESCRIPTION OF ATTACHMENTS: (Consisting of report body and supporting documentation, in order.) {**Bold** text indicates project critical documents.}

1. System Performance Chart 1 "cloudy day" 1-27-97.
2. System Performance Chart 2 "sunny day" 1-16-97.
3. Project Abstract.
4. Project Photo – Aerial view with Electrolysis Module surrounded by the PV array and hydrogen storage tanks and fueling station in upper left of fenced area. Surrounding area is portion of Xerox' El Segundo facility.
5. Project Photo – Electrolysis Module amidst Photovoltaic array.
6. Project Photo – Electrolytic Cells.
7. Project Photo – Dr. Scott refueling one of Xerox' hydrogen trucks, with PV array in background.
8. Project Photo – Dr. Scott at refueling island with commercial hydrogen storage tanks in background.
9. **Financial Status Report for period 10-1-95 to 9-30-96.**
10. Project Billings Recap; Billings through 12-31-96.
11. Financial Status Report for period 7-1-95 to 9-30-95.
12. Financial Status Report for period 4-1-94 to 6-30-95.
13. Project Assessment dated 8-2-95.
14. Final Project El Segundo City **Building Permit** dated 2-14-96, and Fire Department Safety Inspection Record.

15. Energy Technology Engineering Center's Final Report for "**Safety Assessment of the Clean Air Now Solar Photovoltaic Hydrogen Generation and Dispensing System**" dated 3-15-96. (Test Plan available upon request)

16. Design Detail for Phase I Fueling System.

17. Hydrogen Plant Maintenance Schedule.

18. Hydrogen Trucks' **Experimental Permit** allowing operation on California roads issued by the California Air Resources Board, and supporting documentation, dated 7-26-96.

19. CARB letter regarding hydrogen trucks' emissions testing and ZEV rating, dated 9-3-93.

20. ETEC's follow-up letter to Test Report "**Xerox-CAN H_2 Fueled Ford Ranger Test Report**", dated 4-5-96.

21. ETEC's Final Test Report "**Xerox-CAN H_2 Fueled Ford Ranger Test Report**", dated 7-13-95. (Test Plan available upon request)

22. ETEC's Final Report "**Safety Evaluation For Unrestricted Use of the H_2 Fueled CAN Ford Ranger**", dated 9-29-95. (Test Plan available upon request)

23. Summary of Emissions Characteristics, addendum to CE-CERT's Final Report "Evaluation of Supercharged Hydrogen Fueled Ford Ranger Trucks", dated 3-5-97.

24. University of California at Riverside CE-CERT's Final Report "**Evaluation of Supercharged Hydrogen Fueled Ford Ranger Trucks**" on emissions and performance, dated 96.

25. Kaiser Engineering's Final Report "**Xerox-CAN! Hydrogen Fueled Lean Burn – Supercharged Ford Ranger Pickup Trucks**", dated 4-29-95.

26. Kaiser Engineering's Operating and Maintenance Procedures for "Xerox-CAN! Hydrogen Fueled Lean Burn – Supercharged Ford Ranger Pickup Trucks", dated 4-21-96.

27. R.M. Zweig, M.D., Clean Air Now. "PM10 Pollution//Solar Hydrogen Solution", presented at the *World Car Conference*, Riverside, California, January 1997.

28. J. Provenzano, P.B. Scott, Ph.D., R. Zweig, M.D., "Solar Hydrogen for Urban Trucks", presented at the *National Hydrogen Association's 8th Annual U.S. Hydrogen Meeting*, Alexandria, Virginia, March 1997.

29. K. Knudsen, presentation paper on ETEC's findings and "lessons learned" from CAN contract deliverables, presented at the *National Hydrogen Association's 8th Annual U.S. Hydrogen Meeting*, Alexandria, Virginia, March 1997.

30. J. Provenzano, P.B. Scott, Ph.D., "Clean Air Now's Solar Hydrogen Vehicle Project – A Hydrogen Fuel Technologies Deployment Project at Xerox Corporation in El Segundo, California USA", presented at the *11th World Hydrogen Energy Conference*, Stuttgart, Germany, June 1996.

31. R.M. Zweig, M.D., "The Developing Hydrogen Corridor – Southern California", presented at the *11th World Hydrogen Energy Conference*, Stuttgart, Germany, June 1996.

32. J. Provenzano, P.B. Scott, Ph.D., R. M. Zweig, M.D., "Demonstration of Fleet Trucks Fueled with PV Hydrogen", presented at the *11th World Hydrogen Energy Conference*. Stuttgart, Germany, June 1996.

33. J. Provenzano, Clean Air Now, presentation at the *Association of Environmental Professionals*, Los Angeles, California, April 1996.

34. W. Kaiser, J. Provenzano, P.B. Scott, P. Staples, R. Zweig, Clean Air Now. "Supercharged Hydrogen Fueled Trucks", presented at the *World Car Conference*, Riverside, California, January 1996.

35. J. Provenzano, Clean Air Now, "Clean Air Now/Xerox Solar Powered Hydrogen Generating Facility and Hydrogen Powered (Utility) Vehicle Fleet. An Hydrogen Fuel Technologies Demonstration Project, El Segundo, California", presented at the *National Hydrogen Association's 6th Annual U.S. Hydrogen Meeting*, Alexandria, Virginia, March 1995.

36. C. Buntine, "Driving Towards Renewable Energy – Encouraging the use of Hydrogen Fuel in Automobiles", Final Paper, *Department of Urban Planning, School of Public Policy and Social Research, University of California at Los Angeles*, June 1995. (Also available is a study on the development of a sustainable energy component village concept.)

37. Award from U.S. Department of Energy to Clean Air Now for efforts related to the Clean Cities Program. (Commendations from the Lt. Governor's Office of California, and the City of Los Angeles are available upon request.)

38. Letter from International Energy Agency to Clean Air Now re: tour, dated Spring 1996.

39. Media and Public Outreach Kit, including project graphics, photos and information, commissioning press release, articles, brochure, newsletters, events, and Congressional statements.

12. SIGNATURE OF RECIPIENT AND DATE:

James J. Provenzano, Executive Director 5-16-97

13. SIGNATURE OF DOE REVIEWING REPRESENTATIVE AND DATE:

Design and Operation of the PV Powered "Stand-Alone" Electrolyzer System

8.0 Introduction

The intent to manufacture hydrogen without polluting emissions dictated that the electrolyzer operate from solar power, without aid from the utility grid. Hence the system was built to "stand alone" , with no connection to the electrical power grid. The electrolyzer and the hydrogen compression system as well operate directly from the photovoltaic (PV) array. The hydrogen generated is - in entirety - *Solar Hydrogen*, in the sense that the energy to generate it comes from the sun. Thus the hydrogen generation occurs only during the sunlit hours of the day, with effectively no generation even on cloudy days.

This section will start with a description of the PV array and the current collection bus bar, proceeding to the electrolyzer and to hydrogen compression and storage. The description of the system is followed with typical operation data and analysis.

8.1 The Photovoltaic System

Sun tracking Fresnel lens concentrators make up the bulk of the photovoltaic (PV) array, supplemented by a fixed panel array. The single axis tracker array consists of forty sub-arrays of 12 tracking concentrators each. Each sub-array has an electronic sun-seeker tracker which at dusk returns the concentrators to point towards the zenith overnight - so as to better sense the morning sun.

The extruded plexiglass Fresnel lens concentrates the sun's energy by ten times onto the single crystal silicon cells which are mounted on an extruded aluminum heat sink. Two sizes of concentrators are represented in the array - 11" and 15" width. The concentrators are approximately 11.5 feet in length, so at a time with insolation of 850 watts/M^2 the two sizes intercept respectively 254 and 346 watts optical, or 3.05 and 4.15 KW per subarray.[1] The fins of the heat sink are cooled by convection and radiation to the ambient air.

Figure 8.1 illustrates the plan view of the PV array, the bus bar collecting the current from the array, and the electrolyzer. Each concentrator yields several amperes at approximately 15 volts, and all are connected in parallel. The sub-arrays are tied together with cables, and the one adjacent to the bus-bar is tied by cables to said bus. The bus is made of 1/4" x 6" copper bar, with doubling in the parts that conduct near a thousand or more amperes

1 Eventually we will get to the question of how much land area is required to supply fuel for a vehicle. Here it is of interest to distinguish a first inefficiency of the tracking array, which requires - in our case - a footprint of approximately 20 by 24 feet for the tracking subarray. At most, a total of 1.25' x 11.5' x 12 = 173 ft^2 of normal insolation is intercepted, as compared to the 480 square feet of the foot print. A flat plate array on the same footprint would intercept (at spring or fall solistice, 35° latitude) as much as 393 square feet at solar noon, decreasing rapidly for the morning or afternoon sun.

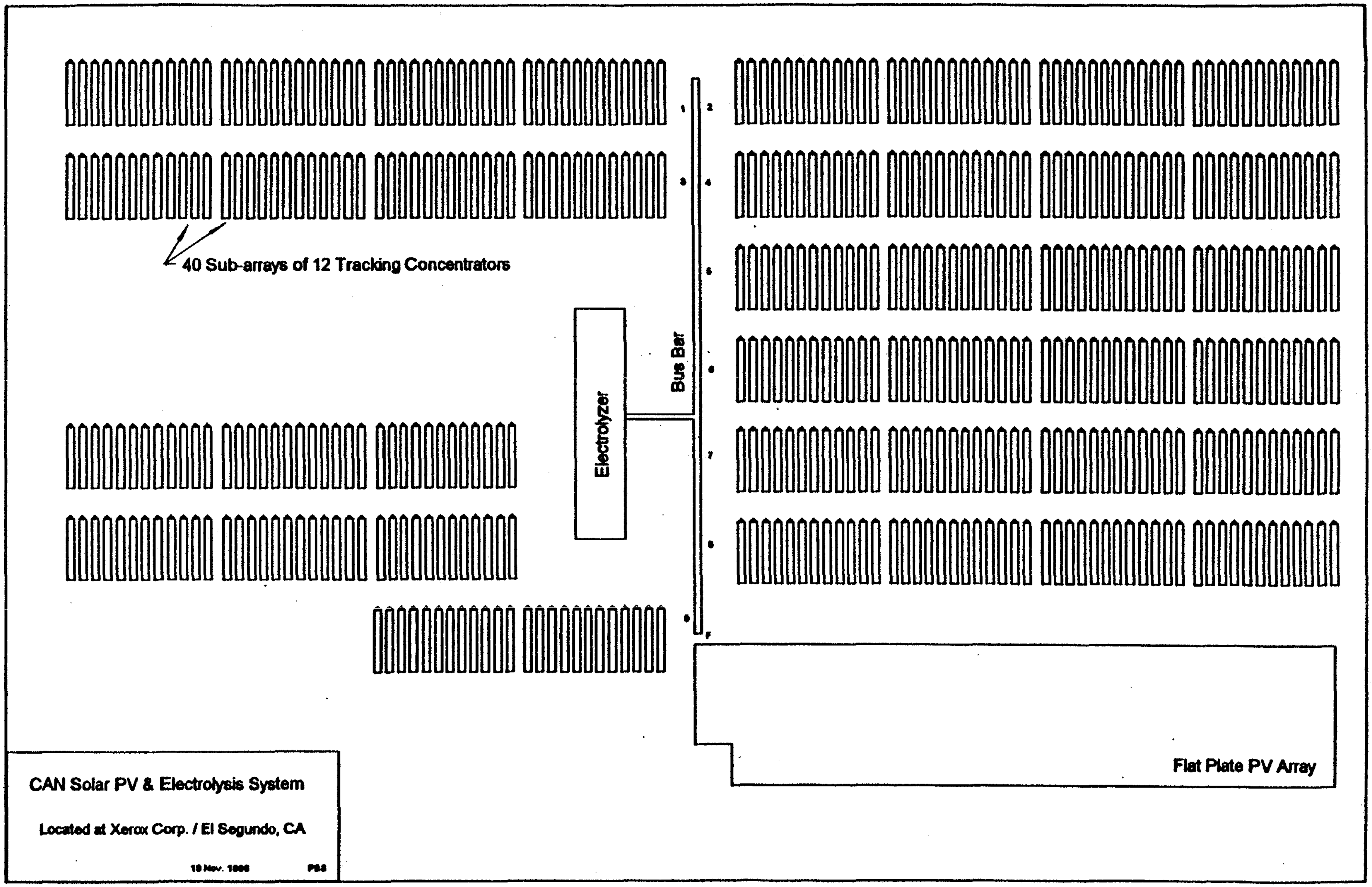
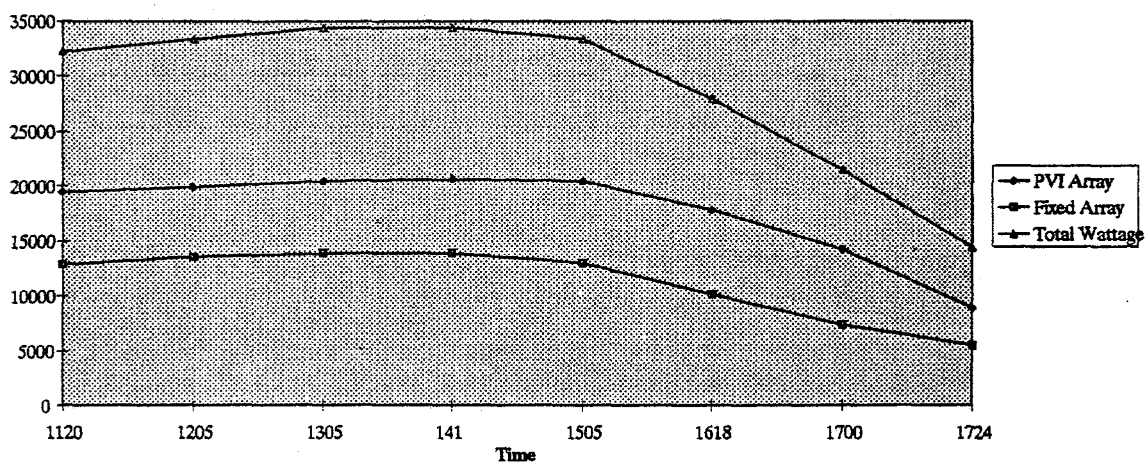


Figure 1 Plan view schematic of the PV array, bus bar and electrolyzer. The numbers by the bus bar represent the current collection points discussed in the text.

PV array performance on 14 August 1996 was measured by voltage and current measurements at the 9 major points of interconnection to the primary bus bar. Viewing Figure 8.1, collection point 1 is at the right end of the upper - left four subarrays, noted by the number 1.

The performance of the PV array on that date is shown in Figure 8.2. As it was a cloudless although hazy day, with peak direct insolation measured at 817 watts/M^2, it is representative of a typical summer day at this coastal locale. Solar noon is at 12:58.[2] It is notable that although the tracker curve tends to be more flat than the curve obtained from the flat plate array, both fall notably at more than 2 hours from solar noon.

Figure 8.2 . PV Array Wattage on 8/14/96



8.2 Description of the Electrolyzer System

The electrolyzer is schematically illustrated in the following block diagram. Water from the city mains is demineralized and added to the cell bank to replenish that lost in the electrolysis process. Oxygen is kept separate by membrane separators and by the water seal. The oxygen generated is vented to atmosphere, while the hydrogen passes through a porous mist eliminator and thence to temporary storage in the gas holder. If the compressor is not run - due for instance to low sun or cloud cover - the hydrogen is vented by the gas holder when full.

The PV Array power is available to the electrolysis process or to the inverter for compression. The inverter requires from 500 to 800 amperes, depending on gas pressure and voltage. The PV Array also supplies current to the battery charger, to maintain the batteries used to maintain control power at all times.

[2] We use the 24 hour format for representing time in the data figures.

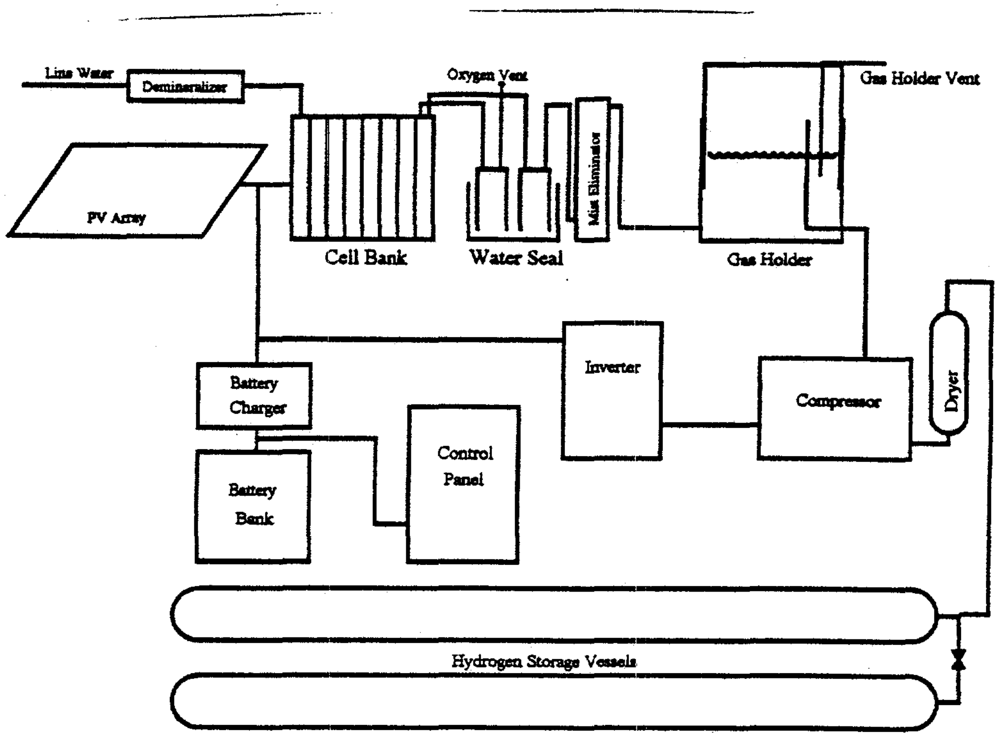


Figure 8.3 Illustrating the Components used in the PV Hydrogen Production Process

The compressed gas contains excessive water, which is removed by the dryer before the hydrogen is passed to storage.

The electrolysis system was constructed in a ten meter shipping container by The Electrolyser Corporation. Included therein are:

* Eight electrolysis cells, each rated at 3200 amperes. They are connected in series so as to provide a system of 16 volt nominal rating. The electrolyzer cells can produce to 400 SCF (standard cubic feet) of hydrogen per hour.

* Gas handling to release the oxygen to atmosphere and to provide low pressure temporary storage of hydrogen production in a 1.5 M^3 capacity gasholder.

* A 15 HP compressor suitable for operation with hydrogen at pressures to 5000 psi - now derated to 4200 psi. A dryer stage reduces the water content to attain dewpoints below 0°C.

* A variable speed inverter (designed for operation from voltages as low as 12 volts) to provide a "soft start" of the compressor.

* An electrolyzer control and data logging system which allows operation without an attendent 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 the dark nights (at which time no hydrogen is produced).

The compressed solar hydrogen is stored in two forged steel cylinders of 7 meter length and water volume of 823 liters (29.1 cubic feet). A regulator is provided such that one cylinder can be held at a higher pressure - as may be appropriate for 2 stage filling. At the present peak operation pressure of 4200 psi the tanks store 245.33*29.1*2=14,278 SCF hydrogen.[3]

These tanks are used solely for the solar hydrogen. To provide capability for large vehicles, an additional 80,000 SCF of commercial hydrogen are stored in adjacent tanks.

The solar and the commercial hydrogen are used to fuel the trucks by means of a fueling station which can access either storage system. Check valves assure that the high pressure solar hydrogen cannot enter the commercial hydrogen tanks. The connection to the trucks is by means of a CGA (Compressed Gas Association) 350 connector.

8.3 Examples of System Performance

Datalog traces of insolation and other performance parameters are illustrated in Figures 8.4-6, showing three days following a Thanksgiving Day rain.

Friday the first response of the system to the morning light (starting at approximately 6:40) is the system voltage rising from near zero to ten volts and more, even before notable insolation is recorded. The insolation appears to rise rathur suddenly - but it is likely that the signal is delayed by the fact that the solar sensor is mounted on one of the tracking concentrators and hence pointing toward the zenith. As the trackers "wake up" to the sun and turn east the recorded insolation suddenly rises.

Curiously, the current rises slowly, with a near linear rise with time from 7 am for the next couple hours. This unexpected phenomen is certainly due in part to the lack of participation of the flat plate array, which sees but little of the sun at 7-8 am. The reluctance of the current to rise also reflects an initial high resistance of the circuit - which may be attributed to the cold electrolyzer[4] and/or polarization effects. (The inverter - in standby mode - is at high impedance so the current passes through the electrolyser.) Clouds interfere with the increase of current, first at about 7:35 and more substantially at approximately 8:30.

The bottom trace represents the inverter current Iinv. The inverter starts only after the gasholder is full, which is generally the case first thing in the morning - as the late afternoon sun has replenished the gasholder hydrogen. (The hydrogen automatically vents

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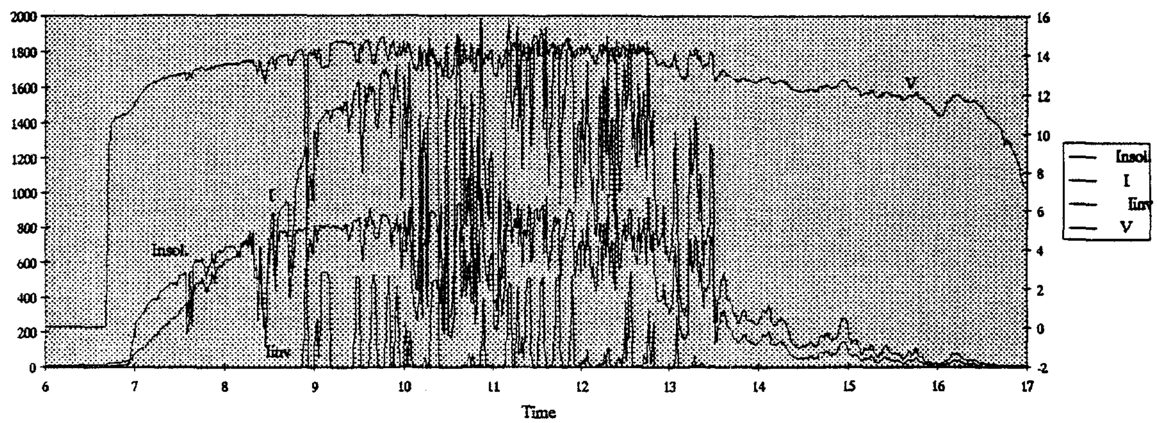
[3] The Electrolyser Corp. rates these tanks at 4700 psi with storage volume of 17,158 SCF.

[4] The 6 am temperature was 59°F.

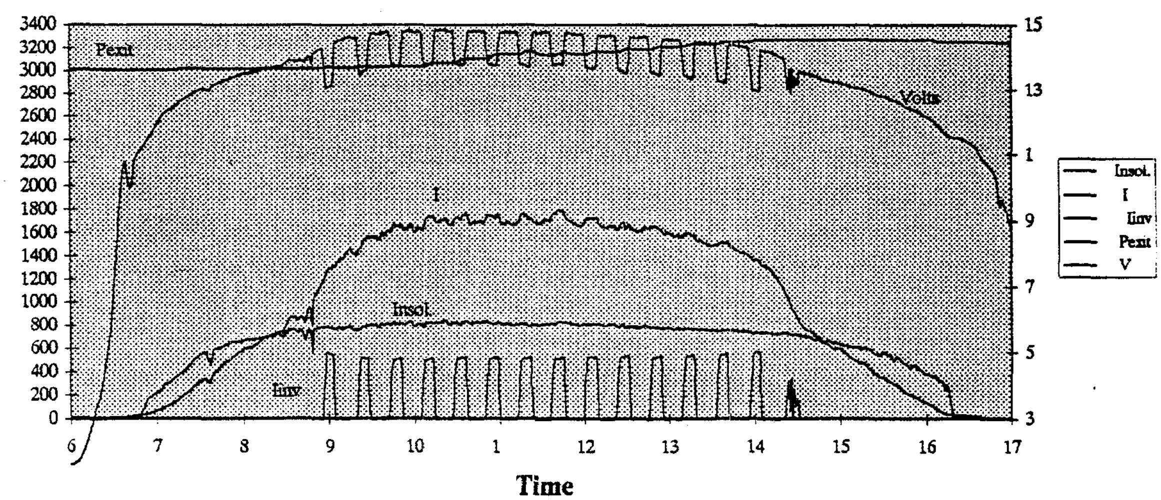
until the inverter can run.) The inverter is allowed to run only after the current I rises above 1000 amperes. We note that it comes on at about 8:53 and compresses gas for a

Figure 8.4. I, Insol., Iinv & Voltage for Friday, Nov. 22



couple minutes until another wisp of cloud interferes.[5] Just after 9 am we see (by the bottom trace of Iinv) the compressor start and run for nearly ten minutes as it compresses a gasholder of hydrogen. Having emptied the gasholder, it is turned off and all the current again goes to generate hydrogen. The next compression cycle, at approximately 9:30, is interupted by another cloud . By about 10 am the broken cloud ceiling has interrupted all productive activity, the hydrogen is vented as the compressor repeatedly attempts to start but a cloud then intereferes. We see a good compression cycle at approximately 10:20, followed by cloud interference until several productive cycles between 11 am and noon. The afternoon deteriorates rapidly as the broken coastal layer causes the current to drop to only a few hundred amperes by 2 am.

Figure 8.5. Pexit, V(at right), Insolation, I and Iinv for Saturday Nov. 23



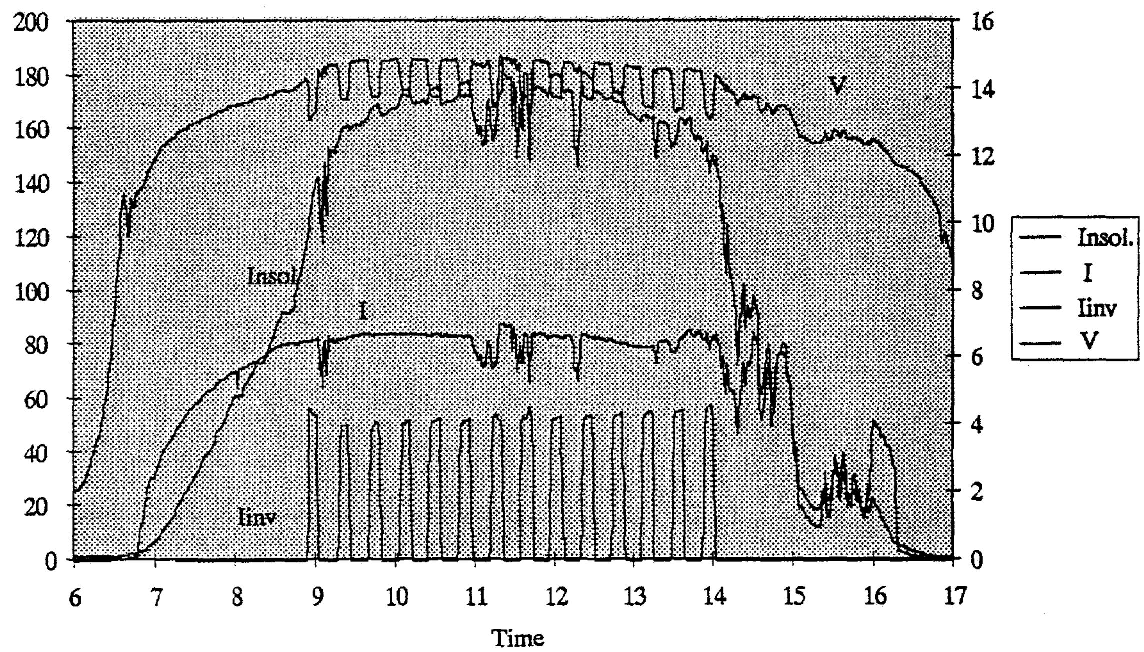
[5] The recorded voltage behavior here - a drop to 1.47 volts at 8:55 - appears to be of instrumental origin. Other parameters - current, insolation and Iinv - are consistant with one another and represent correct operation of the system.

The following day (Saturday, Nov. 23) was clear of the moisture which interfered with compressor operation on Friday. The only suggestions of clouds occur before 9 am, and the day proceeds with regular compression cycles until the last is terminated by insufficient current just before 14:30. The very rapid decline of the current following 14:00 is likely due to the coastal breeze bringing in haze, which caused the direct radiation needed by the concentrators - to be scattered

We have presented the pressure Pexit at top of the figure. The pressure increased from 3015 psi in the morning to 3272 psi at 16:00. Part of this gain is due to heating of the system with the warming of the day, but some 200 pounds of pressure increase can be attributed to the hydrogen generation and compression.[6]

The following day, Sunday Nov. 24, was also a good production day, as illustrated in the following figure. Five hours of good production are observed, with the days compression being terminated by the coastal haze at 2 pm.

Figure 8.6 I, Insol., Iinv and Voltage for Sunday 24 Nov.



These results show that in November about 5 hours of production is compressed to the tanks, Figure 8.2 suggests that as many as 10 hours of production is possible in August. (We have no hydrogen production from that date.) The production is thus expected to be over 7 hours per day average, with approximately three compression cycles

[6] The hydrogen storage volume is composed of two forged steel pressure vessels of 823 liter (29.1 cubic feet) water volume each. Thus a 200 psi pressure increase corresponds to hydrogen production of 200*29.1*2/14.7=792 std. cubic feet.

per hour. At a average current of 1800 amperes through the eight cells, we would expect 225 standard cubic feet per hour.

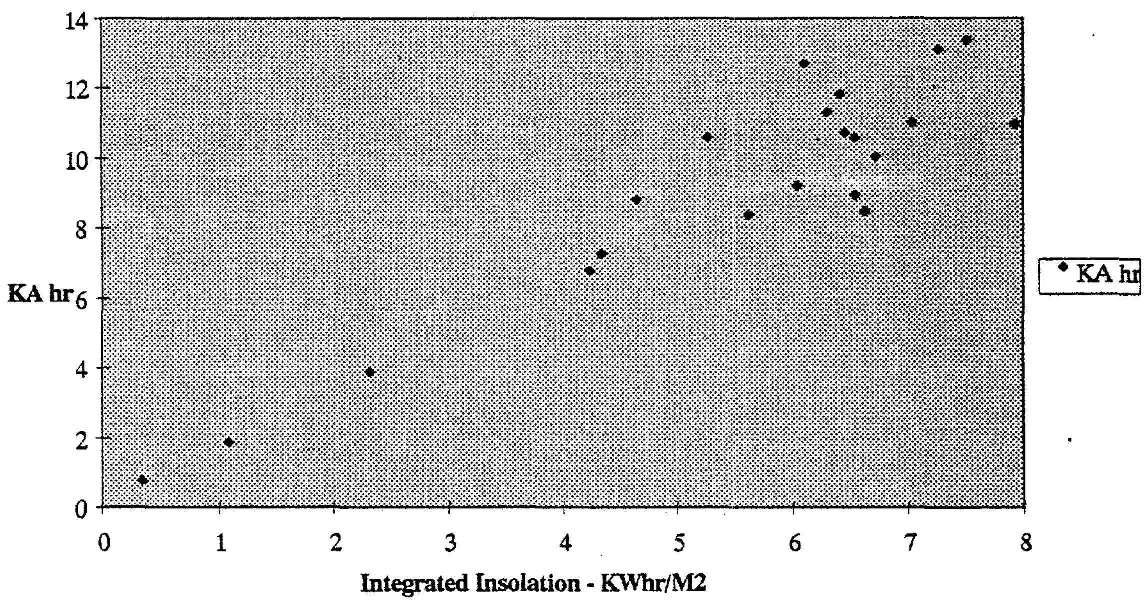
We proceed to correlate and discuss the production as experienced.

8.4 Data Evaluation and Discussion

8.4.1 Relationship of sun to current to production

Figure 8.7 shows the time integrated current from the PV array as dependent upon the insolation, where we use the integrated insolation as measured by the Licor sensor which tracks with one of the concentrators.

Figure 8.7 Days Amp-Hrs as driven by Insolation

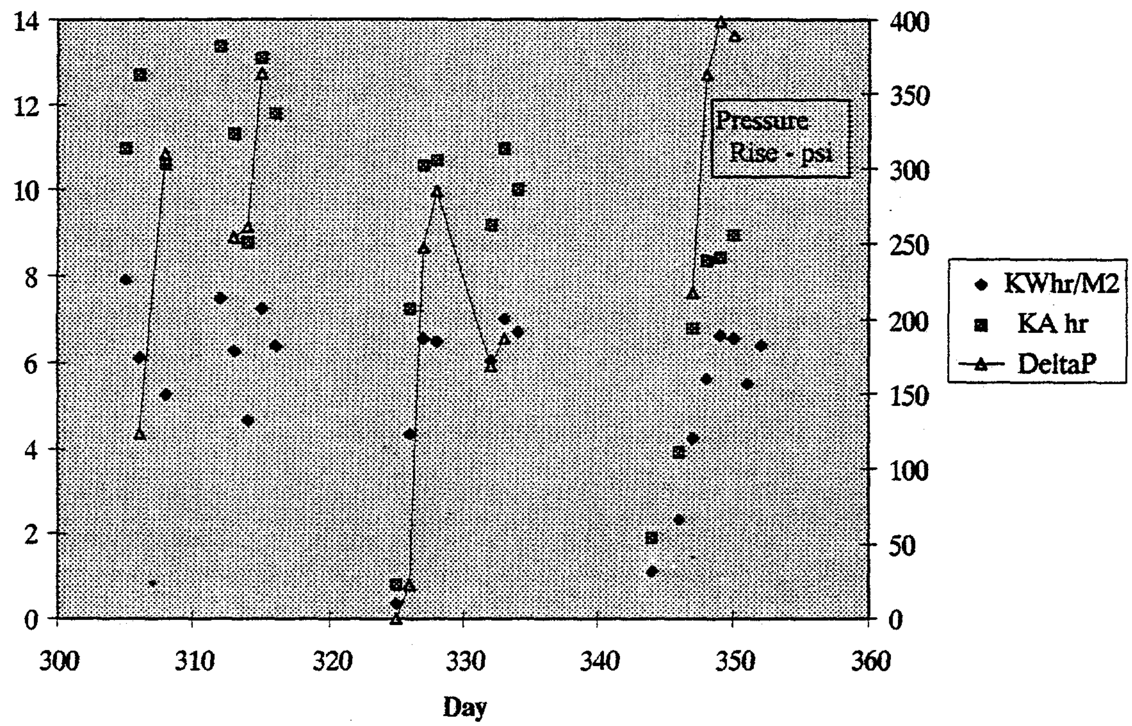


The dependence varies from the expected linear dependence, especially on the better solar days - perhaps due to the increased effectiveness of the direct insolation.

Figure 8.8 illustrates the integrated insolation, current and pressure rise (increase in Pexit, the pressure measured by the Rosemont pressure transducer) for days starting the first of November (represented here as day 305). There are two gaps in the data, first, around day 320 (Saturday, Nov. 15) due to an electrical failure of the inverter which took a week to correct, and secondly, in early December (days 335-343). The high pressure rises of days 347-350 represent single tank filling (the west tank was shut off) and hence should be halved for comparision with the others.

The largest values of integrated insolation approach 14 KWhr/M2. We note that the peak KA hr and thus the pressure rises decrease with time, probably largely due to the shortening of the days towards the winter solstice.

Figure 8.8 Days Insolation, Amp-hr & Production



8.4.2 Production as estimated from the integrated current

There are two approaches to estimating the hydrogen production. The fundamental approach is to use the electrochemical approach, where each electron transfered is related to a hydrogen atom released. Alternatively, one can estimate the production from the observed increase of pressure.

The former approach has its limitations, in that one must be careful to count only those electrons that result in hydrogen which is compressed. Thus cloudy day current does not count (because that hydrogen is lost as the current required to run the compressor is not available, and after the gasholder is full the hydrogen is released to the atomosphere), and some of the early and late day current is not collected (for the same reason). Finally, even on the sunniest of days, current used to run the compressor does not generate hydrogen. (This is of note as our current shunts measure total current and inverter current - only the difference is used for generation. Total current is plotted in the prior two figures.)

Starting from the electrochemical equation for electrolysis of water,

$$H_2O \dashrightarrow 2\,H^+ + O^{--} \dashrightarrow 2\,H^+ + 2e^- \;+\; O^{--} - 2e^- \;\dashrightarrow\; H_2 + O$$

and noting that the generation of a mole of H_2 takes 2 moles of electrons (= 2 x 6.023 x 10^{23} electrons), or two times 96,500 coulombs, it follows that

1 kg H_2 requires 96.5 x 10^6 ampere seconds = 26,805.6 amp. hr.

(The power demand is related to the voltage, which depends on temperature in a complex way.[7]) The solar hydrogen generator uses eight cells in series - and each generates a mole of diatomic hydrogen with 2 moles of electrons. Hence for the eight cell stack, 3350.7 amperes for one hour generates one kg H_2. From Fig. 8.7 we infer that the best of November days we might expect solar production of three kilograms of hydrogen.

Putting this in energy terms, a kilogram of hydrogen has a high heat value of 142 MJ or low heat value of 120 MJ.[8] In turn relating this to the capability of propelling an advanced vehicle[9] it appears the kilogram of hydrogen has the potential of fueling a Ford Taurus sized vehicle for a distance of approximately 80 miles.

As we often refer to production in terms of standard volume, it is useful to note that a kilogram hydrogen at NTP (70°F and 14.70 psia) occupies 432.2 cubic feet (or occupies 11.36 cubic meters at STP - 0° C).

It is appropriate to compare the total amperage I with I_e (the **effective amperage**), defiined as that which generates hydrogen which is compressed.[10] This depends on the weather, with clouds there is loss of compression capability. Also, in the early morning and late afternoon there may be a loss of current due to an inability to run the compressor even though the gasholder is full. Figure 8.9 relates the total amperage (as was presented in Figure 8.7) to the useful amperage, defined for this figure as that current available to the electrolyzer cells from the start of the compressor in the morning until the current drops to 1000 amperes in the afternoon. (Or at an earlier hour if clouds interfere.) This data set includes all days of useful hydrogen production during November, 1996.[11] The data can

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7 S.S. Penner & L. Icerman, *Energy, V. II Non-Nuclear Technologies*, Addison Wesley (1975)

8 J.B. Heywood, *Internal Combustion Engine Fundamentals*, McGraw-Hill (1988)

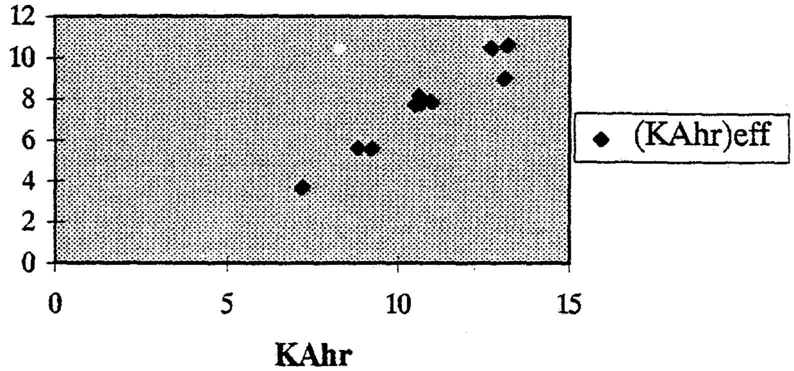
9 J. Ray Smith, *Hydrogen Hybrid Design*, Lawrence Livermore Radiation Laboratory UCRL-JC-115425 (1993)

10 As I includes the current used to compress the hydrogen <u>and</u> that used to generate hydrogen, I_e will always be less than I by some 20% at best. The optimal system design - that with the highest quotient of I/I_e - will be able to efficiently compress the gas even under low sun conditions.

11 Note the data point right side at 9 KAhr ordinate - this was from the day preceeding an observed failure of the inverter, which caused the system to be inoperative for over a week in mid-November. This point should likely be disregarded, as the inverter currents are unusually high during the latter part of the day, causing the $(KAhr)_{eff}$ to be lowered.

be fitted by a straight line which can be represented as $(KAhr)_{eff} = 1.21\ (KAhr - 4.1)$.

Figure 8.9 Effective amp-hours as dependent on total KA-hr from the PV Array - Nov. 1996



8.4.3 Production as estimated from pressure rise - The influence of temperature and leakage

As indicated in footnote 6 (Page 7), the observed increase in pressure resulting from hydrogen generation can be related to production - but there are limitations and uncertainties. We proceed to discuss this in some detail.

As noted towards the end of Section 8.2, the tanks hold 14,278 SCF hydrogen at 4200 psig, or 3.40 SCF/psig. The clearest November days (Figs. 8.5, 8.6) yielded an average of 10.64 KA hr and an average of 266 psi pressure increase. Production and compression occurred for a 5.2 hour period, and we can estimate that the production was 266*3.4=904 SCF, or 174 SCF/hr. In fact, we were losing some production to leakage and in turn some of the pressure rise was due to heating. Potentially useful observations of leakage come from the periods in which we are not operating but the weather is sunny - such as mid-November and early December.

As we lack hydrogen production data during the summer, it is useful to estimate the production as a function of time of year. We note that during the short days of November and December, the best days show hydrogen compression which begins approximately 2 hours after sunrise and ends 2 hours before sunset. Thus in "the dead of the Los Angeles winter", with days 9-10 hours long, the best days have 5 hours of production and compression.

To further quantify this, we refer to the representation of the length of the day [12] as dependent upon the latitude of the site and the declination.

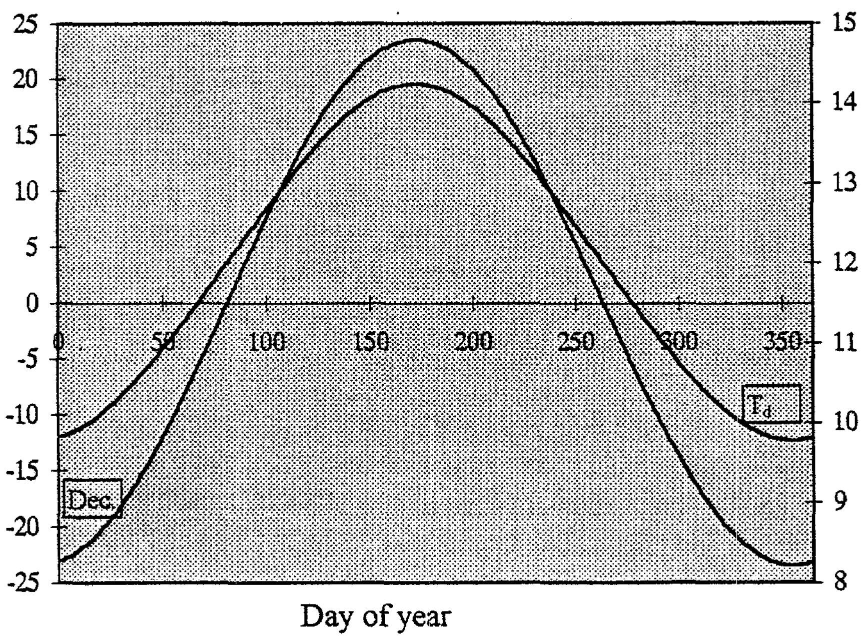
[12] J. A. Duffie & W..A. Beckman, *Solar Energy Thermal Processes*, Wiley (1974)

The latitude angle ϕ is 33.56° for our site in Los Angeles. The declination (the angular position of the sun at solar noon with respect to the plane of the equator) is dependent upon the day of the year. Calculating some representative values of the duration of the day T_d :

Date	Day	δ	T_d
January 1	1	-23.01	9.82 hrs
March 21	80	-0.40	11.96 hrs
June 21	172	23.45	14.23 hrs
Nov 1	305	-15.36	10.60 hrs
Dec 1	335	-22.11	9.92 hrs

Graphically representing the dependence:

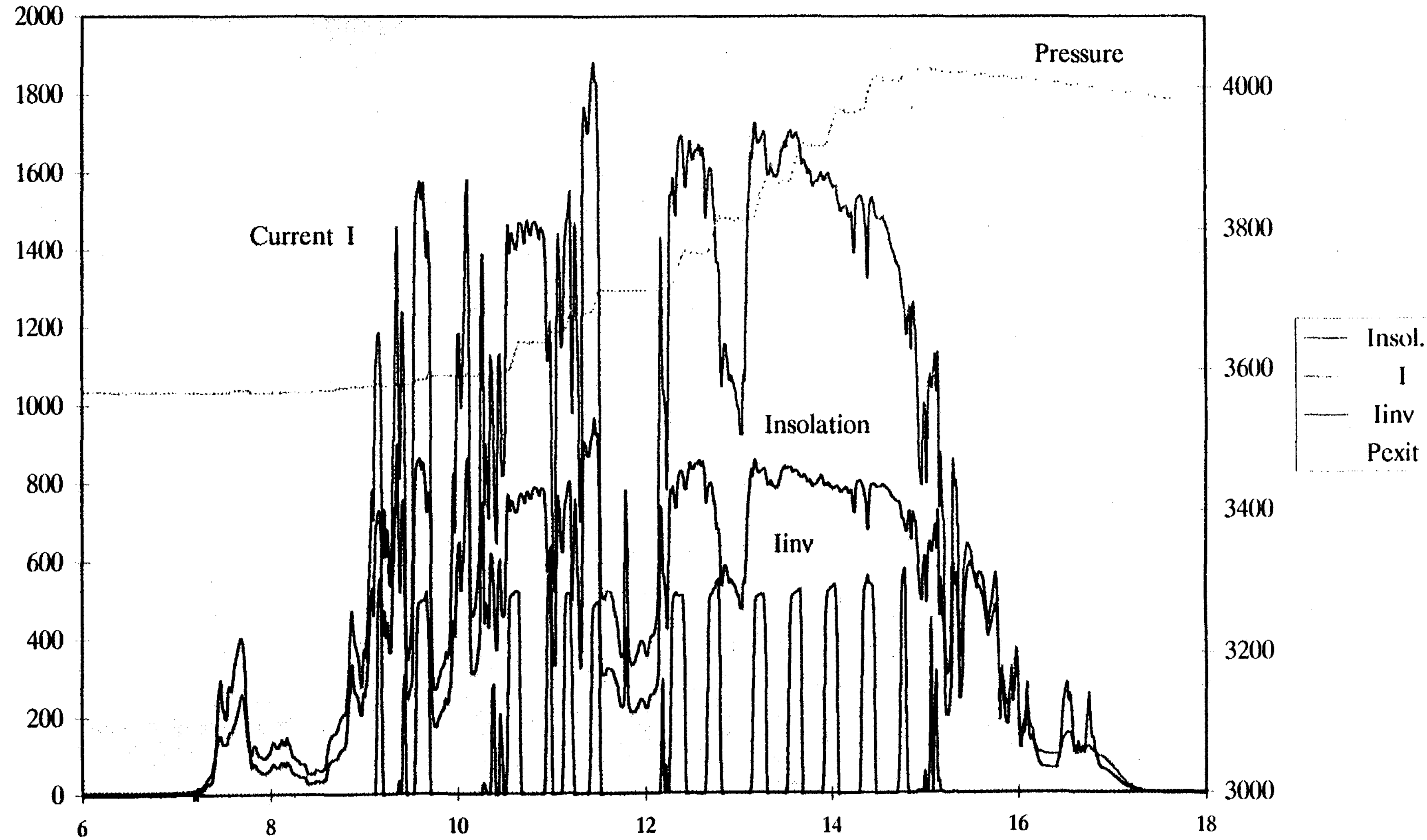
Figure 8-10 Day length, declination over year.



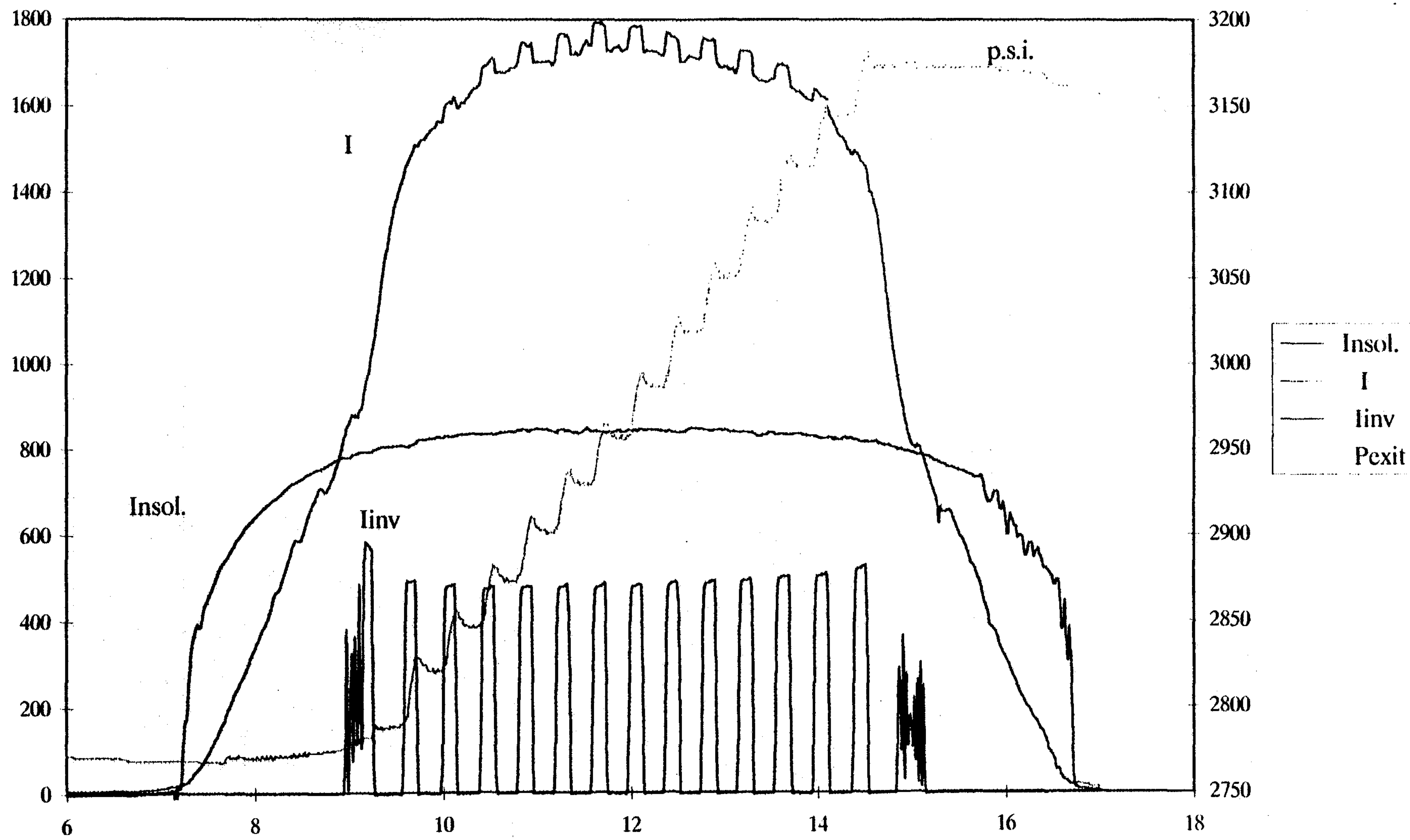
From this representation it appears that the summer production will occur for 9 or more hours, and so is expected to be nearly double that of the winter.

JAN2897 Chart 1

Jan. 27, 1997



January 16, 1997



CLEAN AIR NOW
SOLAR-POWERED HYDROGEN GENERATING FACILITY AND HYDROGEN POWERED VEHICLE FLEET

A HYDROGEN FUEL TECHNOLOGIES DEMONSTRATION PROJECT EL SEGUNDO, CALIFORNIA

James J. Provenzano
Clean Air Now
Santa Monica, CA 90401
(310) 394-1214, Fax (310) 917-4426

Abstract

Clean Air Now, a California non-profit, public interest and advocacy corporation, has received funding from the White House Technology Reinvestment Project, the state of California, and its project partners to deploy solar hydrogen technologies at the Xerox Corporation facilities in El Segundo, California.

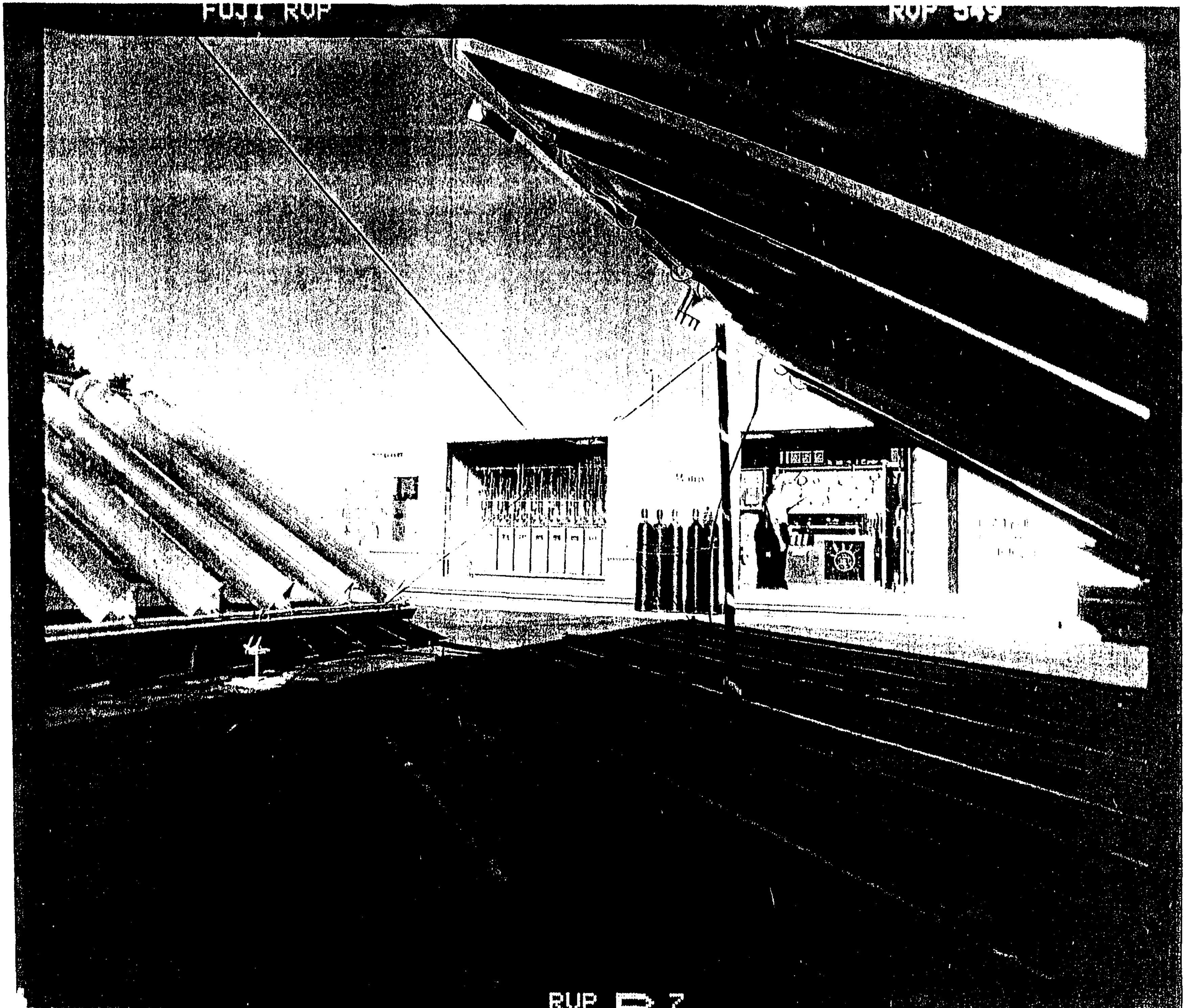
Clean Air Now, along with project participants (U.S. Department of Energy, Xerox, South Coast Air Quality Management District, The Electrolyser Corporation, Praxair, Inc., PhotoVoltaic International, Advanced Machining Dynamics, Energy Technology Engineering Center/Rockwell, University of California at Riverside, W. Hoagland & Assoc., Inc., Touchstone Technologies, and the City of West Hollywood) have installed one of the major components of the developing hydrogen infrastructure in southern California.

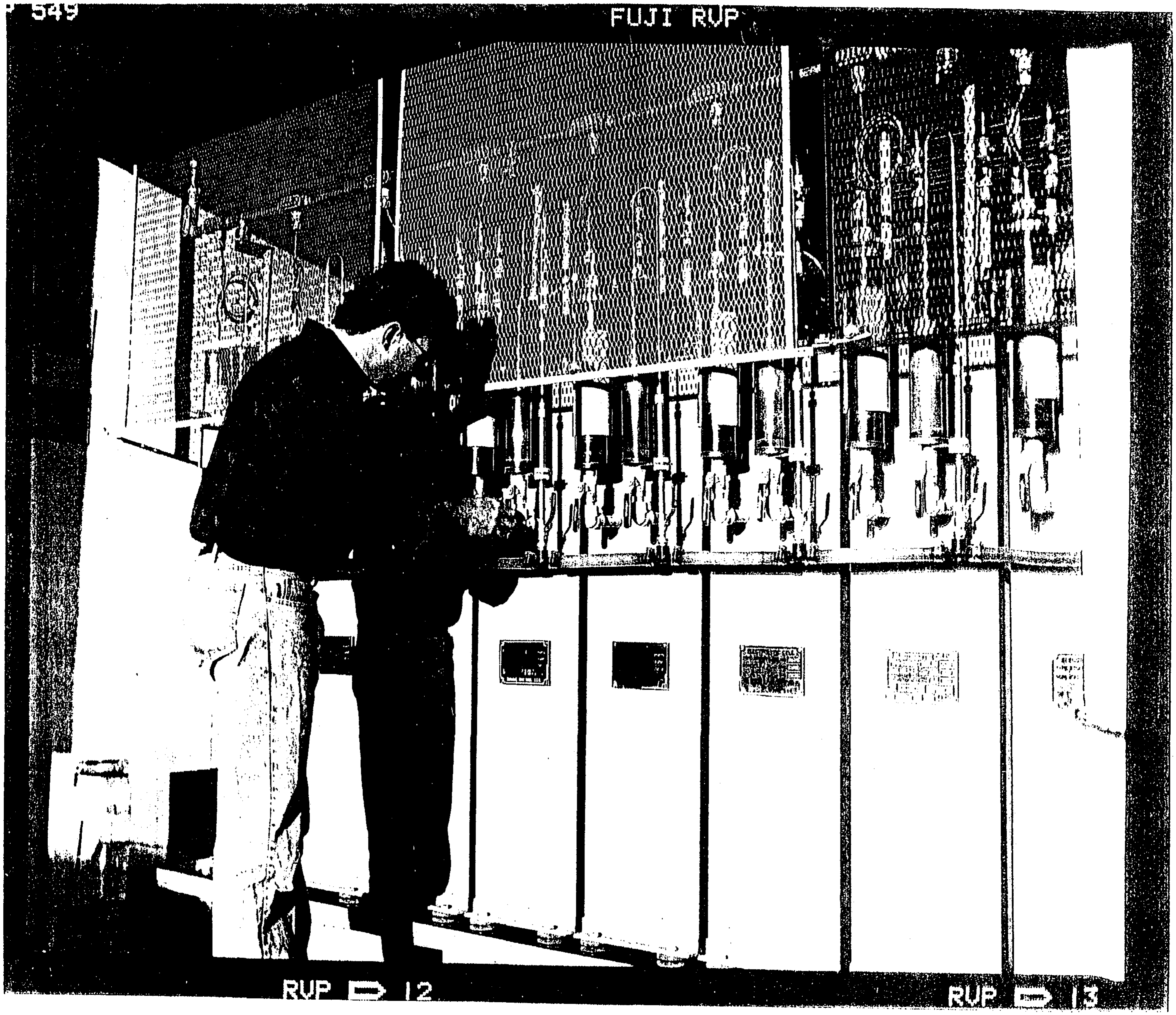
The project consists of: a stand-alone, 100% pollution-free, photovoltaic-electrolysis system that is capable of producing 400 SCFH of pure hydrogen gas; 13,000 SCF of storage @ 5,000 psi; 73,000 SCF of storage @ 2,000psi; three retrofitted ICE utility pickups; and data acquisition capability. The project scope also entails a comprehensive public awareness campaign, a detailed systems safety analysis and review, and the integration into other hydrogen generation and transportation technologies programs.

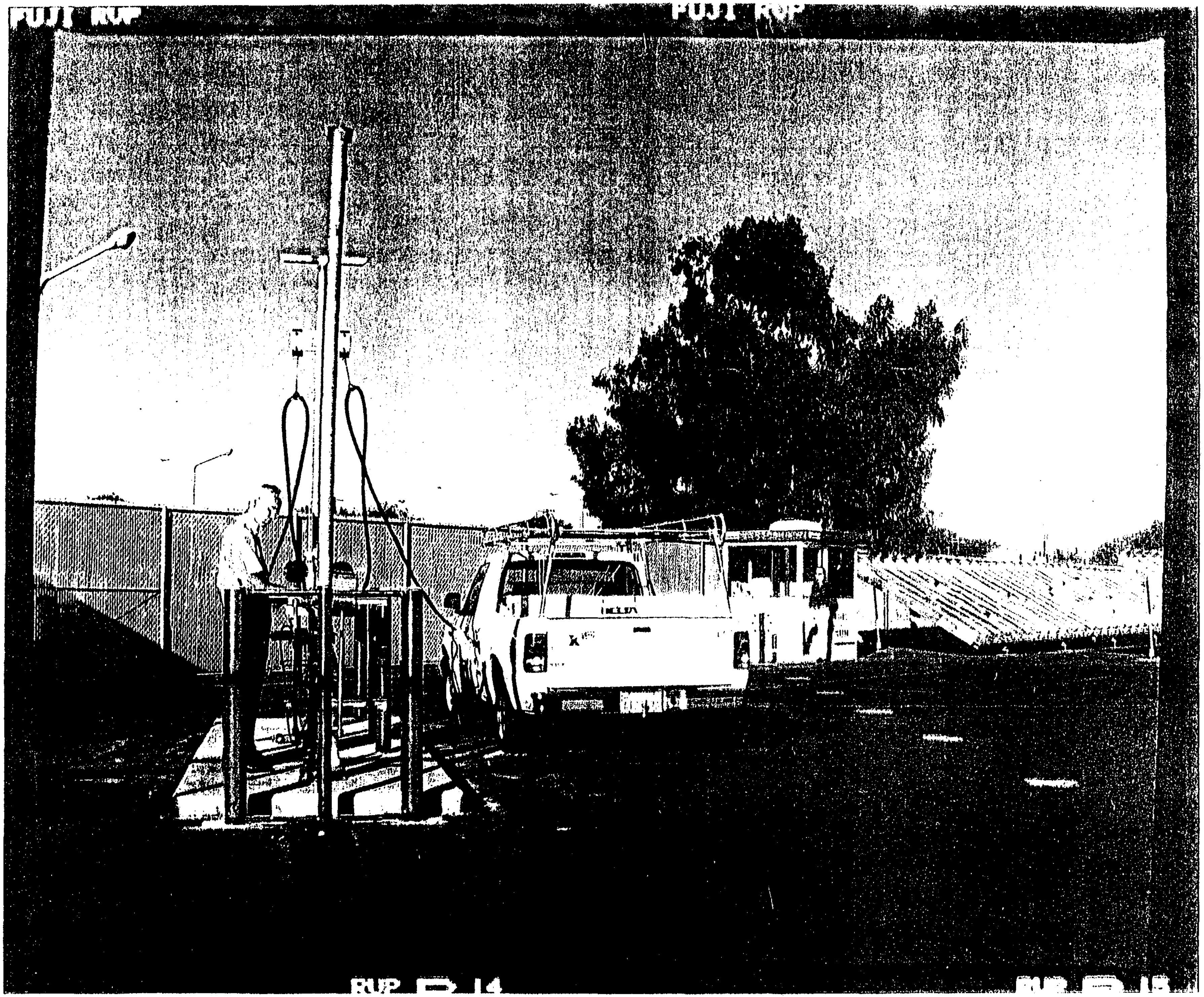
All participants feel that programs such as the Clean Air Now project will lead to greater public acceptance of hydrogen technologies and, subsequently, their use in the mainstream transportation sector.

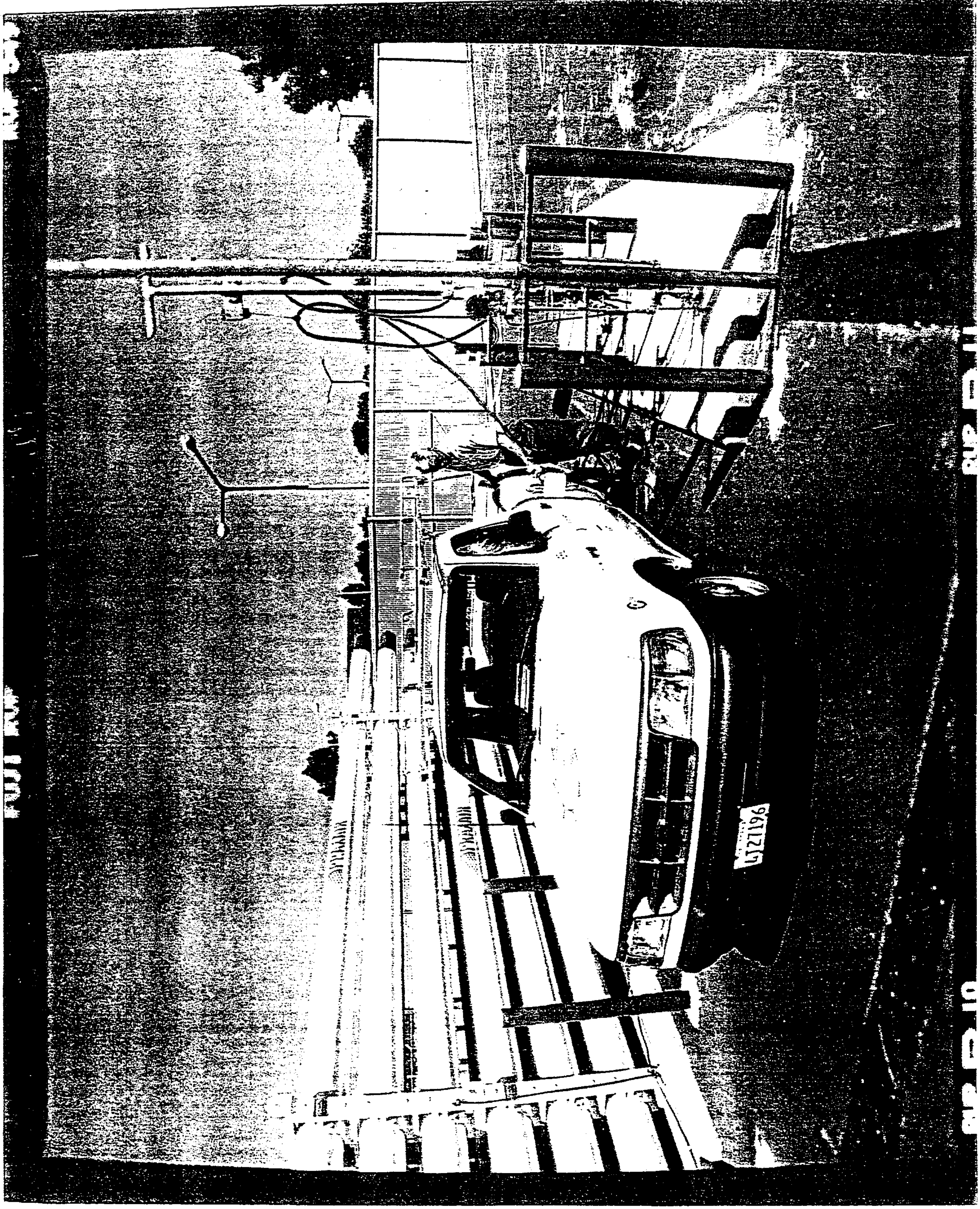
Why is Xerox doing this? -- Because Xerox Corporation is a progressive, proactive and environmentally sensitive company that promotes entrepreneurship and empowerment throughout its operations. This philosophy, along with a strong Corporate Environmental Policy, paved the way for the introduction of this ground breaking, non-core business, demonstration project.

Social and environmental responsibility is no longer considered mutually exclusive, but imperative, to a healthy long-term bottom line. Hydrogen technologies will be playing, increasingly, a significant role in allowing companies to fulfill that promise.


FUJI RUP
RUP 549
RUP 7


549
FUJI RVP
RVP 12
RVP 13


FUJI RVP
FUJI RVP
RVP 14



FINANCIAL STATUS REPORT

(Follow instructions on the back)

1. FEDERAL AGENCY AND ORGANIZATIONAL ELEMENT TO WHICH REPORT IS SUBMITTED: DEPARTMENT OF ENERGY

FEDERAL GRANT OR OTHER IDENTIFYING NUMBER: DE-FC36-94GO10039

OMB Approved No. 80-R.0180

PAGE 1 OF 1 PAGES

3. RECIPIENT ORGANIZATION (Name and complete address, including ZIP code)

4. EMPLOYER IDENTIFICATION NUMBER: 33-0087555

5. RECIPIENT ACCOUNT NUMBER OR IDENTIFYING NUMBER

6. FINAL REPORT: [X] YES [ ] NO

7. BASIS: [ ] CASH [X] ACCRUAL

8. PROJECT/GRANT PERIOD (See instructions): FROM (Month, day, year) August 11, 1994 — TO (Month, day, year) January 6 1997

9. PERIOD COVERED BY THIS REPORT: FROM (Month, day, year) October 1, 1995 — TO (Month, day, year) September 30, 1996

10. STATUS OF FUNDS

PROGRAMS/FUNCTIONS/ACTIVITIES ►	(a)	(b)	(c)	(d)	(e)	(f)	TOTAL (g)
a. Net outlays previously reported	$2,396,619.76	$	$	$	$	$	$ 2,396,619.76
b. Total outlays this report period	184,945.26						184,945.26
c. *Less:* Program income credits	0						0
d. Net outlays this report period *(Line b minus line c)*	184,945.26						184,945.26
e. Net outlays to date *(Line a plus line d)*	2,581,565.02						2,581,565.02
f. *Less:* Non-Federal share of outlays	1,361,594.02						1,361,594.02
g. Total Federal share of outlays *(Line e minus line f)*	1,219,971.00						1,219,971.00
h. Total unliquidated obligations	0						0
i. *Less:* Non-Federal share of unliquidated obligations shown on line h	0						0
j. Federal share of unliquidated obligations	0						0
k. Total Federal share of outlays and unliquidated obligations	1,219,971.00						1,219,971.00
l. Total cumulative amount of Federal funds authorized	1,219,971.00						1,219,971.00
m. Unobligated balance of Federal funds	0						0

11. INDIRECT EXPENSE: a. TYPE OF RATE *(Place "X" in appropriate box)* [ ] PROVISIONAL [ ] PREDETERMINED [ ] FINAL [ ] FIXED — b. RATE — c. BASE — d. TOTAL AMOUNT — e. FEDERAL SHARE

12. REMARKS: Attach any explanations deemed necessary or information required by Federal sponsoring agency in compliance with governing legislation.

13. CERTIFICATION: I certify to the best of my knowledge and belief that this report is correct and complete and that all outlays and unliquidated obligations are for the purposes set forth in the award documents.

SIGNATURE OF AUTHORIZED CERTIFYING OFFICIAL: James J. Provenzano (signature)

DATE REPORT SUBMITTED: 5-14-97

TYPED OR PRINTED NAME AND TITLE: James J. Provenzano, Secretary/Project Managing Dir.

TELEPHONE (Area code, number and extension): 810 394-1354

269-102

STANDARD FORM 269 (7-76)
Prescribed by Office of Management and Budget
Cir. No. A-110

Xerox-CAN Project

PROJECT BILLINGS RECAP
BILLINGS THRU DECEMBER 31, 1996

	BUDGET			ACTUAL			EXCESS
	TOTAL	COST TO GOV'T	COST SHARE	TOTAL	COST TO GOV'T	COST SHARE	COST SHARE OVER BUDGET
Personnel: Executive Director	51,843	35,000	16,843	51,849	35,000	16,849	6
Fringe Benefits 11.95%:	4,153	2,689	1,464	6,196	2,689	3,507	2,043
Total Personnel Costs	55,996	37,689	18,307	58,045	37,689	20,356	2,049
Staff Assistant (Hanan)	10,000	10,000	0	10,000	10,000	0	0
Zweig-Admin Director	0	0	0	0	0	0	0
Provenzano-Program Dir	54,166	35,000	19,166	116,880	35,000	81,880	62,714
Hillr/Hastng/Zwei/Hanan-Admin. Director.	43,333	28,000	15,333	105,554	28,000	77,554	62,221
Electrolyzer	925,043	463,043	462,000	925,000	463,043	461,957	-43
SEA	432,622	397,639	34,983	333,771	397,639	-63,868	-98,851
AMD	150,000	0	150,000	150,000	0	150,000	0
ETEC	71,000	61,700	9,300	62,906	61,700	1,206	-8,094
Mutual Propane	6,820	0	6,820	0	0	0	-6,820
Mc Spadden Attorney	103,500	40,200	63,300	103,400	40,200	63,200	-100
Touchstone Technology	67,500	45,000	22,500	107,235	45,000	62,235	39,735
Hall & Vernazza	31,615	13,800	17,815	38,653	13,800	24,853	7,038
W. Hoagland & Assoc/ Provenzano	46,800	39,000	7,800	40,950	39,000	1,950	-5,850
Provenzano-substitute for Hoagland time	0	0	0	4,875	0	4,875	4,875
W. Hoagland Expenses (Zweig)	5,600	5,600	0	5,309	5,600	-291	-291
University of California, Riverside	29,000	25,000	4,000	29,009	25,000	4,009	9
0	1,976,999	1,163,982	813,017	2,033,542	1,163,982	869,560	56,543
OTHER:							
Xerox plus Praxair-Cost	340,806	0	340,806	349,439	0	349,439	8,633
Operating Expenses	19,288	14,270	5,018	33,347	14,270	19,077	14,059
Equipment	4,000	4,000	0	20,018	4,000	16,018	16,018
W. Hollywood Vehicle	18,000	0	18,000	18,000	0	18,000	0
Insurance BOD	3,250	0	3,250	4,135	0	4,135	885
Travel	2,500	30	2,470	7,772	30	7,742	5,272
BOD Mgmt (764*25/hr)	19,103	0	19,103	18,975	0	18,975	-128
Total Other	406,947	18,300	388,647	451,686	18,300	433,386	44,739
TOTAL DIRECT:	2,439,942	1,219,971	1,219,971	2,543,273	1,219,971	1,323,302	103,331
		50.00%			47.97%		

FINANCIAL STATUS REPORT

(Follow instructions on the back)

1. FEDERAL AGENCY AND ORGANIZATIONAL ELEMENT TO WHICH REPORT IS SUBMITTED: DEPARTMENT OF ENERGY

2. FEDERAL GRANT OR OTHER IDENTIFYING NUMBER: DE-FC36-94G010039

OMB Approved No. 80-R0180

PAGE 1 OF 1 PAGES

3. RECIPIENT ORGANIZATION (Name and complete address, including ZIP code)

4. EMPLOYER IDENTIFICATION NUMBER: 33-0087555

5. RECIPIENT ACCOUNT NUMBER OR IDENTIFYING NUMBER

6. FINAL REPORT: ☐ YES ☒ NO

7. BASIS: ☐ CASH ☒ ACCRUAL

8. PROJECT/GRANT PERIOD (See instructions): FROM (Month, day, year) ~~JULY 1, 1995~~ 8/11/94 TO (Month, day, year) ~~SEPTEMBER 30, 1995~~ 3/8/96

9. PERIOD COVERED BY THIS REPORT: FROM (Month, day, year) JULY 1, 1995 TO (Month, day, year) SEPTEMBER 30, 1995

10. STATUS OF FUNDS

PROGRAMS/FUNCTIONS/ACTIVITIES ►	(a)	(b)	(c)	(d)	(e)	(f)	TOTAL (g)
a. Net outlays previously reported	$1,775,746.52	$	$	$	$	$	$1,775,746.52
b. Total outlays this report period	620,873.23						620,873.23
c. *Less:* Program income credits	0						0
d. Net outlays this report period (*Line b minus line c*)	620,873.23						620,873.23
e. Net outlays to date (*Line a plus line d*)	2,396,619.75						2,396,619.75
f. *Less:* Non-Federal share of outlays	1,198,309.88						1,198,309.88
g. Total Federal share of outlays (*Line e minus line f*)	1,198,309.88						1,198,309.88
h. Total unliquidated obligations	0						0
i. *Less:* Non-Federal share of unliquidated obligations shown on line h	0						0
j. Federal share of unliquidated obligations	0						0
k. Total Federal share of outlays and unliquidated obligations	1,198,309.88						1,198,309.88
l. Total cumulative amount of Federal funds authorized	1.198.309.88						1,198,309.88
m. Unobligated balance of Federal funds	0						0

11. INDIRECT EXPENSE: a. TYPE OF RATE (*Place "X" in appropriate box*) ☐ PROVISIONAL ☐ PREDETERMINED ☐ FINAL ☐ FIXED; b. RATE; c. BASE; d. TOTAL AMOUNT; e. FEDERAL SHARE

12. REMARKS: *Attach any explanations deemed necessary or information required by Federal sponsoring agency in compliance with governing legislation.*

13. CERTIFICATION

I certify to the best of my knowledge and belief that this report is correct and complete and that all outlays and unliquidated obligations are for the purposes set forth in the award documents.

SIGNATURE OF AUTHORIZED CERTIFYING OFFICIAL: [signature]

DATE REPORT SUBMITTED: 11/6/95

TYPED OR PRINTED NAME AND TITLE: JAMES J. PROVENZANO, SECRETARY/PROJECT MANAGING DIR.

TELEPHONE (*Area code, number and extension*): 310 394-1214

269-102

STANDARD FORM 269 (7-76)
Prescribed by Office of Management and Budget
Cir. No. A-110

FINANCIAL STATUS REPORT

(Follow instructions on the back)

1. FEDERAL AGENCY AND ORGANIZATIONAL ELEMENT TO WHICH REPORT IS SUBMITTED	DEPARTMENT OF ENERGY
2. FEDERAL GRANT OR OTHER IDENTIFYING NUMBER	DE-FC36-94G010039
OMB Approved No. 80-RO180	PAGE 1 OF 1 PAGES
3. RECIPIENT ORGANIZATION (Name and complete address, including ZIP code)	
4. EMPLOYER IDENTIFICATION NUMBER	33-0087555
5. RECIPIENT ACCOUNT NUMBER OR IDENTIFYING NUMBER	
6. FINAL REPORT	☐ YES ☒ NO
7. BASIS	☐ CASH ☒ ACCRUAL
8. PROJECT/GRANT PERIOD (See instructions)	FROM (Month, day, year) 8/11/94 — TO (Month, day, year) 9/10/95
9. PERIOD COVERED BY THIS REPORT	FROM (Month, day, year) 4/1/95 — TO (Month, day, year) 6/30/95

10. STATUS OF FUNDS

PROGRAMS/FUNCTIONS/ACTIVITIES ▶	(a)	(b)	(c)	(d)	(e)	(f)	TOTAL (g)
a. Net outlays previously reported	$1,215,033.52	$	$	$	$	$	$1,215,033.52
b. Total outlays this report period	560,714.35						560,714.35
c. *Less:* Program income credits	0.00						0.00
d. Net outlays this report period *(Line b minus line c)*	560,714.35						560,714.35
e. Net outlays to date *(Line a plus line d)*	1,775,747.87						1,775,747.87
f. *Less:* Non-Federal share of outlays	887,873.94						887,873.94
g. Total Federal share of outlays *(Line e minus line f)*	887,873.94						887,873.94
h. Total unliquidated obligations	0.00						0.00
i. *Less:* Non-Federal share of unliquidated obligations shown on line h	0.00						0.00
j. Federal share of unliquidated obligations	0.00						0.00
k. Total Federal share of outlays and unliquidated obligations	887,873.94						887,873.94
l. Total cumulative amount of Federal funds authorized	887,873.94						887,873.94
m. Unobligated balance of Federal funds	0.00						0.00

11. INDIRECT EXPENSE

a. TYPE OF RATE *(Place "X" in appropriate box)*	☐ PROVISIONAL ☐ PREDETERMINED ☐ FINAL ☐ FIXED		
b. RATE	c. BASE	d. TOTAL AMOUNT	e. FEDERAL SHARE

12. REMARKS: *Attach any explanations deemed necessary or information required by Federal sponsoring agency in compliance with governing legislation.*

13. CERTIFICATION

I certify to the best of my knowledge and belief that this report is correct and complete and that all outlays and unliquidated obligations are for the purposes set forth in the award documents.

SIGNATURE OF AUTHORIZED CERTIFYING OFFICIAL: James J. Provenzano

DATE REPORT SUBMITTED: 8/10/95

TYPED OR PRINTED NAME AND TITLE: James J. Provenzano, Managing Dir.

TELEPHONE *(Area code, number and extension)*: (310) 394-1214

269-102

STANDARD FORM 269 (7-76)
Prescribed by Office of Management and Budget
Cir. No. A-110

Assessment
Clean Air Now Solar Hydrogen Vehicle Project
DE-FC36-94G010039
8/2/95
As Requested by Lucito Cataquiz
F 202-586-9811

- Since this is a "deployment" project there is no funded R&D. There have, however, been ancillary improvements to the original design and some of the component integration specifications: The internal combustion engine 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). These improvements stem from the inflow of capital into these new technologies and the renewed hope of greater future sales on the part of the participants. When completed, the solar hydrogen generating facility at the Xerox site will be the third largest in the world.

- On track and ahead of schedule, we have completed the systems' design, the public education materials and the vehicle safety analysis. Construction of the hydrogen generating facility is on schedule with only a possible 2 week delay in completing the installation of 25% of the PV array. The second and third vehicle retrofits have been delayed; they will be completed within the original overall project timeline. In order to acquire adequate data for the Final Technical Report, ETEC and UCR will not be able to have their final reports delivered to Clean Air Now until 11/1/95. This will delay the submission of the Final Technical Report to the DOE till 12/15/95, as been stated in our quarterly reports. We have increased the original scope of work, as all participants agreed, as was necessary to produce valuable deliverables, not only for our project, but in order to advance hydrogen technologies within the country (e.g. engine retrofit improvement; tankage improvement; video of construction; vehicle performance, safety & crash test analysis; high and low pressure storage and refueling, etc.). This is one of the advantages of Clean Air Now being a non-profit entity, as our sole goal is to advance clean fuel technologies for the public's benefit.

- The Total Cost of the Project (as contracted): $2,439,942; **Total Cost to Government: $1,219,971**; Total billed to Project (as of 2nd Qtr. 95): $1,775,747.87; **Total billed Cost to Government (as of 2nd Qtr.95): $887,873.94**.

- A CRADA with ETEC was signed by Clean Air Now ($60k) as additional cofund to project. This has allowed us to perform more extensive testing on the vehicles and generation system than the original scope had specified. In addition, without any increased cost to the project, Clean Air Now went under contract with University of California at Riverside to perform the performance and emissions testing on all 3 project vehicles. This has aided ETEC in their understanding of hydrogen i.c.e's., since UCR CE-CERT has substantial experience in this area as a result of their solar hydrogen project. Construction will be 100% complete by project end date; as stated above, we anticipate that our Final Technical Report will be submitted to the DOE by 12/15/95, 3 months after contracted end date.

- Technical Reports -- can discuss.

- Since the inception of the project, there has been increased activity and interest in hydrogen technologies in southern California. Development of a substantial hydrogen infrastructure in California is underway, as the concept of a "Hydrogen Corridor" has been coined and is becoming a reality with hydrogen projects and installations existing and proposed from the coast to Palm Desert, approximately 200 miles. Large scale production of i.c.e. retrofits is technologically feasible and the public's awareness of hydrogen fuel technologies has improved due to highly visible projects such as this one. We are coordinating efforts with local labs, cities, corporations, politicians, and businesses to advance the use of hydrogen as an alternative to polluting fossil fuels and to improve our energy independence.

- Please see enclosed page on Proposed Projects.

- The concern we have is the lack of funding for a continued PR effort regarding the advantages of hydrogen technologies and a project such as this. We do not want to see the momentum generated from this project to dwindle. The marginal cost to continue our efforts, and get large scale dividends from the current project, is relatively small.

INSPECTION RECORD
DEPT. OF BUILDING SAFETY
CITY OF EL SEGUNDO

350 Main Street
7:30am-5:30pm, M-F 322-4670

Bldg Inspector:__________________ Telephone Extension:__________

24-Hour Inspection Request Telephone 310-322-7069

POST THIS CARD IN A SAFE & CONSPICUOUS PLACE

Job Address

Permit No. 561-95 Date Issued 6/20/95

Owner Xerox

Contractor Matrix

Description of Work Fueling Facility

Inspector Must Sign All Spaces Pertaining To This Job
REQUEST ALL INSPECTIONS 24 HOURS IN ADVANCE

INSPECTIONS	DATE	APPROVED BY
Temporary Power Pole		
Building Location		
Foundation		
Reinforcing Steel		
UFER Ground		
OK to Pour Footings*		
*Do Not Pour Concrete Until the Above is Signed.		
Electrical Underground/Floor		
Plumbing Underground/Floor		
Floor Joists & Sills		
OK to Sheath Floor/Pour Slab*		
*Do Not Sheath Floor/Pour Slab Until the Above is Signed.		
Floor Nailing		
Roof Tear Off		
Roof Sheathing/Nailing*		
*Do Not Apply Roof Covering Until the Above is Signed.		
Roof FINAL		
Do Not Call for Framing** Inspection Until Electrical, Plumbing, & Heating Have Been Installed.		
Rough Electrical		
Rough Plumbing		
Rough Heating & Cooling		
Framing**		
OK to Cover Exterior*		
*Do Not Cover Exterior Until the Above is Signed.		
Sound Insulation		
Energy Insulation		
OK to Cover Interior*		
*Do Not Cover Interior Until the Above is Signed.		
Lathing Exterior		
Lathing Interior		
Dry Wall		
OK to Stucco/Plaster*		
*Do Not Stucco/Plaster Until the Above is Signed.		
Scratch Inspection (48 hours)		
Brown Inspection (72 hours)		
Sewer: cap ☐ hookup ☐		
Gas Test		
NOTICE: A list of subcontractors must be furnished prior to FINAL inspection.		
Final Electrical		
Final Plumbing		
Final Heating & Cooling		
Do Not Call for Final Building Inspection Until All of the Above Have Been Signed Off.		
FINAL BUILDING:	2/14/96	B. [illegible]

Fire Safety Dept by Elec. Corp -
Energy Tech - Engr Certs -

EL SEGUNDO FIRE PREVENTION INSPECTION RECORD
FIRE PREVENTION DIVISION
350 MAIN STREET
EL SEGUNDO, CA 90245

FPF-59
REV 7/95

PHONE# (310) 607 2238 — JOHN MAGES
FAX# (310) 322-4167

JOB ADDRESS: 851 S AVIATION PC# 871-95
OWNER: XEROX PHONE#
JOB DESCRIPTION:
UV DETECTION FOR HYDROGEN PLANT

INSPECTION TYPE	DATE	INSPECTED BY
SPRINKLER SYSTEM (NFPA 13/UFC 10)		
___Underground Hydro		
___Underground Flush		
___Overhead Hydro		
___Final		
STANDPIPE SYSTEM (NFPA 14/UFC 10)		
___Wet___Dry___Comb. (FPBR S-4a-b-d)		
___Hydro___Flow		
___Final		
FIRE HYDRANTS (NFPA 24/UFC 10)		
___Underground Hydro.		
___Underground Flush		
___Flow		
FIRE ALARM SYSTEM (NFPA 72/UFC 10)		
✓ Detectors	12-6-95	[signature]
___Manual Pull Stations		
✓ Audibles	12-6-95	[signature]
✓ Supervision SUPERVISION / FAULT		
✓ Annunciation/Control Panel NOT TESTED		
✓ Final INSTALLATION ONLY OK	12-6-95	[signature]
TENANT IMPROVEMENTS		
___Corridor		
___Exit Signs		
___Fire Estinguishers		
___Other ___		
___Final		
FIRE PROTECTION SYSTEMS		
___CO2 System (NFPA 12/FPBR E-2c)		
___Wet Dry Chemical System (NFPA 17/FPBR E-2-a)		
___Halon 1301 System (NFPA 12A)		
___Functional Test (FPBR E-2c)		
___Final		
U/G TANK (NFPA 30/FPBR F-1b)		
___Removal___Install		
___Hydro___Final		
CRYOGENIC TANK (NFPA 30/FPBR f-1b)		
___Hydro		
___Final		
LPG TANK (FPBR C-a)		
___Tank Installation		
___Dispensing Installing		
___Final		
OTHER___		
FINAL		

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NOTIFY FIRE DEPARTMENT when job is ready for inspection.
48 HOUR inspection notice is required.

APPROVED PLANS SHALL BE ON JOB SITE

EL SEGUNDO FIRE DEPARTMENT INSPECTION RECORD
FIRE PREVENTION BUREAU
314 MAIN STREET
EL SEGUNDO, CA 90245

FPF-59
REV 7/92

PHONE# (310) 322-4311
FAX# (310) 414-0929

JOB ADDRESS: 851 S AVIATION PC# 561-95
OWNER: XEROX PHONE#
JOB DESCRIPTION:
NEW HYDROGEN STORAGE ADDITION

INSPECTION TYPE	DATE	INSPECTED BY
SPRINKLER SYSTEM (NFPA 13/UFC 10)		
___Underground Hydro		
___Underground Flush		
___Overhead Hydro		
___Final		
STANDPIPE SYSTEM (NFPA 14/UFC 10)		
___Wet___Dry___Comb. (FPBR S-4a-b-d)		
___Hydro___Flow		
___Final		
FIRE HYDRANTS (NFPA 24/UFC 10)		
___Underground Hydro.		
___Underground Flush		
___Flow		
FIRE ALARM SYSTEM (NFPA 72/UFC 10)		
___Detectors		
___Manual Pull Stations		
___Audibles		
___Supervision		
___Annunciation/Control Panel		
___Final		
TENANT IMPROVEMENTS		
___Corridor		
___Exit Signs		
___Fire Estinguishers		
___Other		
___Final		
FIRE PROTECTION SYSTEMS		
___CO2 System (NFPA 12/FPBR E-2c)		
___Wet Dry Chemical System (NFPA 17/FPBR E-2-a)		
___Halon 1301 System (NFPA 12A)		
___Functional Test (FPBR E-2c)		
___Final		
U/G TANK (NFPA 30/FPBR F-1b)		
___Removal___Install		
___Hydro___Final		
CRYOGENIC TANK (NFPA 30/FPBR f-1b)		
___Hydro		
___Final		
LPG TANK (FPBR C-a)		
___Tank Installation		
___Dispensing Installing		
___Final		
OTHER GROUNDING BONDING		
LABEL		
PROTECTION		
FINAL	12-8-95	[illegible]

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ENERGY TECHNOLOGY ENGINEERING CENTER

No. 019-TN-0004 Rev. ___

OPERATED FOR THE U.S. DEPARTMENT OF ENERGY
ROCKETDYNE DIVISION, ROCKWELL INTERNATIONAL

Orig. Date January 15, 1996
Rev. Date __________

DRR 26845 BG

TITLE: SAFETY ASSESSMENT OF THE CLEAN AIR NOW SOLAR PHOTOVOLTAIC HYDROGEN GENERATION AND DISPENSING SYSTEM

- APPROVALS -

Originators K. T. Knudsen *K.T. Knudsen* 1-31-96

R. S. Homer *R S Homer* 2-6-96.

[signature] 2-1-96

REV. LTR.	REVISION	APPROVAL/DATE

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ABSTRACT

This report details the results of the safety assessment performed under an agreement between the Energy Technology Engineering Center (ETEC) and Clean Air Now! (CAN). The primary technical objective of this project was to evaluate the solar photovoltaic hydrogen generation, storage, and dispensing system of the CAN Solar Hydrogen Vehicle Project from a safety standpoint. The aforementioned system is located at the Xerox Corporation facilities in El Segundo, California. The system is used by the Xerox Corporation and the City of West Hollywood to fuel a small fleet of utility vehicles with hydrogen gas. These vehicles have been retrofitted with hydrogen storage and fuel injection systems which allow these vehicles to operate on clean burning hydrogen gas.

The safety assessment was qualitative in nature and based upon the effectiveness of system design features implemented by the system designer to mitigate potential casualty events, and on the extent to which the system designer adhered to the applicable codes and standards as identified by ETEC (References 1 through 5). In order for a system to be considered safe, it is recognized that two primary requirements must be met. First, the system should fully conform to the requirements of the applicable codes and standards. Second, the system should contain design features to detect and mitigate potential casualty events from occurring, with these design features based on the planned system operating modes. As a result, if a system is shown to deviate from code requirements, and/or critical design features are absent or lacking, the system is presumed to be unsafe unless significant other evidence is available. During this review, many safety issues and concerns were identified by ETEC. Many of these issues and concerns were direct code deviations which therefore required system modification prior to startup. All required modifications identified by ETEC have been made to the system. Therefore, the safety assessment shows that the solar photovoltaic hydrogen generation, storage, and dispensing system of the CAN Solar Hydrogen Vehicle Project is safe to operate.

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I. Introduction

An agreement for support from the Energy Technology Engineering Center (ETEC) to Clean Air Now! (CAN) was initiated. The primary technical objective of this project was to perform a safety assessment of the CAN solar photovoltaic powered, hydrogen generation, storage, and dispensing system. The system was reviewed against the codes and standards listed in References 1 through 5, and by means of a systematic casualty study using the design information identified by References 8 through 41 and from information obtained during on-site inspections. Per References 41 through 43, the system was designed per the codes and standards of References 1 through 5 by three different designers. The Electrolyser Corporation designed the water electrolysis system and the high pressure compression and storage systems, Praxair Incorporated designed the low pressure storage system and the dispenser station, and Solar Engineering Applications Corporation designed the photovoltaic array. The aforementioned solar hydrogen system is located at the Xerox Corporation facilities in El Segundo, California.

The CAN Solar Hydrogen Vehicle Project demonstrates a practical application of renewable hydrogen. The demonstration features a solar energy hydrogen generating system, fueling station, and a small fleet of hydrogen powered utility vehicles. CAN oversees, directs and manages the overall project. Other team members include the Xerox Corporation; The Electrolyser Corporation; Praxair Incorporated; Solar Engineering Applications Corporation; 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; Matrix Construction and Engineering, Incorporated; and the Energy Technology Engineering Center. The hydrogen powered utility vehicle fleet is operated by the Xerox Corporation in El Segundo and by the City of West Hollywood. The project is funded by the White House Technology Reinvestment Project (contracted through the U.S. Department of Energy), Clean Air Now, the South Coast Air Quality Management District, and the rest of the project team.

Hydrogen is envisioned to be a pollution free energy source of the future. Emissions of carbon monoxide (CO) and oxides of nitrogen (NO_x), especially in southern California, are the major contributors to air pollution. When hydrogen is used as the fuel in internal combustion engines, emissions of CO and carbon dioxide (CO_2) are virtually eliminated, while emissions of NO_x, are drastically reduced. Other energy production systems capable of utilizing hydrogen as a fuel, include fuel cells, gas burners, and gas turbines.

With existing state-of-the-art technologies, hydrogen gas can be derived through the chemical and thermal conversion of hydrocarbon fuels and through the electrolysis of water. In general, the generation of hydrogen gas by chemical and thermal conversion processes (i.e., steam reforming and partial oxidation) is relatively straight forward, well developed, and for the most part, economical. Steam reformers extract hydrogen from carbon based fuels, such as natural gas, using high temperature steam and nickel or platinum based catalysts, while partial oxidation systems generate significant amounts of hydrogen as a result of combusting hydrocarbon fuels with air or oxygen under reducing conditions (i.e., sub-stoichiometric combustion). However, these chemical and thermal hydrogen conversion processes produce an impure hydrogen gas stream. Depending on the chemical or thermal hydrogen conversion process being utilized, the resultant gas stream will always contain varying amounts of CO, CO_2, NO_x, and unreacted hydrocarbons (HCs), all major contributors to air pollution. On the other hand, the use of a water electrolysis system for the production of hydrogen gas, is extremely clean, generating pure hydrogen and pure oxygen only. Additionally, when solar photovoltaics are used as the electrolytic power source, air emissions are virtually non-existent. However, at this time, the major drawbacks for utilizing a solar photovoltaic/water electrolysis system for large scale hydrogen production are the high capital costs and the requirement for large areas of land for the photovoltaics.

The objective of the CAN Solar Hydrogen Vehicle Project is to demonstrate the practical use of solar generated hydrogen for vehicle fuel and to foster the development and growth of California's solar hydrogen infrastructure. The project makes use of state-of-the-art technologies including solar photovoltaics for electrical power generation, water electrolysis for hydrogen production, and modified internal combustion engine powered pickup trucks for utility transportation. The pickup trucks were retrofitted with hydrogen storage and fuel injection kits to allow these vehicles to operate on hydrogen gas (Reference 6).

The CAN Solar Hydrogen Vehicle Project is the largest application of "stand-alone" photovoltaics for hydrogen production in the country and, with the exception of large energy companies, it is the largest in the world. The project paves the way for nationwide use of solar hydrogen powered vehicles and establishes the first in a CAN envisioned series of large "stand-alone" renewable hydrogen fueling stations stretching across Los Angeles.

The CAN Solar Hydrogen Vehicle Project uses a unique photovoltaic system with Fresnel lenses which track the sun, capture and condense sunlight, and convert it into a pollution-free source of electricity. The electricity generated by the photovoltaic arrays power the electrolysis system which separates incoming feedwater into its two component parts, hydrogen and oxygen. The hydrogen produced from this electrolysis system is then dried, compressed, and stored in high pressure storage vessels. Electricity produced from the photovoltaic array also provides power to the hydrogen compressor. The storage vessels are used to supply the fueling station dispensing nozzles with high pressure hydrogen. A fleet of utility vehicles, to be operated by the Xerox Corporation and the City of West Hollywood, are then fueled with these nozzles. The vehicle fleet has been retrofitted to operate on pure hydrogen and air, borrowing U.S. Navy submarine Constant Volume Injection (C.V.I.) technology for the vehicles' hydrogen fuel injection system.

II. Summary

A safety assessment of the CAN Solar Hydrogen Vehicle Project's solar photovoltaic hydrogen generation, storage, and dispensing system was performed. The assessment was qualitative in nature and was based on the effectiveness of system design features used to help mitigate potential casualty events and on the extent to which the system designers adhered to the applicable codes and standards as identified by ETEC (References 1 through 5). The system was designed by three different designers. The Electrolyser Corporation designed the water electrolysis system and the high pressure compression and storage systems, Praxair Incorporated designed the low pressure storage system and the dispenser station, and Solar Engineering Applications Corporation designed the photovoltaic array. Although the system was designed per the codes and standards of References 1 through 5 (as stated in References 41, 42 and 43), the initial assessment identified many safety issues, concerns, and code deviations. These safety issues, concerns, and code deviations were provided to the system designers for review and correction. ***As a result, all of the safety issues, concerns, and code deviations have been adequately corrected through system modifications, and the system as now configured is judged to be safe to operate.***

An important issue identified during this assessment was the fact that the Electrolyser Corporation, by choice, did not use the Reference 4 design code for their portion of the system design. The Reference 4 design code is the code for designing and building compressed natural gas fueling stations. ETEC recognizes that the Reference 4 design code pertains to natural gas systems only. However, since no equivalent code exists for hydrogen use, ETEC believes that the adoption of this code for hydrogen systems is logical and appropriate, until a specific code for hydrogen systems has been generated. The Reference 4 design code requires strict adherence to the design codes of References 1, 2, and 5, but then adds additional design requirements to them, ultimately raising the level of component and system safety. It is believed that the reason for the additional safety requirements is because the resultant compressed natural gas fueling stations are deployed directly into areas of public access, which thereby requires additional safety measures beyond that which is found in an industrial complex. The fact that the Reference 4 design code was not used by the Electrolyser Corporation does not imply that the existing CAN fueling system is unsafe, nor does it imply that the Electrolyser Corporation made a mistake. The codes and standards used by the Electrolyser Corporation are adequate and are recommended and accepted for industrial applications. What it does imply is that the CAN system should be treated as an industrial system and not as a system which would be used in and by the public. This therefore requires that CAN

and the Xerox Corporation limit operation of the facility to trained operators and mechanics with experience in industrial type operations. However, for future CAN hydrogen generation, storage, and dispensing systems where public access can occur, ETEC recommends that these systems be designed and built using the Reference 4 design code until an equivalent hydrogen code is available.

Of significant safety concern identified during the assessment was the identification of valves installed in systems which could be operated at pressure conditions greater than the valves rated design pressure, and the identification of electrical components in locations inappropriate for use in hydrogen service applications. For example, several valves rated for 3,000 psig service were found to be installed in a system rated for 5,000 psig service and protected by safety relief valves with set pressures of 4,740 psig. As a result of this finding, the 3,000 psig valves were either removed from the system entirely, or were removed and replaced with valves rated for 5,000 psig service. Subsequently, several other valves installed in this system were found to be rated for 4,600 psig service. Removal and replacement of these valves was found to be difficult since these valves were socket welded into the system. Therefore, instead of removing and replacing these valves with valves rated for 5,000 psig service, it was decided to simply derate the system design pressure from 5,000 psig to 4,600 psig. This action required that the pressure relief set points of the appropriate safety relief valves be reset for a maximum relief setting of 4,600 psig. As a result of the lowering of the safety relief valve set points to 4,600 psig, the hydrogen storage system should now be limited in operation to a maximum pressure of 4,200 psig, instead of the originally planned 5,000 psig. Operation at 4,200 psig will preclude premature relief valve operation and leakage.

On the electrical side, the electrical code (Reference 5) and the hydrogen code (Reference 3) both classify the electrolytic cell skid area to be a Class I, Division 2, Group B location, i.e., a hazardous location based on the potential existence of hydrogen. As such, the referenced codes require that all electrical devices and components installed and operated in this location be rated for operation in a Class I, Division 2, Group B location. However, during ETEC's review of the system, several electrical components (including electrical conduit and bus bars) were determined to be inappropriate for use in a Class I, Division 2, Group B location. Subsequently however, all electrical deficiencies were reworked to comply with the required codes. It should be noted, that although the Electrolyser Corporation complied with ETEC's request to cover the electrolytic cell bus bars, the Electrolyser Corporation does not agree with ETEC's interpretation of the Reference 3 and 5 design codes with respect to this area. ETEC believes the Reference 3 and 5 design codes require that the electrolytic cell bus bars be covered to preclude the potential for creating sparks in a Class I, Division 2, Group B location.

Of additional concern was the identification of several operations wherein hydrogen gas could be vented from the system for extended time periods without the knowledge of operating personnel. In particular, there are eight (8) operating/upset conditions, six (6) of which are associated with potential problems with the compressor, which will result in the automatic shutdown of the hydrogen compressor itself. The automatic shutdown of the compressor under these eight (8) conditions is appropriate, however, once the compressor has been shutdown, the rest of the system remains operational. This results in the electrolytic cells to continue to generate hydrogen. This hydrogen is redirected from the compressor inlet to a vent outside of the trailer building. Hydrogen venting will continue in this manner until the compressor problem is corrected or until the rest of the system is manually shutdown. Although there is an alarm which activates upon the automatic shutdown of the compressor, there is no guarantee that an operator will be present to acknowledge that alarm and then proceed with corrective action. While it has been determined that the venting of this hydrogen is not a safety hazard, it was nevertheless recommended that the control system be modified to shutdown the rest of the system whenever the hydrogen compressor is automatically shutdown, as a best management practice. The basis for this position is because there is no need to continue to generate hydrogen if it can not be effectively stored or utilized.

A similar venting situation can occur during system startup and during normal operations. For example, if the system operator does not adequately fill the system water seal, hydrogen and oxygen gas is able to vent into the system trailer building. Now, since all of the equipment within the trailer building is adequately ventilated, is rated for operation within a Class I, Division 2, Group B location; and the trailer building is installed with hydrogen detectors (which upon the detection of a hydrogen leak results in an automatic system shutdown); operation in this manner can be considered safe. However, it is believed that the system would be improved by eliminating all potential sources of hydrogen and oxygen leaks into the trailer building. It was therefore recommended, as a best management practice, that an alarm/interlock associated with a low water level within the water seal be installed. Upon the detection of a low water level in the water seal, the interlock would prevent system start-up or would result in an automatic system shutdown.

Another recommended best management practice was the modification of the existing pneumatic cylinder used to actuate the primary DC power cutoff switch. The existing actuator is operated using nitrogen from a regulated 3,000 psig storage cylinder. The pneumatic cylinder used is an air to open/air to close type cylinder (non-fail safe). In the event that the nitrogen supply system were to fail, i.e., the nitrogen cylinder were to become empty or the plastic supply tube were to fail or leak, the pneumatic cylinder would be unable to operate, leaving the DC power cutoff switch in its last position. If that position were in the closed position, i.e., power from the PV array is available to the rest of the system, and if an upset condition were to occur requiring the DC power cutoff switch to go open, the present system would be unable to do so. Although the nitrogen system will be routinely examined for problems, and a low pressure alarm exists which activates during a low pressure event, it is still recommended that the existing air to open/air to close pneumatic cylinder be replaced with a spring to open/air to close type cylinder (i.e., fail safe open), as a best management practice.

Finally, a situation where plant personnel could potentially be exposed to asbestos fibers was also identified. Specifically, each electrolytic cell contains three anodes which are surrounded by asbestos cloth diaphragms. These diaphragms prevent the mixing of the hydrogen and oxygen gases formed in each cell. Although regular maintenance of these anodes is not anticipated, at some point during the life of the plant, the replacement of these asbestos diaphragms may be necessary. As a result, workers may be exposed to asbestos fibers. It is therefore up to the Xerox Corporation to ensure that all personnel which will work on these asbestos diaphragms are adequately trained to work with asbestos, and that all used asbestos diaphragms are properly disposed of per local, State, and Federal regulations. Personnel exposure to asbestos fibers is only possible during this maintenance phase.

A total of twenty-four (24) code deviation categories were identified during the system review. Subsequently, the system was modified to conform with all of the required codes and standards (References 1 through 5), and was therefore deemed safe to operate.

III. Conclusions and Recommendations

Based on ETEC's safety assessment of the CAN solar photovoltaic powered, hydrogen generation, storage, and dispensing system, it appears that the CAN system can be operated safely. Although safety issues and code deviations were identified during ETEC's initial review (see Table 4 for more detail), adequate modifications to the system have been made such that the existing system appears to comply and conform with the applicable codes and standards. It was also brought to ETEC's attention that some of ETEC's findings were the result of certain construction activities being incomplete, and not that the system in its completed state was in violation of the codes (these deviations are noted in Table 4). Additionally, to maintain system safety and to minimize personnel exposure to the identified hazards, CAN and the Xerox Corporation must provide adequate system maintenance, personnel training, and system operating procedures.

The codes and standards utilized by the Electrolyser Corporation for the water electrolysis system and the high pressure compression and storage systems are adequate for industrial type applications. However, as CAN deploys additional hydrogen fueling stations throughout southern California, the Reference 4 design code, as a minimum, should be used until an equivalent hydrogen code is available. The Reference 4 design code is the code for designing and building compressed natural gas fueling stations. ETEC recognizes that the Reference 4 design code pertains to natural gas systems only. However, since no equivalent code exists for hydrogen use, ETEC believes that the adoption of this code for hydrogen systems is logical and appropriate. This code requires strict adherence to the design codes of References 1, 2, and 5, but then adds additional design requirements to them, ultimately raising the level of component and system safety.

It should also be noted that as a result of this safety assessment, a modification of the system was required which now precludes system operation and hydrogen storage at 5,000 psig. Moreover, by the time this safety assessment had been completed, the system was determined to be unsafe to operate above 4,600 psig. That is, operation of the system above 4,600 psig would be in direct conflict with the engineering requirements deemed necessary for the safe design and construction of pressure piping as detailed in the Reference 1 design code. As a result, the pressure relief valves downstream of the compressor had to be reset to relieve at 4,600 psig. It was further concluded that, to preclude premature operation of system relief valves, the maximum operating pressure of this system should be limited to 4,200 psig.

Also identified during this safety assessment were several operations wherein hydrogen gas could be vented from the system for extended time periods without the knowledge of operating personnel. It was therefore recommended, as a best management practice, to preclude this venting from happening by modifying the control system to shut down the hydrogen generation process whenever the hydrogen compressor is automatically shutdown.

Another best management practice identified by ETEC during this safety assessment, was the recommendation to install an alarm/interlock associated with a low water level within the electrolytic cell system water seal. Upon the detection of a low water level in the water seal, the interlock would prevent system start-up or would result in an automatic system shutdown. This alarm/interlock would help to preclude a potentially hazardous source of hydrogen and oxygen from being generated within the electrolytic cell trailer building.

The final recommendation emanating from this safety assessment dealt with the modification of the pneumatic cylinder used to actuate the primary DC power cutoff switch. The existing actuator cylinder used to operate the primary DC power cutoff switch is a non–fail safe type, ETEC recommends that this actuator cylinder be replaced with a fail safe type actuator (i.e., fail safe open).

IV. Safety Assessment and Systems Performance Analysis

A. Program

The primary technical objective of this project was to assess the CAN solar photovoltaic powered, hydrogen generation, storage, and dispensing system from a safety standpoint. A simplified flow diagram of the system is provided in Figure 1. During this assessment, the following systems, subsystems, and components were analyzed: the Photovoltaic Array; the Feedwater Treatment System; the Electrolyser System and its Ancillary Equipment; the Hydrogen Compression and Storage System; the Hydrogen Dispensing System; and the Power Conditioning and Ancillary Electrical Systems. A safety and performance review of the retrofitted fleet vehicles was previously performed by ETEC (References 6 and 7), and therefore will not be covered herein.

B. Safety Assessment

System Safety Overview

This safety assessment was qualitative in nature and was based upon the effectiveness of system design features implemented by the system designers to mitigate potential casualty events and on the extent to which the system designer adhered to the applicable codes and standards, as identified by ETEC (References 1 through 5). In order to perform this safety assessment, a casualty study was first performed for the CAN system. The casualty study systematically identified events which could cause components or whole subsystems to fail or be damaged. It is important to understand that the casualty study pertains to equipment and hardware only and does not pertain to personnel safety. However, the safety assessment utilizes the identified potential casualty events to determine the impact of these events on personnel safety. As a result of the casualty study, several potential casualty events were identified for the overall system. Again, these identified potential casualty events were then used as inputs to the overall safety analysis. It is noted that some potential casualty events were given a "major incident" severity classification due to potential damage to a critical component. Even though the damage may be minimal, it could result in extended system downtime, thereby becoming a "major incident". A casualty table was produced which lists the potential casualty events and their initiating events, fault frequency classification, potential effects, severity without protection, detection system, protection system, protective action, and their severity with protection. Additionally, the system design (References 8 through 41) and installation was reviewed against the codes and standards identified in References 1

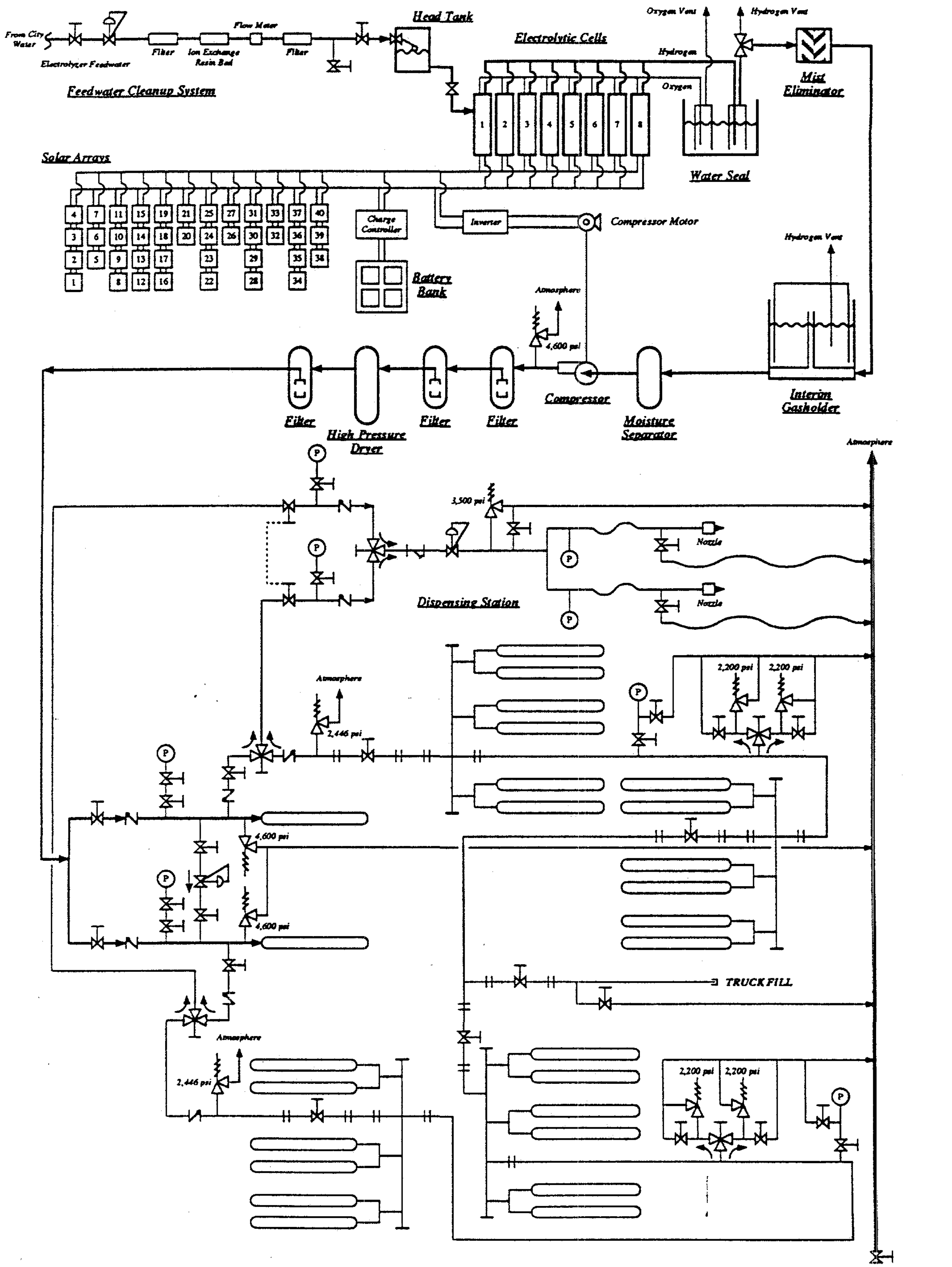


Figure 1. CAN Solar Photovoltaic Hydrogen Generation, Storage, and Dispensing System Flow Diagram

through 5. These codes and standards are felt by ETEC to be applicable for this project. Although for the most part the codes and standards identified were followed and applied, portions of the system initially deviated from these codes and standards. Only after the system conformed to the referenced codes and standards, was the system deemed safe to operate. Descriptions of the equipment and individual subsystems, the casualty events, and the resultant safety assessment are provided below.

1. Equipment/Subsystems Descriptions

a. Photovoltaic Array

The photovoltaic system was designed, manufactured, and installed by the Solar Engineering Applications Corporation. The solar photovoltaic array is composed of 480 photovoltaic panels grouped in modules of twelve (12) panels each. The modules are SeaCorp Power Grid 1000 design. These modules have a rated voltage of 16.9 volts, with 62 amperes and 1,000 watts at the rated voltage. The modules of the photovoltaic array are connected in parallel giving a total output current of 2,500 amps or 42 kW_e peak. Electrical current is maximized when the photovoltaic array directly faces the sun. As a result, the arrays are installed with tracking mechanisms to automatically track the movement of the sun. Power from the photovoltaic array is then distributed to the electrolyser, the hydrogen compressor, storage batteries, and miscellaneous controllers and subsystems.

b. Feedwater Treatment System

When operating at full capacity, the electrolytic cells will consume approximately 1.2 liters (0.3 gallons) of water per hour. To prevent scaling of the electrolytic cell system and to maximize electrolytic cell performance, feedwater to the cells must be high purity demineralized or distilled water. As a result, the electrolyte feedwater is filtered and demineralized using a system of filters and an ion exchange resin bed. A conductivity meter and cell are supplied for measuring the conductivity of the water to the plant.

c. Electrolytic Cell Skid

The electrolytic cell skid was provided by the Electrolyser Corporation. The system is a direct current (DC) unipolar type design and utilizes 76 gallons (288 liters) of liquid electrolyte

(25% potassium hydroxide (KOH) and 75% water). The system consists of eight (8) electrolytic cells and is rated to produce 424 scfh of hydrogen gas and 212 scfh of oxygen gas. The system is designed to operate with a maximum current of 3,400 amps with a nominal 1.95 voltage drop across each cell. The system also operates at a maximum temperature of 140°F (60°C) and at a maximum pressure of 0.356 psig (0.025 kg/cm^2).

d. Hydrogen Compression and Storage System

The hydrogen gas leaving the electrolytic cells carries off some of the potassium hydroxide electrolyte in the form of a mist. Most of this entrainment is removed in the cell gas coolers and returned to the electrolytic cells. Some is removed in the water seal. The remainder is removed in the mist eliminator. The mist eliminator element consists of a hollow cylindrical fiber packed unit. The hydrogen gas leaving the mist eliminator exits with a humidity level of 100%. The mist eliminator has an operating pressure of 0.18 psig. The humid hydrogen gas leaving the mist eliminator is then sent to the low pressure gasholder. The low pressure gasholder is used to provide the hydrogen compressor with adequate suction pressure. The gasholder has a nominal volume of 100 cubic feet, and has an operating pressure of 0.18 psig.

The hydrogen compressor is a Compair Reavell, Model 5409, 4 stage, air cooled, oil lubricated, reciprocating type compressor. The compressor operates at 950 RPM, and has a capacity of 388 cubic feet per hour at a discharge pressure of 5,000 psig. The compressor is driven by a 11.2 kilowatt [15 horsepower] motor which operates at 1450 RPM. The power to operate the compressor is derived from the solar photovoltaic array. To preclude damage to the compressor, each stage of the compressor is protected by a safety relief valve (Reference 16). The exhaust of these relief valves is returned to the top of the moisture separator mentioned above.

In addition to the aforementioned safety relief valves, there is an interlock within the compressor system which is used to protect the hydrogen compressor from damage. When activated, the interlock initiates a shutdown of the compressor. There are six (6) primary operating conditions which cause this interlock to be activated. The first operating condition to activate the interlock is the detection of a low oil pressure condition in the compressors lube oil system. Low oil pressure could result in inadequate lubrication which could then cause the compressor to overheat or to seize up. The second operating condition to activate the interlock is the detection of a high temperature condition at the discharge of the second stage of the compressor. The third operating condition to activate the interlock is the detection of a high temperature condition at the discharge of the fourth stage of the compressor. Allowing the compressor stages to operate in an over-temperature condition could cause mechanical components within the compressor to fail. The fourth operating condition to activate the interlock is the detection of a low pressure condition at the discharge of the gasholder. The gasholder supplies electrolyser hydrogen to the compressor. A low compressor suction pressure may cause the compressor to overheat, potentially causing the compressor to fail. The fifth operating condition to activate the interlock is when the first compressor inlet block valve is determined to be closed, while the sixth operating condition to activate the interlock is when the second compressor inlet block valve is determined to be closed. Either of these valves being closed would cause a low compressor suction pressure, which again, could cause the compressor to overheat.

In addition to the six (6) previously discussed operating conditions, there are two (2) additional operating conditions which cause the compressor interlock to be activated. These operating conditions are associated with the system operating conditions, and are not associated with the protection of the compressor. The first of these two operating conditions activates the interlock when the maximum operating pressure of the high pressure hydrogen storage vessels is reached, while the other operating condition activates the interlock when the hydrogen at the discharge of the compressor is determined to contain more than 10 ppm of moisture. To maintain the moisture content of the hydrogen gas to below 10 ppm, a high pressure gas drier and three water traps/filters are located at the discharge of the hydrogen compressor. The removal of water from the hydrogen gas precludes the compressor discharge piping and the hydrogen storage vessels from accumulating water. All components within the compression and drying systems were designed to operate at pressures at or above 4,600 psig. As a result, a safety relief valve at the discharge of the compressor is installed and is set to relieve at 4,600 psig. This safety relief valve was originally set to relieve at 5,450 psig. However, after determining that several valves downstream of the compressor discharge were only rated for operation at 4,600 psig, this safety relief valve was reset to relieve at 4,600 psig.

The hydrogen storage system consists twenty-four (24) 2,200 psig, 22.5 cubic feet A.S.M.E. storage vessels (holds ≈74,000 standard cubic feet of hydrogen at 2,200 psig) and two (2) 5,000 psig, 26.6 cubic feet A.S.M.E. storage vessels (holds ≈14,000 standard cubic feet of hydrogen at 5,000 psig). The two 5,000 psig vessels are the only vessels filled from the electrolysis system. The 2,200 psig vessels are filled by an external hydrogen supply source, and are only used when hydrogen is not available from the two high pressure storage vessels. The two high pressure vessels are protected with two (2) safety relief valves, one valve on each vessel, with each relief valve set to relieve at 4,600 psig. The twenty-four (24) low pressure vessels are protected with a total of three (3) safety relief valves, one set at 2,446 psig, the other two set at 2,200 psig.

e. Hydrogen Dispensing System

The hydrogen dispensing system consists of an ANGI fueling post and the piping and valving shown in Figure 1. The ANGI fueling post is a dual–hose unit rated for operation at 5,000 psig and conforms to the Reference 4 design code. The system is termed a "fueling post" simply because there are no automatic dispensing or metering functions provided. The piping and valving downstream of the high pressure storage vessels are all designed to operate to at least 4,600 psig. The dual–hose unit features hose retractors and breakaway connectors anchored to an integral barricade structure. The manufacturer states that the breakaway force is "25 pounds pull on hose (approximate)." These components are protected from overpressure conditions by means of the two pressure relief devices installed on the two high pressure storage vessels. The safety relief valves on these vessels were originally set to relieve at 4,740 psig. However, after determining that several socket welded valves were only rated for operation at 4,600 psig, these safety relief valves were reset to relieve at 4,600 psig. To preclude the overpressurization of the utility vehicle hydrogen storage tanks (maximum operating pressure of 3,600 psig), a relief valve set to relieve at 3,500 psig is installed on the nozzle side of the dispensing system.

It should be noted that with the safety relief valve set to relieve at 3,500 psig, the maximum operating pressure of this system should be limited to approximately 3,200 psig to prevent premature relief valve operation and leakage. However, with this 3,200 psig limitation, the CAN vehicles can not be fueled to 3,600 psig as required to maximize vehicle range. This limitation can be eliminated by increasing the set point of the 3,500 psig relief valve and installing additional fueling equipment and instrumentation. The Reference 4 design codes states ..."An overpressure protection device, other than a rupture disc, shall be installed in the fueling transfer system to prevent overpressure in the vehicle. The set pressure of the device shall not exceed 125 percent of the service pressure of the fueling nozzle it supplies." This 125 percent pressurization of onboard tanks is permitted only if the settled pressure of the tanks returns to 100 percent of the service pressure upon cooling (due to hydrogen compression within the vehicles storage tank during refueling operations, the temperature of the hydrogen and the storage tank itself will increase during refueling operations). As a result, the 3,500 psig relief valve can be reset to relieve at a maximum pressure of 4,500 psig. However, in doing this, additional safety responsibility is placed on the fueling station operator to ensure that the settled pressure of the onboard storage tanks after cooling does not exceed 3,600 psig. To ensure a safe fill at higher pressures, additional fueling equipment, instrumentation, and operating procedures would have to be installed and utilized at the Xerox site. The final settled pressure can be determined using calculations or temperature/pressure compensation charts. Depending on the method used, the refueling operator will need to know the initial tank temperature, the outside ambient temperature, and the tank temperature and pressure during the fill. Therefore, if CAN feels that it is necessary to fuel the existing vehicles to 3,600 psig at ambient temperature, a portion of the existing system should be redesigned and the fueling operations be modified.

Furthermore, with the aforementioned 125% allowable overpressure in mind, the existing fueling system with the 3,500 psig relief valve installed, should never be used to fuel a vehicle with onboard storage tanks rated for less than 2,800 psig. If the 3,500 psig relief valve is reset to relieve at 4,500 psig, then this fueling station should never be used to fuel a vehicle with onboard storage tanks rated for less than 3,600 psig.

f. Power Distribution and Control System

The power distribution and control system consists of a battery system, a controller/inverter, and a control panel. The battery system consists of a 24 volt, 265 amp hour battery bank, a 1,000 watt inverter (nominal 12 VDC to 120 VAC), and a 24 VDC, 30 amp battery charger (120 VAC input). Battery capacity is sufficient to power the control functions for 48 hours. Power from the photovoltaic array is applied to the inverter through a fusible switch. The inverter supplies regulated 120 VAC power to the battery charger. The battery charger charges the 24 volt battery bank at regulated voltage and current, tapering the charge when the batteries are full. The inverter is remote controlled from a Programmable Logic Controller (PLC). Thus, only when the photovoltaic array current is greater than 200 amps will the battery charging system be operating. The batteries supply power to the control system day and night. Most of the equipment and electronics operate directly from the 24 VDC. However, a few devices require 120 VAC and this is supplied through a 250 watt auxiliary inverter. The controller/inverter is a variable speed motor drive for operating the three phase compressor motor. It operates directly off the photovoltaic array and provides controllable, regulated AC voltage at 208 VAC to the motor. It comprises 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 contains two main sections: Control and Data Acquisition. The control panel contains the control, annunciation, and instrumentation systems for the plant. It is dedicated to the 24 VDC, 12 VDC, and 120 VAC devices. The PLC is the core of the system annunciation and control. It controls the compressor, battery charging system, solenoid valves, and the DC switch. The PLC also performs the annunciator function.

2. Casualty Study

The purpose of the casualty study was to identify those events which could cause damage to facility equipment and subsystems. In performing this study, only single component failures were analyzed, while the analysis of simultaneous double component failures was not performed. Table 1 defines the casualty fault classifications in terms of event frequency and severity. Table 2 lists the potential casualty events with their respective initiating events, fault frequency classification, potential effects, severity without protection, detection system, protection system, protective action, and their severity with protection. The potential casualty events identified were Abnormal Temperature High, Abnormal Pressure High, Abnormal Pressure Low, Abnormal System Fluid Level Low, Abnormal System Fluid Level High, Unplanned Hydrogen Combustion, Excessive Water Vapor In Hydrogen Gas, Abnormal Water Purity Low, Unplanned Venting of Hydrogen, Excessive System Dynamic Loading, Excessive System Static Loading, and Chemical Spill.

Because this system will be compressing, storing, and utilizing hydrogen gas at high pressure levels, one of the primary casualty concerns identified during this study was a system failure caused by pressurizing components or subsystems beyond their rated service pressures. As a result, Table 3 was created to show how each component in the system is protected from an overpressure event.

It should be noted that this casualty study was performed with the assumption that the system design (References 8 through 41) and installation conformed to the codes and standards identified in References 1 through 5. Although for the most part, it appeared that the codes and standards identified were followed and applied, portions of the system did not initially conform to these codes and standards. The deviations from these codes and standards are listed in Table 4, and as discussed in this table, all safety issues have since been adequately addressed. As discussed previously, it was determined that the Electrolyser Corporation, by choice, did not use the Reference 4 design code during the system design. ETEC recognizes that the Reference 4 design code pertains to the design and construction of compressed natural gas dispensing systems only. However, since no equivalent code exists for hydrogen use, ETEC believes that the adoption of this code for hydrogen systems is logical and appropriate. However, since the codes and standards used by the Electrolyser Corporation are adequate and are recommended and accepted for industrial applications, ETEC did not require complete conformance to the Reference 4 design code. Nevertheless, since future CAN hydrogen generation, storage, and dispensing systems should, as a minimum, be designed and built using the Reference 4 design code. Table 4 includes recommendations from this code. Additionally, Table 5 is provided to show how individual components and subsystems are protected with interlocks and alarms. Table 5 lists the system interlocks and alarms along with the respective corrective actions to be taken upon the activation of those alarms.

FAULT FREQUENCY

Anticipated Fault - An off-normal condition which individually may be expected to occur once or more during the plant lifetime.

Unlikely Fault - An off-normal condition which individually is not expected to occur during the plant lifetime; however, when integrated with overall plant components and systems, events in this category may be expected to occur a number of times.

Extremely Unlikely Fault - An off-normal condition of such extremely low probability that no events in this category are expected to occur during the lifetime, but which represents extreme or limiting cases of failures which are identified as possible.

FAULT SEVERITY

Operational Incident - An occurrence in which no significant loss of effective lifetime for any component occurs unless failure of the component constitutes the initiating event.

Minor Incident - An occurrence in which damage to replaceable components is not greater than some specified loss of effective lifetime. For the total number of such occurrences expected in the lifetime of the facility, damage to permanent or semipermanent components results in a reduction of effective lifetime below the design value.

Major Incident - An occurrence in which damage necessitates replacement or repair of replaceable and semipermanent components or systems, and replacement or repair of permanent components before operations can be resumed.

Table 1. Casualty Analysis, Fault and Incident Definitions

Potential Casualty Event	Initiating Events	Fault Frequency Classification	Potential Effects	Incident Severity without Protection	Detection System	Protection System	Protective Action	Incident Severity with Protection
1. Abnormal Temperature High	1. Insufficient air cooling at the interstages of the hydrogen compressor.	Anticipated Fault	Failure of or damage to the hydrogen compressor.	Major	ITSH-513 TSH-515	Interlock and alarm.	Automatic compressor trip.	Operational
	2. Low electrolyte level or excessive current in electrolytic cells.	Anticipated Fault	Overheating of the electrolytic cells causing the cells to fail or be damaged.	Major	TSH-404	Interlock.	Automatic trip of photovoltaic array contactor, which removes all power from the electrolytic cells.	Operational
2. Abnormal Pressure High	1. Hydrogen compressor operating at too high of pressure.	Anticipated Fault	Failure of or damage to components and piping downstream of compressor.	Major	PSH-316 PT-332 PI-312	Interlock and alarm. Pressure relief valve PRV–310.	Automatic compressor trip when set point of PSH-316 is reached.	Operational
	2. Hydrogen in the higher pressure compressor stages leaks into lower pressure compressor stages.	Unlikely Fault	Failure of or damage to the hydrogen compressor.	Major	PI-501 PI-502 PI-503 PI-504	Pressure relief valves PRV-507, PRV-508, PRV-509, and PRV–510.	Manual shutdown of compressor.	Operational

Table 2. System Casualty Events

Potential Casualty Event	Initiating Events	Fault Frequency Classification	Potential Effects	Incident Severity without Protection	Detection System	Protection System	Protective Action	Incident Severity with Protection
2. Abnormal Pressure High (continued)	3. Failed pressure regulator feeding moisture detection system.	Unlikely Fault	Failure of or damage to components and piping downstream of regulator.	Major	None.	Pressure relief valves PSV-318A and PSV–318B.	Manual shutdown of compressor.	Operational
	4. Failed pressure regulator at filling station dispenser.	Unlikely Fault	Failure of or damage to high pressure storage tank on vehicle.	Major	Pressure gage at hose station.	Pressure relief valve PSV-122.	Manual closure of isolation valves V-122A and V-122B.	Operational
	5. Compressor condensate receiver filled.	Anticipated Fault	Failure of or damage to condensate receiver vessel.	Major	None.	Pressure relief valve PRV-511.	Manual shutdown of compressor.	Operational
	6. Over-pressurization of high pressure storage vessels due to ambient temperature changes.	Anticipated Fault	Failure of or damage to high pressure storage vessels.	Major	PI-112A PI-112B	Pressure relief valves PSV-113A and PSV–113B.	None.	Operational
	7. Hydrogen from compressor leaks into crank case.	Unlikely Fault	Failure of or damage to crank case.	Major	None.	Pressure relief valve PSV-512	None.	Operational

Table 2. System Casualty Events (continued)

Potential Casualty Event	Initiating Events	Fault Frequency Classification	Potential Effects	Incident Severity without Protection	Detection System	Protection System	Protective Action	Incident Severity with Protection
3. Abnormal Pressure Low	1. Insufficient lubricating oil in compressor lubricating system.	Anticipated Fault	Failure of or damage to the hydrogen compressor.	Major	PSL-506 PI-505	Interlock and alarm.	Automatic compressor trip. Routine maintenance checks.	Operational
	2. Insufficient hydrogen accumulation in low pressure gas holder.	Anticipated Fault	Failure of or damage to the hydrogen compressor.	Major	PSL-301 PD-302	Interlock and alarm.	Automatic compressor trip.	Operational
	3. Inadvertent closure of valves V-303 and V-305	Unlikely Fault	Failure of or damage to the hydrogen compressor.	Major	ZS-303 ZS-304	Interlock and alarm.	Automatic compressor trip on activation of valve position limit switches.	Operational
4. Abnormal System Fluid Level Low	1. Draining of demineralizer head tank or plugging of feedwater line.	Anticipated Fault	Failure of or damage to the electrolytic cells.	Operational	LSL-105	Interlock and alarm.	Eventual over-temperature or low level trip.	Operational
	2. Insufficient electrolyte level in electrolytic cells.	Anticipated Fault	Poor performance, or failure of or damage to the electrolytic cells.	Minor to Major	LSL-402 LSL-403	Interlock and alarm.	Automatic trip of photovoltaic array contactor, which removes all power from the electrolytic cells.	Operational

Table 2. System Casualty Events (continued)

Potential Casualty Event	Initiating Events	Fault Frequency Classification	Potential Effects	Incident Severity without Protection	Detection System	Protection System	Protective Action	Incident Severity with Protection
4. Abnormal System Fluid Level Low (continued)	3. Insufficient hydrogen in low pressure gas holder.	Anticipated Fault	Failure of or damage to the hydrogen compressor.	Major	ZSLL-110 ZSL-109	Interlock and alarm.	Automatic compressor trip.	Operational
	4. Water seal level low.	Unlikely Fault	Venting of hydrogen and oxygen inside trailer building.	Major	Hydrogen detectors (Three places)	Trailer building designed as Class I, Division 2, Group B location.	Routine maintenence verifies seal level. Automatic system shutdown on detection of hydrogen in trailer building.	Operational
5. Abnormal System Fluid Level High	1. Water seal level high.	Anticipated Fault	Water or potassium hydroxide [KOH] spill.	Minor	LSH-212	Interlock and alarm. Secondary contain-ment.	Automatic system trip.	Operational
	2. Excessive hydrogen in low pressure gas holder.	Anticipated Fault	Venting of hydrogen into atmosphere.	Operational	ZSHH-107 ZSH-108	Interlock and alarm.	Automatic startup of compressor.	Operational

Table 2. System Casualty Events (continued)

Potential Casualty Event	Initiating Events	Fault Frequency Classification	Potential Effects	Incident Severity without Protection	Detection System	Protection System	Protective Action	Incident Severity with Protection
6. Unplanned Hydrogen Combustion	1. Spark igniting flammable mixture of oxygen and hydrogen from within the hydrogen process line.	Unlikely Fault	Explosion and/or fire.	Major	AOR-209 AO-208 AO-207	Interlock and alarm.	Automatic system trip.	Operational
	2. Spark igniting flammable mixture of oxygen and hydrogen inside the electrolytic cell skid.	Unlikely Fault	Explosion and/or fire.	Major	Room hydrogen detectors. (Three places)	Interlock and alarm. Adequate ventilation. Class I, Division 2, Group B equipment.	Automatic system trip.	Operational
7. Excessive Water Vapor In Hydrogen Gas	Failure/degradation of water/moisture removal system.	Anticipated Fault	Reduction of high pressure storage capacity due to the accumulation of water. Contamination of vehicle storage vessels with water.	Minor	ADPI-320 ADPE-319	Interlock and alarm.	Automatic compressor trip.	Operational
8. Abnormal Water Purity Low	Failure or malfunction of demineralizer system.	Anticipated Fault	Reduction in electrolytic cell efficiency.	Operational	CE-102 CE-103	Alarm.	None.	Operational

Table 2. System Casualty Events (continued)

Potential Casualty Event	Initiating Events	Fault Frequency Classification	Potential Effects	Incident Severity without Protection	Detection System	Protection System	Protective Action	Incident Severity with Protection
9. Unplanned Venting Of Hydrogen	1. Leak at vehicle fueling nozzle.	Anticipated Fault	Explosion and/or fire.	Major	Manual leak check at time of fueling.	None.	Fueling mechanic depressurizes fueling nozzle and repairs nozzle. Nozzle replaced if irreparable.	Operational
	2. Fueling line rupture due to vehicle drive away while still connected.	Unlikely Fault	Explosion and/or fire.	Major	None	Excess flow valve within fueling system stops flow.	Mechanic closes emergency isolation valves.	Operational
	3. Tank; vessel; pipe; or tube rupture due to vehicle collision.	Extremely Unlikely Fault	Explosion and/or fire.	Major	None	Crash barrier posts.	None.	Operational
10. Excessive System Dynamic Loading	1. Earthquake beyond design basis.	Extremely Unlikely Fault	Earthquake may cause excessive component, system, or support stress.	Major	None. Operator observa-tion.	None.	Shutdown system and inspect for damage. Hydrogen detectors will shutdown system if a leak is detected.	Major

Table 2. System Casualty Events (continued)

Potential Casualty Event	Initiating Events	Fault Frequency Classification	Potential Effects	Incident Severity without Protection	Detection System	Protection System	Protective Action	Incident Severity with Protection
10. Excessive System Dynamic Loading (continued)	2. Mechanical vibration caused by imbalanced compressor.	Extremely Unlikely Fault	Dynamic loading may cause excessive component, system, or support stress.	Major	None. Operator observa-tion.	None.	Upon observation of excessive vibration take corrective action, i.e., shutdown the compressor.	Minor
	3. Condensate accumulation in hydrogen line downstream of compressor, resulting in a slug of water being propelled at a high speed.	Unlikely Fault	Dynamic loading may cause excessive component, system, or support stress.	Major	ADPI-320 ADPE-319	Interlock and alarm.	Automatic compressor trip.	Operational
11. Excessive System Static Loading	1. Pipe or vessel support failure	Extremely Unlikely Fault	Support failure may cause excessive component, piping, or vessel stress.	Major	None. Operator observa-tion.	Hydrogen detectors will shutdown system if a leak is detected.	Hydrogen detectors will shutdown system if a leak is detected.	Major

Table 2. System Casualty Events (continued)

Potential Casualty Event	Initiating Events	Fault Frequency Classification	Potential Effects	Incident Severity without Protection	Detection System	Protection System	Protective Action	Incident Severity with Protection
11. Excessive System Static Loading (continued)	2. Design error	Extremely Unlikely Fault	Design error may cause excessive component or piping stress.	Major	None. Operator observation.	Hydrogen detectors will shutdown system if a leak is detected.	None. Assumed all design drawings and calculations conform to applicable codes/standards.	Major
	3. Misuse of piping or components for temporary support of miscellaneous heavy loads.	Anticipated Fault	Utilizing piping, etc. as a support for heavy loads may cause excessive component or system stress.	Major	None.	Hydrogen detectors will shutdown system if a leak is detected.	Procedures and operator training act to minimize the probability of these faults.	Major
12. Chemical Spill	1. Fittings and hoses loosen, or are damaged to due to corrosion.	Anticipated Fault	Tubing, piping, components, or vessels leak electrolyte causing damage to equipment and personnel.	Major	None. Operator observation.	Secondary containment.	Maintenance, inspection, and operator training act to minimize the probability of these faults.	Major
	2. Operator error during system electrolyte (KOH) fill.	Anticipated Fault	Electrolyte spill causes damage to equipment and personnel.	Major	None. Operator observation.	Secondary containment.	Operator training acts to minimize the probability of these faults.	Major

Table 2. System Casualty Events (continued)

Component or Line	System Design Pressure (psig)	Pressure Relief Device	Pressure Transducer or Indicator	Remarks
V-101, V-102, V-103, V-104, LCV-104, FI–101, CE–102, Demineralizer Cartridges.	100	None	None	Raw water comes in from city tap. All components rated for incoming pressure.
V-105, V-106, V-107, V-108, V-109, V–110, V-112, V-113, V-114, V-115, V-201, V-202, V-203, V-204, V-205, V-206, V-207, V-208, V-209, V-210, V-211, V-212, V-213, V-214, V-215, V-401, V-402, V–403, V–404, V–405, V–406, V–408, SV–106, FI–101, Low Pressure Gasholder, Demin. Water Head Tank, LSL-105, Electrolytic Cells, PI–203, PI-204, PDI–205, PI-206, AO–207, AO-208, FI–214, FI-213, PDI–210, #202 Mist Eliminator, XV-211, A–201, A-202, LSL–402, LSL–403, #403 Mist Eliminator, #404 Mist Eliminator.	10	None	None	Maximum available pressure is generated by 8 feet of water (3.5 psig).
V–301, V–302, PD–302, V–303, V–304, V–305, V–306, V–307, V–308, V–309, V–310, #301 Strainer, LI–306, #302 Moisture Seperator.	10	None	PD-302	Gasholder vents at 0.35 psig. PSL–301 stops compressor on low pressure condition.

Table 3. Pressure Limits and Protection

Component or Line	System Design Pressure (psig)	Pressure Relief Device	Pressure Transducer or Indicator	Remarks
V–311, V–312, V–313, V–314, V–315, V–316, V–317, V–318, V–319, V–320, V–321, V–322, V–323, V–324, V–325, V–326, V–327, V–328, V–329, NRV–314, PCV–313, PCV–317A, Filter #305, Filter #306, Dryer #304, Filter #307, Filter #308, PD–311, PI–312, PD–315, PSH–316, PT–332.	4,600	PSV-310	PI–312, PT–332	PSV–310 set to relieve at 4,600 psig. PSH–316 shutsdown compressor at 4,200 psig.
PCV–317B, V–330, ADPE–319, FI–321	15	PSV–318A PSV–318B	None	PSV–318A and PSV–318B are set to relieve at 15 psig.
Compressor - 1st Stage, PI–501, V–502, 502 condensate trap, XV–518, XV-516.	55	PRV–507	PI–501	PRV–507 is set to relieve at 55 psig.
Compressor - 2nd Stage, PI–502, V–503, 503 condensate trap, XV–516.	304	PRV–508	PI–502	PRV–508 is set to relieve at 304 psig.
Compressor - 3rd Stage, PI–503, V–504, 504 condensate trap, XV–517.	1451	PRV–509	PI–503	PRV–509 is set to relieve at 1,451 psig.
Compressor - 4th Stage, PI–504, V–505, 505 condensate trap, XV–517, XV–520, NRV–519, Filter #506, V–506, NRV–520.	5,500	PRV–510	PI–504	PRV–510 is set to relieve at 5,500 psig.

Table 3. Pressure Limits and Protection (continued)

Component or Line	System Design Pressure (psig)	Pressure Relief Device	Pressure Transducer or Indicator	Remarks
Compressor crankcase, PI–505, V–501.	10	PRV–512	PI–505	PRV–512 is set to relieve at 10 psig.
Number 507 compressor condensate reciever.	30	PRV–511	None	PRV–511 is set to relieve at 30 psig.
V–116A, V–116B, V–117A, V–117B, V–118, V–119, NRV–117A, NRV–117B, V–120A, V–120B, V–121A, V–121B, NRV–115A, NRV–115B, NRV–116A, NRV–116B, V–122A, V–122B, V–123A, V–123B, V–124, NRV–120A, NRV–120B, PI–112A, PI–112B, PCV–114, PCV–121, PI–118A, PI–118B, Strainer #108, 5,000 psig storage vessels.	4,600	PSV-113A PSV-113B	PI–112A PI–112B	PSV–113A and PSV–113B are set to relieve at 4,600 psig.
V–125, V–126, vehicle storage vessel.	3,600	PSV-122B	Gauge at dispenser.	PSV–122 is set to relieve at 3,500 psig.

Table 3. Pressure Limits and Protection (continued)

During this safety assessment it was determined that portions of the system did not conform with the appropriate and required codes and standards. The deviations from these codes and standards are listed here in Table 4, all of the identified safety issues have since been adequately addressed.

Code: NFPA 50A, *Standard for Gaseous Hydrogen Systems at Consumer Sites*, 1994 Edition.

Deviations:

1. Section 3-2.2. In accordance with Table 3-2.2 of Section 3-2.2, the separation distance between hydrogen storage systems in excess of 15,000 SCF and parked vehicles and public sidewalks is 15 feet. The present layout alloys for vehicles to be parked within the 15 feet requirement. (Note: the vehicle in violation would be parked in an unmarked parking space.)

   Action: The Xerox Corporation has ensured that the 15 feet no parking zone will be met.

Code: NFPA 52, *Standard for Compressed Natural Gas (CNG) Vehicular Fuel Systems*, 1992 Edition.

(Note: ETEC recognizes that NFPA 52 is for natural gas systems. However, since no equivalent code exists for hydrogen use, ETEC believes that the adoption of this code for hydrogen systems is logical and appropriate, until an equivalent hydrogen code is developed.)

Deviations:

1. Section 2-6.1. "A pressure gauge, if provided, shall be capable of reading at least 1.2 times the system design pressure." This requirement has not been met throughout the system.

   Action: Recommendation only. No requirement to follow this code.

Table 4. Deviations From Applicable Codes and Standards

2. Section 2-7.1. "A pressure regulator inlet and each chamber shall be designed for its maximum service pressure with a pressure safety factor of at least 4." Need vendor data to verify that this requirement has been met.

__Action__: Recommendation only. No requirement to follow this code.

3. Section 2-8.2. "Pipe, tubing, fittings, and other piping components between a container and the first shutoff valve shall be capable of withstanding a hydrostatic test of at least four times the rated service pressure without structural failure." Need vendor data to verify that this requirement has been met.

__Action__: Recommendation only. No requirement to follow this code.

4. Section 2-8.3. "Natural gas piping shall be fabricated and tested in accordance with ANSI/ASME B31.3, *American National Standard Code for Chemical Plant and Petroleum Refinery Piping*." Need designer to verify that this requirement has been met.

__Action__: None required. Designer provided verification in Reference 41.

5. Section 2-9.1.1. "Shutoff valves shall have a rated service pressure not less than the rated service pressure of the entire system and shall be capable of withstanding a hydrostatic test of at least four times the rated service pressure without rupture. Leakage shall not occur at less than 1.5 times the rated service pressure using dry air as the test medium." Need vendor data to verify that this requirement has been met.

__Action__: Recommendation only. No requirement to follow this code.

6. Section 2-9.4. "The manufacturer shall stamp or otherwise permanently mark the valve body to indicate the service ratings." Many system valves have not been stamped/marked.

__Action__: Recommendation only. No requirement to follow this code.

__**Table 4.** Deviations From Applicable Codes and Standards (continued)__

7. Section 4-11.2. "The fill line on a storage container shall be equipped with a back-flow check valve to prevent discharge of natural gas from the container in case of line, hose, or fittings rupture." Present low pressure fill system does not meet this requirement.

<u>Action</u>: The low pressure vessels are not filled from the Electrolysis system. These vessels are used as backup and are filled by Praxair personnel from Praxair trucks which are equipped with back flow check valves. Recommended as a best management practice.

Code: <u>NFPA 70, *National Electrical Code*, 1993 Edition.</u>

Deviations:

1. Article 501-16. "*Class I Locations - Grounding, Class I, Divisions 1 and 2.*" No grounding system for enclosure and equipment inside Class I, Division 2 area exists. Ground rods and ground wires from equipment should be added for safety. Bonding jumpers from each piece of electrical gear should be installed with proper fittings at conduit entries.

<u>Action</u>: Electrolyser installed ground rods and routed bonding wires from each piece of equipment to the ground rods. The trailer building was grounded as well. System now complies with code. *(This deviation was due to incomplete work at the time of ETEC's initial review, this work was however, scheduled prior to ETEC's initial review).*

2. It's unclear whether device LSL-105 is rated for use in a Class I, Division 2, Group B location, as no nameplate is installed on unit.

<u>Action</u>: Electrolyser has stated that this wiring is protected by the means of a Zener barrier (MTL761) device which limits the energy in that circuit so that no spark, arc, or sufficient thermal energy to exceed the ignition temperature of hydrogen can be achieved. ETEC concurs, and system now complies with the code.

<u>**Table 4.** Deviations From Applicable Codes and Standards (continued)</u>

3. Article 500-3. "*Hazardous Locations - Special Precaution.*" Hydrogen sensor conduit boxes, installed in the electrolytic cell skid, are rated for Class I, Division 2, Groups C, D, E, F, and G locations only, and not for Group B locations which is for hydrogen service.

   Action: The Xerox Corporation has modified the system to comply with the code.

4. Device PSH-315 has a nameplate indicating it is CSA rated but does not have a U.L. label. The governing agency has relied on U.L. approved devices in a Class I, Division 2, Group B location.

   Action: PSH-315 has been shown to be U.L. approved, system complies with the code.

5. Article 501-15. "*Class I Locations - Live Parts Class I, Divisions 1 and 2.*" Open bussing above the electrolytic cells should be covered to prevent sparking.

   Action: Electrolyser has covered the bussing in this area to comply with the code.

6. Bussing outside between photovoltaic array and control enclosure should be insulated for personnel protection.

   Action: Electrolyser installed warning signs and protective covering to comply with code.

7. DC conductors entering back of electrical cabinet should have a proper bushing to prevent damage to conductors.

   Action: Electrolyser installed proper entrance bushings to protect cables and to comply with code. *(This deviation was due to incomplete work at the time of ETEC's initial review, this work was however, scheduled prior to ETEC's initial review).*

Table 4. Deviations From Applicable Codes and Standards (continued)

8. Article 501-4 (501-16b). *"Class I Locations - Wiring Methods/Grounding Requirements."* Equipment with liquid tight, flex conduit should be grounded or a ground wire across flex conduit should be added.

Action: Electrolyser has installed bonding jumpers to comply with the code. *(This deviation was due to incomplete work at the time of ETEC's initial review, this work was however, scheduled prior to ETEC's initial review).*

9. In electrical room: Article 110-16. *"Requirements for Electrical Installations - Working Space About Electric Equipment (600 Volts, Nominal, or Less)."* Battery charger does not have adequate working clearances and access for working on charger. Disconnect switch does not have adequate working clearances.

Action: Electrolyser has relocated equipment to comply with the code.

10. Article 504-10b. *"Intrinsically Safe Systems - Equipment Installation Location."* Intrinsically safe equipment shall be rated for Class I, Division 2, Group B in the electrolytic cell skid. Devices OAI-207 and OAI-208 are not rated for Group B location.

Action: Electrolyser has shown that OAI-207 and OAI-208 are rated for Group B service.

11. Article 504-50. *"Intrinsically Safe Systems - Grounding."* Intrinsically safe devices OAI–207 and OAI-208 shall be grounded.

Action: Electrolyser has grounded these devices to comply with the code. *(This deviation was due to incomplete work at the time of ETEC's initial review, this work was however, scheduled prior to ETEC's initial review).*

12. Article 350-2. *"Flexible Metal Conduit - Uses Not Permitted."* Flexible metal conduit routed to main shut–off switch should be liquid tight.

Action: Electrolyser changed the conduit to seal–tight flexible type to comply with code.

Table 4. Deviations From Applicable Codes and Standards (continued)

13. Article 430. *"Motors, Motor Circuits, and Controllers."* The disconnect switch for the compressor motor is inside the inverter cubicle. This disconnect switch should be mounted with the handle exposed and lockable to provide proper lock-out protection for working safely on the compressor skid.

    Action: Electrolyser installed a new disconnect switch which complies with the code.

14. Article 300 *"Wiring Methods"* and 346-12 *"Supports."* The conduit in the electrical room is not adequately supported.

    Action: Electrolyser has installed additional conduit supports to comply with the code.

Code: ASME/ANSI B31.3-1993. *Code for Chemical Plant and Petroleum Refinery Piping.*

Deviations:

1. Section 322.6.3. *"Pressure Relieving Systems - Pressure Reliving Devices"*. Requires that all piping systems be protected with pressure relief devices with relief set points no greater than the systems design pressure.

   Action: Electrolyser has reset relief valves PSV-310, PRV-510, PSV-113A, and PSV–113B to relieve at a maximum pressure of 4,600 psig to comply with the code.

Code: Code of Federal Regulations

Deviations:

1. 29CFR1910.331. *"Safety Related Work Practices"*. The main electrical disconnect switch is unable to be locked in the open position. This condition violates 29CFR1910.331, resulting in an unsafe working condition when work is performed on the electrical system.

   Action: Electrolyser has installed a locking mechanism to the main electrical disconnect switch to comply with 29CFR1910.331.

Table 4. Deviations From Applicable Codes and Standards (continued)

Alarm/Interlock Device	Description	Set Point	Indicating Instrument	Corrective Action
LSH-212	Hydrogen/Oxygen Water Seal Level High	12 inches from bottom of water seal.	LSH-212	Alarm alerts operator to investigate level problem (checks for drain blockage); interlock trips photovoltaic array contactor, thereby de-energizing the electrolytic cells.
AOR-209	% Oxygen In Hydrogen Supply High	1% and 2% (see corrective action)	AO-207 AO-209	Alarm alerts operator and interlock vents hydrogen to atmosphere when oxygen level reaches 1%; when oxygen level reaches 2%, interlock opens breaker to stop hydrogen production.
CI-103	Feedwater Purity Low	1 Meg-Ohm	CI-103 CE-102	Alarm alerts operator to check out the feedwater demineralization system. Change cartridge or repair as required.
LSL-105	Feedwater Level Low	1 inch from bottom.	LSL-105	Alarm alerts operator that a low feedwater level exists.
ZSHH-107	Gasholder Level High High	42 inches above floor level.	ZSHH-107	Alarm alerts operator that hydrogen is venting from gasholder. Manual system shutdown may be required if level can not be decreased.
ZSH-108	Gasholder Level High	40 inches above floor level.	ZSH-108	Interlock starts the hydrogen compressor.
ZSL-109	Gasholder Level Low	20 inches above floor level.	ZSL-109	Interlock stops the hydrogen compressor.
ZSLL-110	Gasholder Level Low Low	12 inches above floor level.	ZSLL-110	Alarm alerts operator that hydrogen level in gasholder is very low. Operator to investigate electrolytic cell operation. Interlock stops the hydrogen compressor.

Table 5. Interlocks, Alarms and Corrective Actions

Alarm/Interlock Device	Description	Set Point	Indicating Instrument	Corrective Action
LSL-402	Electrolytic Cell Level High	1 inch from top.	LSL-402	Alarm alerts operator to investigate problems with the feedwater system. Repairs made as required.
LSL-403	Electrolytic Cell Level Low	5 inches from top.	LSL-403	Alarm alerts operator to investigate problems with the feedwater system. Interlock trips the photovoltaic array contactor after 24 hours of low level, thereby de-energizing the electrolytic cells. Repairs made as required.
TSH-404	Electrolytic Cell Temperature High	65°C (149°F)	TSH-404	Alarm alerts operator to investigate problems with the electrolytic cells. Interlock trips the photovoltaic array contactor, thereby de-energizing the electrolytic cells.
PSL-301	Hydrogen Compressor Suction Pressure Low	1 inch water.	PSL-301	Alarm alerts operator to investigate problems with the compressor and electrolytic cells. Interlock stops the compressor.
ADPI-320	Dryer Output Moisture High (≥ 10 ppm)	0°F Dew Point	ADPE-319 ADPI-320	Alarm alerts operator to that dryer output is too wet. Operator checks out dryer system. Interlock stops the compressor. Repairs made as required.
PSH-316	Storage Tanks Full	4,200 psig	PSH-316 PT-332	Alarm alerts operator to that hydrogen storage vessels are full. Interlock stops the compressor.
PSL-506	Low Oil Pressure in Compressor Crankcase	68 Kg/cm^2 (967 psig)	PI-505	Alarm alerts operator that the crankcase oil pressure is low. Interlock stops the compressor. Repairs made as required.
TSH-515	Fourth Stage of Compressor Temperature High	80°C (176°F)	TSH-515	Alarm alerts operator that the fourth stage of the compressor is running hot. Interlock stops the compressor.

Table 5. Interlocks, Alarms and Corrective Actions (continued)

Alarm/Interlock Device	Description	Set Point	Indicating Instrument	Corrective Action
ZS-303	Compressor Suction Block Valve Closed	Fully Open	ZS-303	Interlock stops the compressor.
ZS-304	Compressor Suction Block Valve Closed	Fully Open	ZS-304	Interlock stops the compressor.
SV-106	Demineralizer Water Tank Supply Valve	200 Amps array current	SV-106	Interlock opens SV-106 when sunlight is available.

Table 5. Interlocks, Alarms and Corrective Actions (continued)

3. Safety Assessment

This Safety Assessment addresses the hazards associated with the activities to be conducted during the operation of the CAN solar photovoltaic powered, hydrogen generation, storage, and dispensing system. The assessment is qualitative in nature and is based on the potential casualty events identified in the casualty study, as summarized in Table 2, and on the complete adherence of the system designer to the applicable codes and standards as identified by ETEC (References 1 through 5).

The results of the Safety Assessment are summarized in Table 6. These results show that the CAN solar photovoltaic powered, hydrogen generation, storage, and dispensing system, is safe to be operated by trained operators and mechanics familiar with industrial type operations. Furthermore, the hazards to be encountered by CAN and Xerox Corporation personnel during system operation can be categorized as being similar to those hazards routinely encountered and accepted by the general public. Table 7, provided for information and comparison purposes only, contains a list of those equivalent hazards which are routinely encountered by the general public. It is ETEC's assessment that the operations covered by this Safety Assessment will not result in a significant injury or occupational illness, nor provide a significant negative impact on the environment. Again, CAN and the Xerox Corporation must provide adequate system maintenance, personnel training, and system operating procedures to maintain the present level of safety and to minimize personnel exposure to the hazards detailed in Table 6.

Potential Hazard	Hazard Source	Potential Effects	Method of Mitigation
High Pressure Gases	5,000 psig Gas Storage Vessels; Tubing; Pipe; Hydrogen Compressor; Inert Cover Gas	Body Injury Due To Flying Shrapnel from System Explosion or Rupture	Piping, Vessels, and Components designed, built, and installed per ASME codes, i.e. system contains relief valves where required by code and entire system has been pneumatically leak tested per code requirements. Operating procedures and training are required to minimize hazard exposure.
Fire and/or Explosion	Hydrogen and Air; Hydrogen and Oxygen	Body Injury Due To Flying Shrapnel, Thermal Burns	System contains hydrogen detectors. System trips preventing explosive mixtures from forming. Adequate ventilation built into system. Operating procedures and training are required to minimize hazard exposure. System designed for operation within a hydrogen and oxygen atmosphere.
High Temperature	Electrolytic Cells; Compressor	Thermal Burns	Electrolytic Cells contain high temperature trip. Compressor contains high temperature trip. Operating procedures/training minimize hazard exposure.
Electrical	Photovoltaic Array, Electrolytic Cell Bus Bars [22 VDC, 2500 Amps]	Electric Shock	All bus bars to be wrapped with non conducting insulating tape or covering. Operating procedures and training are required to minimize hazard exposure.
Noise	Hydrogen Compressor	Ear Damage	Compressor built to meet OSHA noise requirements. Operating procedures and training are required to minimize hazard exposure.
Toxic Chemicals	Electrolyte [Potassium Hydroxide (KOH) solution]	Chemical Burns; Chemical Spill; Poisoning	Operating procedures, training, and maintenance are required to minimize hazard exposure. Secondary Containment.
Collision	Fleet Vehicles	Body Injury Due Impact With Vehicle	Operating procedures and training are required to minimize hazard exposure.
Tripping	Bus Bars; Hydrogen Piping; Electrical Conduit; Feedwater Piping	Body Injury Due To Fall	Limited Access. Operating procedures and training are required to minimize hazard exposure.

<u>**Table 6.** System Hazard Assessment</u>

Potential Hazard	Hazard Source	Public Equivalent
High Pressure Gases	5,000 psig Gas Storage Vessels; Tubing; Pipe; Hydrogen Compressor; Inert Cover Gas	Hospitals, Medical Supply Houses, Helium Tanks, SCUBA Bottles
Fire and/or Explosion	Hydrogen and Air ; Hydrogen and Oxygen	Gas Barbecues, Home Heating Systems, Gas Stoves, Gas Stations
High Temperature	Electrolytic Cells; Compressor	Ceramic Kilns, Oven and Stove Heater Elements, Radiant Heaters
Electrical	Bus Bars Connecting the Photovoltaic Array and Electrolytic Cells [22 VDC, 2500 Amps]	Portable TV's; Radios; Metal Detectors, Electric radiant Heaters
Noise	Hydrogen Compressor	Home Air Compressors, Lawn Mowers, Emergency Generators
Toxic Chemicals	Electrolyte [Potassium Hydroxide (KOH) solution]	Household Chemicals and Cleaners, i.e. Oven Cleaners and Degreasers
Collision	Fleet Vehicles	Personal Vehicles; Public Transportation
Tripping	Bus Bars; Hydrogen Piping; Electrical Conduit; Feedwater Piping	Typical Household Tripping Hazards

Table 7. Equivalent Hazards Routinely Encountered by the Public

References

1. ASME/ANSI B31.3-1993, *Code for Chemical Plant and Petroleum Refinery Piping*.

2. ASME *Boiler and Pressure Vessel Code*-1986, Section VIII, Rules for the Construction of Pressure Vessels.

3. NFPA 50A, *Standard for Gaseous Hydrogen Systems at Consumer Sites*, 1994 Edition.

4. NFPA 52, *Standard for Compressed Natural Gas (CNG) Vehicular Fuel Systems*, 1992 Edition.

5. NFPA 70, *National Electrical Code*, 1993 Edition.

6. Larson, D. A., Xerox-CAN H_2 Fueled Ford Ranger Test Report, Report No. 019–TR–0003, Energy Technology Engineering Center, U.S. Department of Energy, Canoga Park, CA (June 8,1995).

7. Sprouse, K. M., Safety Evaluation For Unrestricted Use of the H_2 Fueled CAN Ford Ranger, Report No. 019–TN–0003, Energy Technology Engineering Center, U.S. Department of Energy, Canoga Park, CA (September 19,1995).

8. Drawing Number 2076-C-100 (1 Sheet), Rev. No. R-0, UCELL Gas Offtake and Vent Pipe System, The Electrolyser Corporation (July 12, 1995).

9. Drawing Number 2076-C-409 (1 Sheet), Rev. No. R-0, Moisture Separator, The Electrolyser Corporation (February 9, 1994).

10. Drawing Number 2076-D-000 (1 Sheet), Process Flow Diagram, Unicell Cluster™, The Electrolyser Corporation (February 28, 1995).

11. Drawing Number 2076-D-001 (1 Sheet), Rev. No. R-2, Process and Instrumentation Diagram, Unicell Cluster™ System, The Electrolyser Corporation (June 22, 1995).

12. Drawing Number 2076-D-002 (1 Sheet), Rev. No. R-2, Process and Instrumentation

Diagram, Electrolytic Cell Skid of the Unicell Cluster™, The Electrolyser Corporation (June 22, 1995).

13. Drawing Number 2076-D-003 (1 Sheet), Rev. No. R-2, Process and Instrumentation Diagram, Hydrogen Compression and Gas Purification Skid For Unicell Cluster™, The Electrolyser Corporation (May 24, 1995).

14. Drawing Number 2076-D-004 (1 Sheet), Rev. No. R-1, Process and Instrumentation Diagram, Cell Schematic (Typical of Eight Cells, The Electrolyser Corporation (May 17, 1995).

15. Drawing Number 2076-D-005 (1 Sheet), Rev. No. R-0, Process and Instrumentation Diagram, Hydrogen Compressor, The Electrolyser Corporation (February 8, 1995).

16. Drawing Number 2076-D-016 (8 Sheets), Title Sheet - Existing Plan Hydrogen Fueling Facility, Matrix Engineers and Contractors, Inc., 6-29-95.

17. Drawing Number 2076-D-018 (1 Sheet), Rev. No. F, Proposed Site Layout Details For Unicell Cluster™, The Electrolyser Corporation (June 7, 1995).

18. Drawing Number 2076-D-020 (1 Sheet), Rev. No. 1, Proposed Site Layout Unicell Cluster™ System, The Electrolyser Corporation (May 31, 1995).

19. Drawing Number 2076-D-201 (1 Sheet), Rev. No. R-0, Water Seal and Mist Eliminator Skid Outline, The Electrolyser Corporation (March 17, 1995).

20. Drawing Number 2076-D-202 (1 Sheet), Rev. No. R-0, Electrolytic Cell Skid Outline, The Electrolyser Corporation (March 17, 1995).

21. Drawing Number 2076-D-203 (2 Sheets), Rev. No. R-0, Water Seal and Mist Eliminator Skid Fabrication Detail, The Electrolyser Corporation (April 3, 1995).

22. Drawing Number 2076-D-204 (1 Sheet), Rev. No. R-0, Cell Base, The Electrolyser Corporation (April 10, 1995).

23. Drawing Number 2076-D-205 (1 Sheet), Rev. No. R-0, Piping Details at Water Seal, Mist Eliminator and Demin. Water Storage Tank, The Electrolyser Corporation (May 30, 1995).

24. Drawing Number 2076-D-206 (1 Sheet), Rev. No. R-0, Manometer Panel Fabrication Details and Demin. Water Head Tank Details, The Electrolyser Corporation (May 30, 1995).

25. Drawing Number 2076-D-207 (1 Sheet), Rev. No. R-0, Header Pipes, The Electrolyser Corporation (June 16, 1995).

26. Drawing Number 2076-D-208 (1 Sheet), Rev. No. R-0, KOH Collection Headers Details, The Electrolyser Corporation (June 20, 1995).

27. Drawing Number 2076-D-301 (3 Sheets), Rev. No. R-0, H2 Production Plant Schematic Diagram Power Distribution, The Electrolyser Corporation (May 24, 1995).

28. Drawing Number 2076-D-302 (1 Sheet), Rev. No. R-0, Control Panel Wiring Diagram, The Electrolyser Corporation (August 1, 1995).

29. Drawing Number 2076-D-303 (1 Sheet), Rev. No. R-0, Control Panel Outline, The Electrolyser Corporation (July 17, 1995).

30. Drawing Number 2076-D-308 (3 Sheets), Rev. No. R-0, Conduit Layout, The Electrolyser Corporation (August 8, 1995).

31. Drawing Number 2076-D-401 (1 Sheet), Rev. No. R-0, Hydrogen Mist Eliminator, The Electrolyser Corporation (February 27, 1995).

32. Drawing Number 2076-D-402 (1 Sheet), Rev. No. R-0, Hydrogen Compression and Purification Skid Outline, The Electrolyser Corporation (March 28, 1995).

33. Drawing Number 2076-D-403 (1 Sheet), Rev. No. R-0, Hydrogen Gasholder Water Tank Details, The Electrolyser Corporation (April 29, 1995).

34. Drawing Number 2076-D-404 (1 Sheet), Rev. No. R-0, Hydrogen Gasholder Gas Bell

Details, The Electrolyser Corporation (May 2, 1995).

35. Drawing Number 2076-D-405 (1 Sheet), Rev. No. R-0, Hydrogen Gasholder Level Switches, The Electrolyser Corporation (May 2, 1995).

36. Drawing Number 2076-D-406 (1 Sheet), Rev. No. R-0, Hydrogen Gasholder Outline For Unicell Cluster™, The Electrolyser Corporation (May 3, 1995).

37. Drawing Number 2076-D-407 (1 Sheet), Rev. No. R-0, Compressor Skid Fabrication Detail, The Electrolyser Corporation (May 3, 1995).

38. Drawing Number 2076-D-408 (1 Sheet), Rev. No. R-0, Hydrogen Compression and Purification Skid Piping Details, The Electrolyser Corporation (May 19, 1995).

39. Drawing Number 2076-D-410 (1 Sheet), Rev. No. R-0, System Isometric - Storage Tanks and Filling Station, The Electrolyser Corporation (August 10, 1995).

40. Drawing Number 2076-L-011, Rev. 1, Instrument List, The Electrolyser Corporation (May 25, 1995).

41. Electrolyser FAX Transmittal Number 9511/ET098, Matthew Fairlie to Kevin Knudsen, (November 13, 1995).

42. Praxair, Inc. Letter, Tom Halvorson to Kevin Knudsen, Subject: Draft of ETEC's Safety Evaluation of the Xerox/CAN Solar Photovoltaic Hydrogen Generating and Dispensing System (December 11, 1995).

43. Instruction Manual For A Stuart Photovoltaic–Hydrogen Generator Unicell–Cluster TM.

Design Detail Attachment
Xerox/Praxair/CAN Hydrogen Vehicle Demonstration Project

1.0 Background

Clean Air Now, a non-profit corporation founded in Riverside, CA, in 1969, and Xerox Corporation have teamed together to initiate a project which would publicly demonstrate the capability to produce solar generated hydrogen and then provide it as fuel for Xerox utility vehicles. The location for the project is at the Xerox complex in El Segundo, CA.

Although funding required to accomplish the entire project in its full scope has not yet been secured, enough money is available to begin the first phase of the project. During this phase, two Ford Ranger pickup trucks will be modified to burn hydrogen gas in their 4 cylinder, 2.3 liter engines. Hydrogen will be stored onboard the trucks in lightweight, high pressure composite cylinders. Praxair will provide an interim fueling facility at the Xerox site to provide hydrogen gas for these vehicles. Praxair intends on providing a supply of backup hydrogen to Xerox when the full hydrogen generating system becomes operational.

This interim facility can be considered a "Partial Fill" fueling system due to the fact that each refueling operation will leave the vehicle tanks partially filled. Gas will be transferred from on-site receivers directly into the vehicle tanks without additional compression. Since the vehicle tanks are expected to have a service pressure of 3600 psig and the supply system will operate with a pressure no higher than 2000 psig, the vehicle tanks will not become fully pressurized. The direct result of this partial fill is to reduce the maximum operating range of the vehicles between refuelings.

This "Partial Fill" fueling system is designed with simplicity and safety in mind. The direct transfer of gas by pressure difference between the site receivers and the vehicle tanks allows the facility to be independent of all utility services, particularly electrical where explosion-proof components would be required.

The site layout for the interim fueling system has provided for the potential expansion of the facility into a "Fast Fill" system where equipment for gas compression, high pressure cascade storage, and automatic metered gas dispensing would be added.

2.0 Facility Overview

The "Partial Fill" fueling system will consist of high pressure gas receivers for storing hydrogen brought to the site by Praxair, a vehicle fueling post with two delivery hoses and fueling nozzles, interconnecting piping, a fueling panel with manual valves and pressure gauges, and a vent stack for the safe discharge of hydrogen gas should a release occur from safety relief valves.

The fueling operation is intended to be done manually by the driver of the utility vehicle. He or she will be expected to follow a set of operating instructions (described in Section 5.0) to safely accomplish vehicle refueling. The transfer of gas from the receivers will be done in two separate steps to maximize the quantity of fuel transferred. These transfers will be done simply by opening and closing a series of manual valves while monitoring system pressures. It is expected that the refueling operation can be accomplished in a period of approximately 10 minutes or less.

The facility will be completely fenced and occupy an area of approximately 3000 square feet. Vehicle access for refueling will be provided through gates on opposite sides of the fenced area. The receiver modules will be refilled with hydrogen by deliveries from Praxair tube trailers. Access for refilling will be provided through a swing gate positioned appropriately for ease of positioning the tube trailer adjacent to the facility fence. Further details of the system design will be discussed in Section 4.0.

3.0 Supply Performance Expectations

The capability of the "Partial Fill" fueling system to supply hydrogen to the utility vehicles will vary depending on ambient temperature, residual gas pressure within the vehicle tanks, and the pressures of the two receiver modules. The receiver modules will be maintained as two separate gas sources with the ability to transfer product in separate transfer steps or cascades. Each refueling will decrease the pressure in the receivers as hydrogen product is withdrawn. Subsequent refuelings will result in shortened vehicle range since less gas will be transferred.

Figure 1 on the following page presents a curve of usable vehicle range as a function of the number of refuelings accomplished since the receivers were previously filled. This curve is based on the following assumptions:

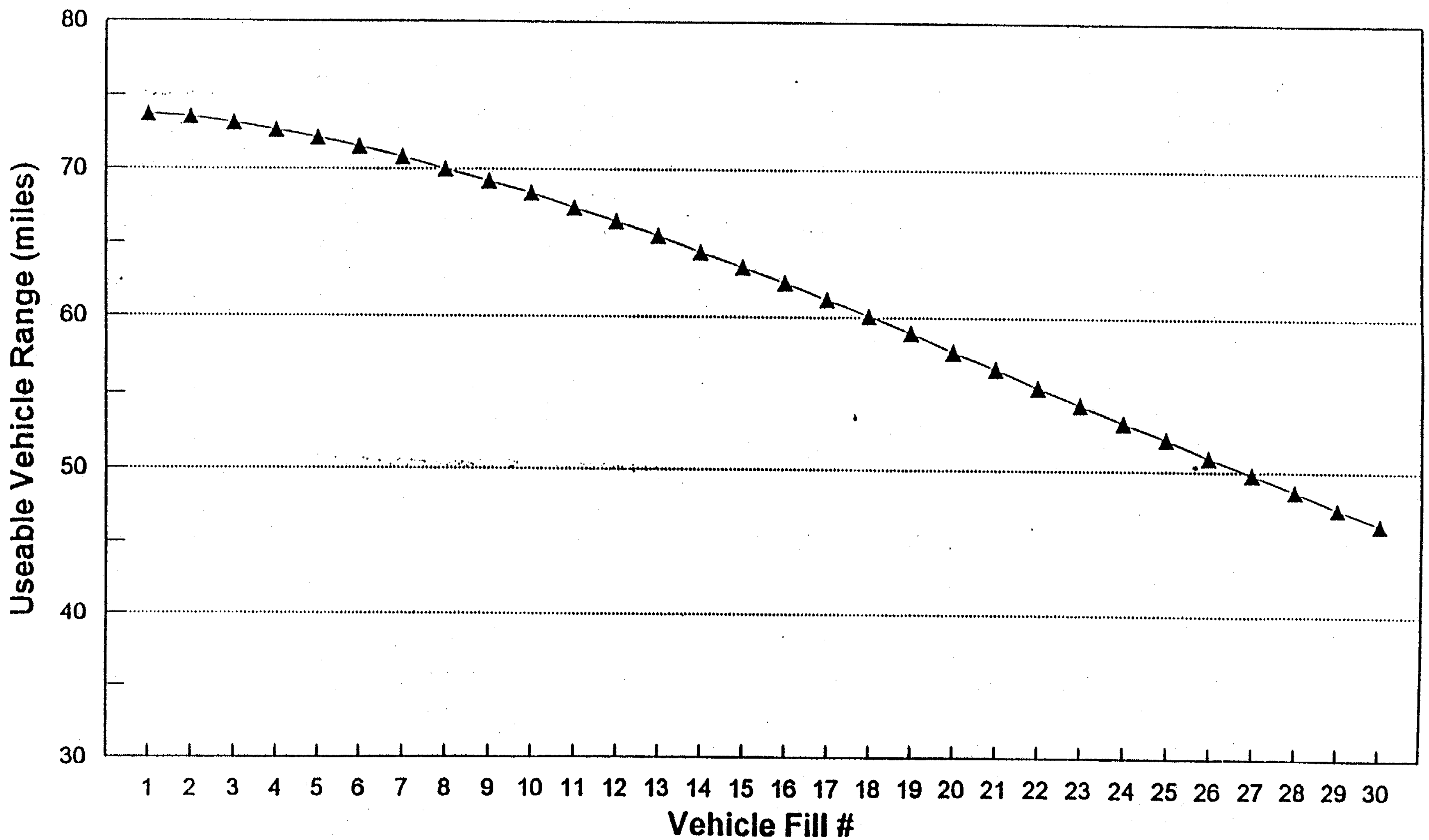
a) Water volume of vehicle tanks is 13 cubic feet;

b) Expected vehicle range is 120 mi with tanks at 3000 psig;

c) Residual vehicle tank pressure is 200 psig at refueling 200 psig residual pressure provides 9.6 mile reserve; and

d) Temperature remains at 70F throughout refueling process.

Figure 1. Useable Vehicle Range
"Partial Fill" Fueling System



What the curve indicates is that the usable vehicle range would be maximum after the first fueling (74 miles) and would fall off to approximately 50 miles after 26 consecutive vehicle fills. Xerox personnel feel that 50 miles would be acceptable as a minimum range while functioning as a shuttle vehicle around the Xerox El Segundo facilities.

Figure 2 projects the residual hydrogen contents of the site receivers as a function of vehicle fills. After 26 fills, approximately 57% of the full contents would remain. However, at this time the 12-Pack receiver modules must be refilled by Praxair to restore system capability. A transfer of 32,800 SCF of hydrogen gas would be required.

4.0 Fueling System Design

The design of the "Partial Fill" fueling system is intended to meet the functional requirements discussed in the previous section as well as meet all safety requirements of the El Segundo Fire Department. The siting of the system will be done to maintain or exceed the separation distances detailed in NFPA 50A, "Standard for Gaseous Hydrogen Systems at Customer Sites". The fueling operation and equipment will be patterned after NFPA 52, "Standard for Compressed Natural Gas (CNG) Vehicular Fuel Systems". Where appropriate, materials or components will be substituted or modified for hydrogen service.

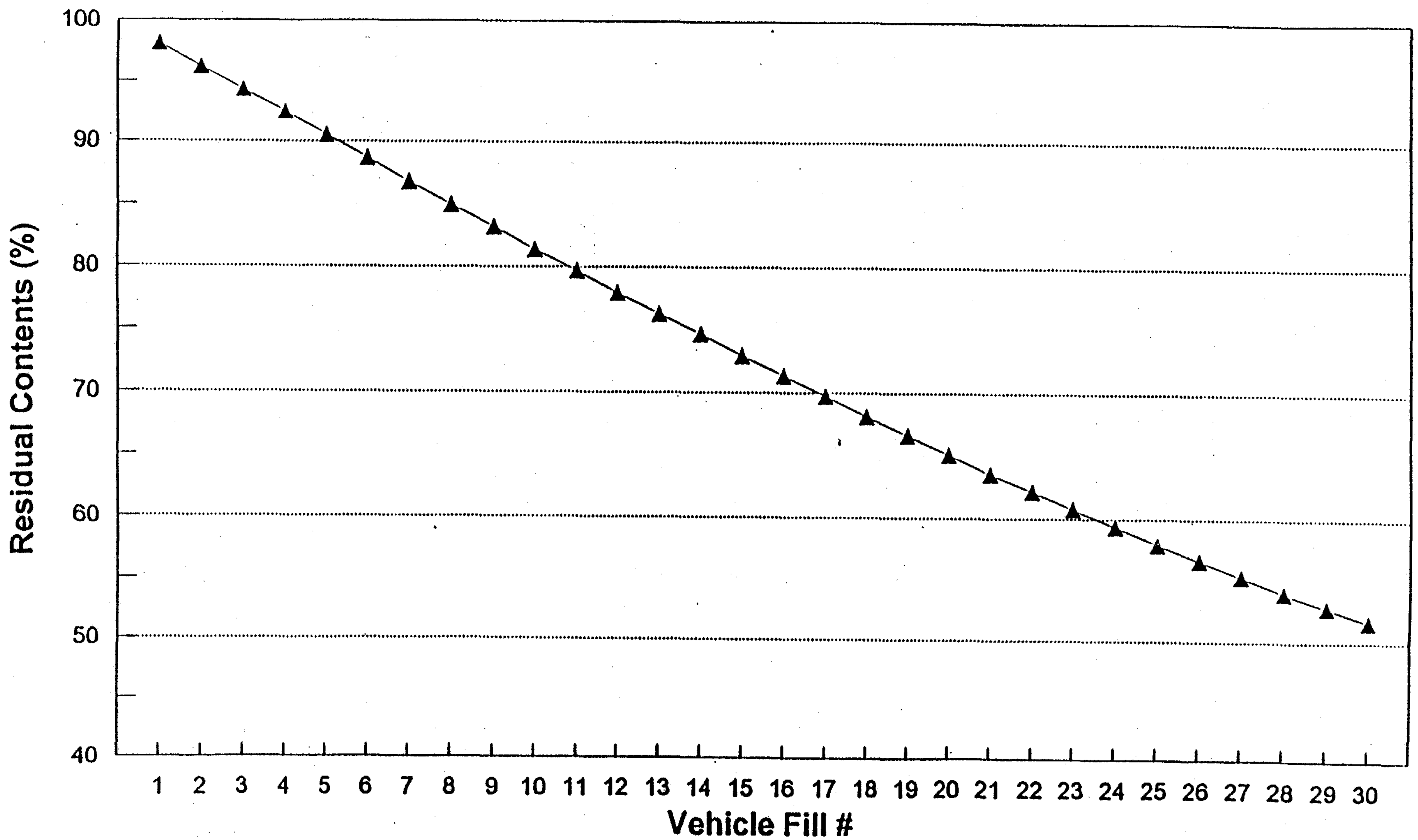
4.1 Process and Instrumentation Diagram

The proposed system is presented in the Process and Instrumentation Diagram (P&ID) shown in Praxair Drawing B-TGH-01. Referring to the drawing (Sheet 1) and its legend (Sheet 2), hydrogen gas will be delivered to the facility and transferred into both 12-Pack Modules A and B. Two high pressure transfer lines will deliver gas from each module independently to a vehicle fueling post assembly. There will be one or more valve panels mounted on the post for operator control of the fueling process. Information will be available to the operator regarding the storage pressure in each module as well as the local fueling pressure at the fueling hose connected to the vehicle. The internal pressure of the vehicle tanks will also be available to the operator locally at the vehicle fueling connection.

The fueling process will be described in Section 5.0 and will refer to the valve and gauge tag numbers shown on the P&ID. Either fueling hose can be used to fuel a vehicle and two vehicles can be fueled simultaneously.

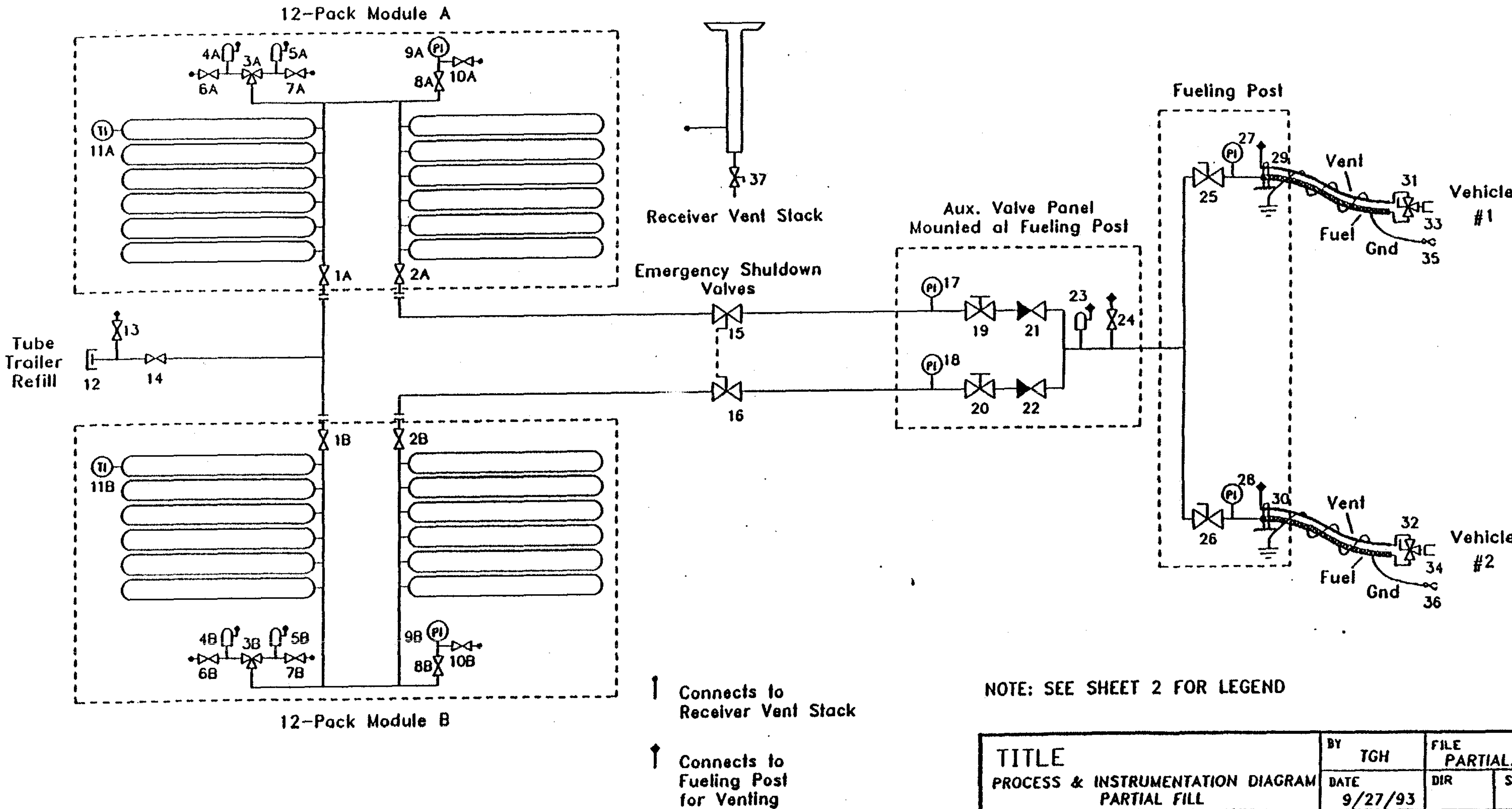
Should an emergency occur for some reason during refueling, the flow of hydrogen gas can be immediately terminated remotely from the fueling post by closing the Emergency Shutdown Valves. The quarter-turn valves will be joined together so that a single motion will close both module supply lines.

Figure 2. Residual Contents of "12-Packs"
"Partial Fill" Fueling System



U/M	ITEM	LINDE P/N	QTY	MATERIAL AND DESCRIPTION		ALT

FIRST USED ON DWG. NO.



NOTE: SEE SHEET 2 FOR LEGEND

TITLE
PROCESS & INSTRUMENTATION DIAGRAM
PARTIAL FILL
HYDROGEN FUELING SYSTEM
XEROX – EL SEGUNDO, CA

PRAXAIR, INC.
DISTRIBUTION DEVELOPMENT & ENGINEERING
TONAWANDA, NEW YORK

BY TGH	FILE PARTIAL.SKD	
DATE 9/27/93	DIR	SCALE
REVIEWED	SHT.NO 1	ALT
APPROVED	NO.SHT 2	

B-TGH-01

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U/M	ITEM	LINDE P/N	QTY	MATERIAL AND DESCRIPTION		ALT

LEGEND

12-PACK RECEIVER MODULES

1A,1B	TRAILER SUPPLY VALVE
2A,2B	ISOLATION VALVE
3A,3B	3-WAY DIVERTER VALVE
4A,4B,5A,5B	RELIEF VALVE, SET @ 2200 PSIG
6A,6B,7A,7B	PURGE/BLEED VALVE
8A,8B	PRESSURE GAUGE VALVE
9A,9B	PRESSURE GAUGE, 0-6000 PSIG
10A,10B	PURGE/BLEED VALVE
11A,11B	TEMPERATURE GAUGE

TUBE TRAILER REFILL

12	TRAILER HOSE CONNECTION
13	PURGE/BLEED VALVE
14	FILL LINE ISOLATION VALVE

HIGH PRESSURE SUPPLY LINES

15,16	EMERGENCY SHUTDOWN VALVE
17,18	PRESSURE GAUGE, 0-3000 PSIG
19,20	CASCADE BANK SUPPLY VALVE
21,22	CASCADE BANK CHECK VALVE
23	SUPPLY LINE RELIEF VALVE, SET @ 2200 PSIG
24	PURGE/BLEED VALVE

FUELING POST

25,26	FUELING HOSE ISOLATION VALVE
27,28	PRESSURE GAUGE, 0-6000 PSIG
29,30	HOSE BREAKAWAY CONNECTION
31,32	3-WAY FUELING VALVE
33,34	FUELING NOZZLE
35,36	GROUNDING CLAMP

MISCELLANEOUS

37	VENT STACK DRAIN VALVE

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TITLE
PROCESS & INSTRUMENTATION DIAGRAM
PARTIAL FILL
HYDROGEN FUELING SYSTEM
XEROX - EL SEGUNDO, CA

PRAXAIR, INC.
DISTRIBUTION DEVELOPMENT & ENGINEERING
TONAWANDA, NEW YORK

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B-TGH-01

4.2 Hardware Description

4.2.1 12-Pack Receiver Modules

The site storage of hydrogen gas will be in two (2) separate modules of 12 tubes each. These ASME receiver tubes are 11 3/4-inch O.D. and approximately 40 ft. in length. They are arranged in three rows of four tubes each while supported inside a modular mounting frame. The two modules will be stacked vertically to minimize area requirements.

The total water volume of a single 12-Pack is approximately 350 cu. ft. The maximum allowable working pressure (MAWP) of the tubes is 2200 psig, but their operating pressure will be no higher than 2000 psig. This will provide reasonable margin below the safety relief valve setpoint so inadvertent release of gas is avoided. At 2000 psig operating pressure, the stored volume corresponds to almost 38,000 SCF of hydrogen (76,000 SCF for both modules).

The 12 tubes are connected together on one end to a common piping manifold. There is a dual safety relief valve module attached to the manifold to provide overpressure protection. A 3-way switching valve provides the opportunity to remove one valve for maintenance or testing purposes while leaving the module in service. Any release of gas through the safety valves is directed to the vent stack to aid in safe dispersion into the air.

The two receiver modules will be isolated from each other in order to provide a "cascade" dispensing system. By transferring gas from the lowest pressure bank first and then from the highest pressure bank, a higher final pressure can be achieved than if only one transfer occurred with all 24 tubes connected in common.

4.2.2 Fueling Post

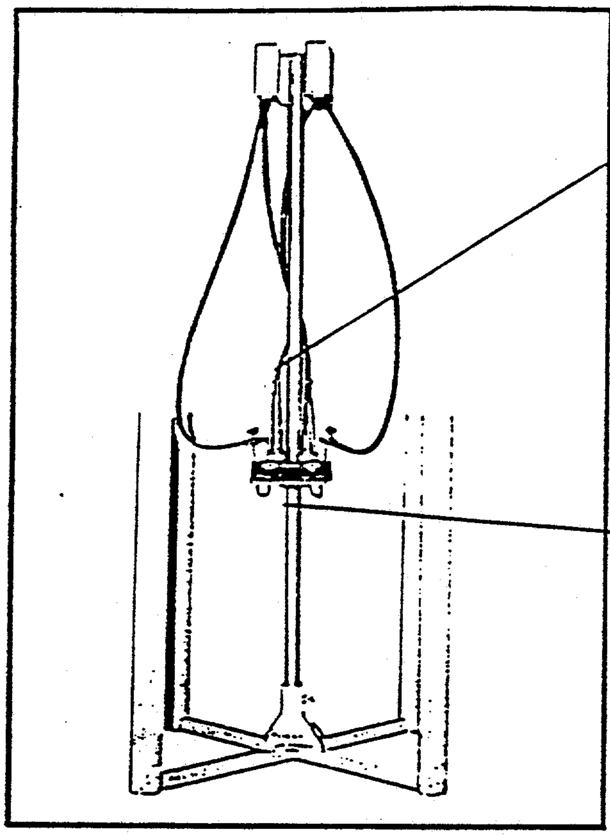
Fueling of the Xerox utility vehicles will be done through the use of a commercially available fueling post designed for compressed natural gas (CNG). Figures 3 and 4 show typical details of a CNG fueling post supplied by Automotive Natural Gas Inc. The use of this fueling post in hydrogen service has been discussed with ANGI and should not create operating or safety problems.

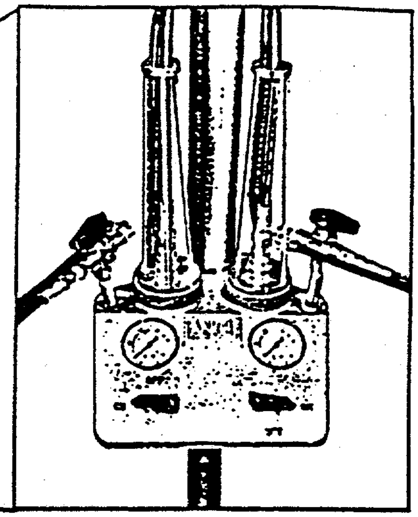
This unit includes two fueling hoses with hose retractors mounted at the top of the post to aid in keeping the hoses off the ground and neatly stowed. The hoses are typically 14 ft. in length and rated at 5000 psi. They are constructed with an electrically conductive thermoplastic liner which is compatible with CNG and H_2.

NFPA 52 requires the use of a hose breakaway system for CNG fueling. This prevents the possibility of severing the hose if

Figure 3

ANGI FUELING POST





(OPTIONAL EQUIPMENT SHOWN)

A UNIQUE DESIGN, AVAILABLE WITH ONE TO FOUR REFUELING HOSES. BREAK AWAY SYSTEM ON EACH HOSE. EACH FUELING POST ASSEMBLY COMES WITH COMPLETE BARRICADE SYSTEM.

THE ANGI FUELING POST STANDARD FEATURES:

- REFUELING POST BASE ONE PIECE, COMPLETE WITH BARRICADE POST
- REFUELING POST MAST DISASSEMBLES FROM BASE
- REFUELING POST HAS MASTER SHUT - OFF VALVE
- BREAK AWAY SYSTEM ON EACH HOSE
- HOSE RETRACTOR WITH EACH HOSE
- CONFORMS TO NFPA-52
- THREE WAY VENT BACK REFUELING VALVE
- TIME FILL OR FAST FILL

OPTIONS:

- LIQUID FILLED HOSE PRESSURE GAUGES
- DOUBLE ISOLATION VALVES

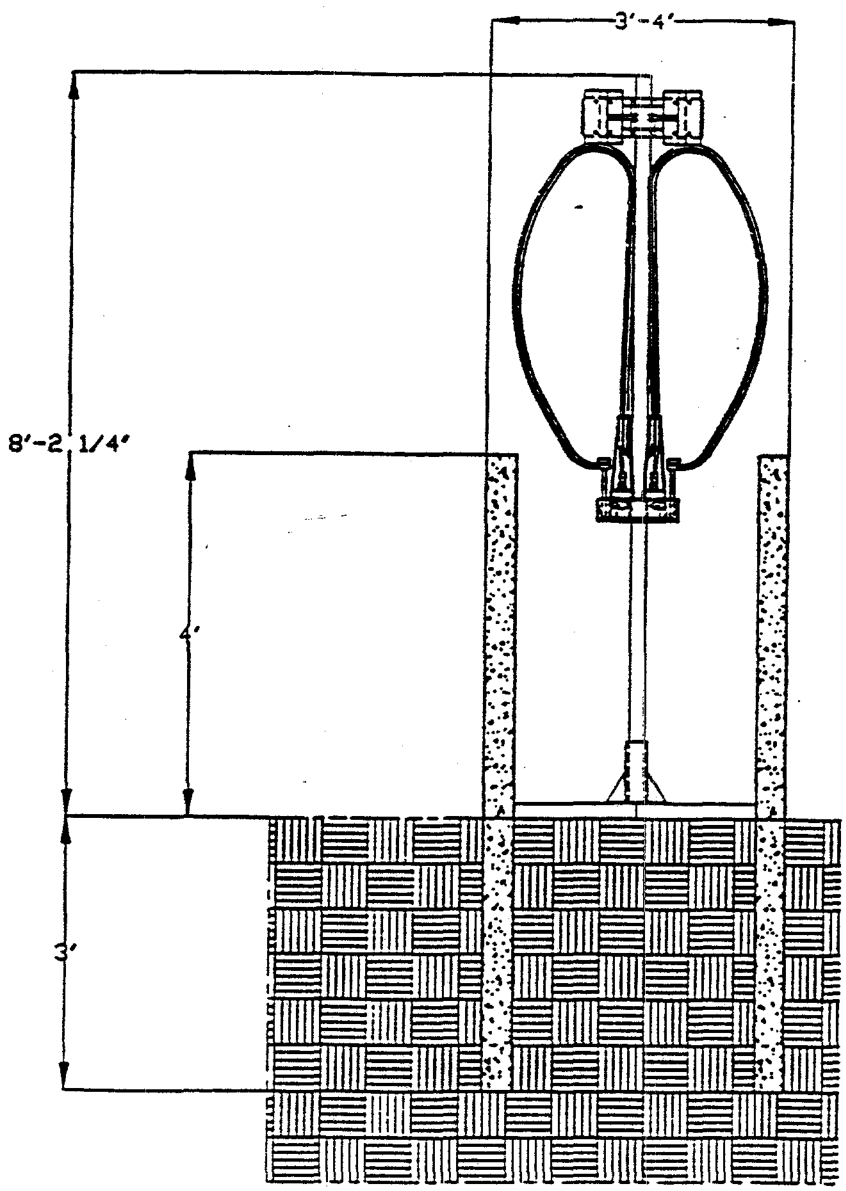
ANGI Automotive Natural Gas Inc.

• 265 N. Janesville • Milton, WI 53563 • (800) 955-4626 • FAX (608) 868-2723

Figure 4

SPECIFICATIONS

- WORKING PRESSURE 5000 PSI.
- REFUELING HOSE SLOW FILL 12' STANDARD, OPTIONAL LENGTHS AVAILABLE.
- REFUELING HOSE FAST FILL 14' STANDARD, OPTIONAL LENGTHS AVALILABLE.
- MAST POST 2" DIAMETER.
- BARRICADE POST 4" DIAMETER, LENGTH 7' APPROXIMATE, 4" ABOVE GRADE, 3" BELOW GRADE.
- CONSTRUCTED TO MEET THE UNIFORM BUILDING CODE.
- BREAK AWAY PRESSURE - 25 POUNDS PULL ON HOSE (APPROXIMATE).



for some reason the vehicle were to be driven away while the hose remained attached. This breakaway device must separate with a horizontal force not exceeding 44 lb. and be designed not to release gas from either side of the break. This system will be supplied for both hoses.

The fueling hose terminates with a 3-way fueling valve. This valve provides vent relief of the fueling nozzle after completing the delivery of high pressure gas. The vented gas (less than 0.25 SCF) will return through a second smaller hose attached to the fueling hose. This vent hose discharges directly into the inside of the fueling post and then safely out the top into the atmosphere.

4.2.3 Fueling Connector

The fueling connector attached to the end of the hose will be used to connect directly to the matching receptacle located on the side of the vehicle. Praxair has conducted a Preliminary Safety Risk Review of the proposed "Partial Fill" fueling system and has determined that the fueling connector must be a CGA-350 nut and nipple system. This is an industry standard for transferring compressed hydrogen gas to and from high pressure cylinders. The choice of this connector may be less "user friendly" than a "quick connect" style connector, but it has a proven track record of making leak-tight joints and also eliminates any potential cross-fueling situations with CNG vehicles or fuel dispensers.

This connector features a metal-to-metal seat and has left hand threads. Making and breaking the connection will require use of a wrench by the fueling operator. The connector has a pressure limitation of 3000 psig which is sufficient for the "Partial Fill" fueling system but will need to be upgraded when a 3600 psig fast fill system is installed. At that time, it may be possible to also consider the use of a "quick connect" style fueling connector if current evaluation work qualifies its use.

4.2.4 Grounding System

Transfer of hydrogen gas, and additionally the making and breaking of connections, can be hazardous if a small electrostatic spark or discharge were to occur near a flammable mixture. The ignition energy required to ignite a hydrogen-air mixture is very low, approximately 0.02 millijoules. This is only about 1/15 of what is needed for a methane-air mixture.

To insure that no static discharges occur in the fueling process, additional direct grounding of the vehicle to a site grounding system will be made prior to connecting the fueling hose. This is common practice in the transfer of hydrogen gas from commercial tube trailers to industrial customers.

The grounding will be done by connecting a clamp attached to the end of a grounding wire directly to a grounding stud located adjacent to the fueling receptacle on the vehicle. The grounding wire will be wrapped along the fueling hose and will have its own retracting reel to take up slack.

The grounding system at the fueling facility will be directly connected to a buried ground rod. This system will also provide direct grounding of the receiver modules, the vent stack, the fence, and the tube trailer when it arrives to recharge the receivers with additional hydrogen.

4.2.5 Vent Stack

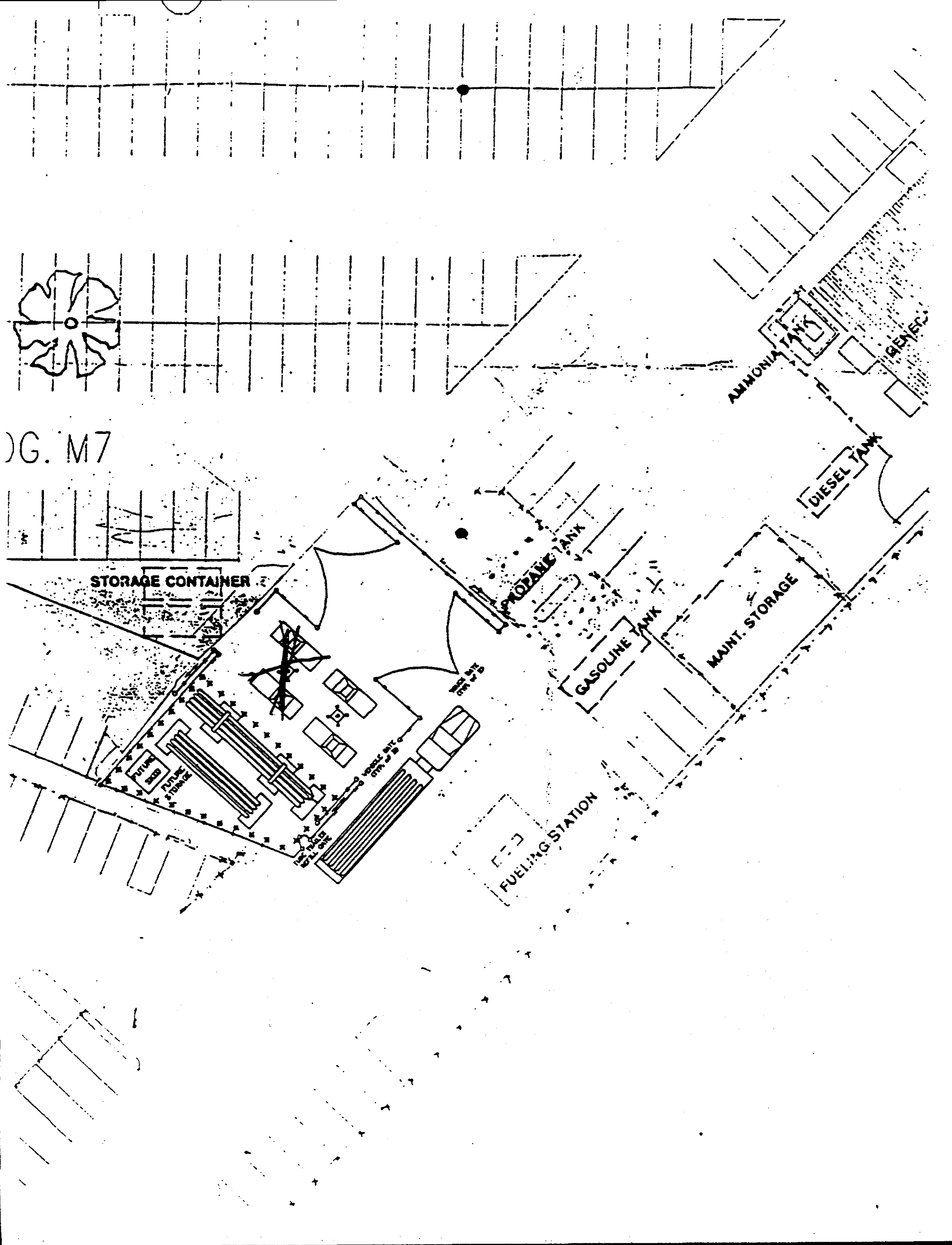
A vertical vent pipe will be supported from the 12-Pack modules and provide discharge of hydrogen released from safety valves. The top of the vent pipe will terminate in a tee to provide horizontal gas discharge and minimize rain water accumulation within the stack. The discharge point will be a minimum of 5' above the top row of receiver tubes (or 10' from the highest equipment in a 25' radius, whichever is higher). A drain valve will be mounted on the bottom of the vent stack to permit periodic removal of moisture should some accumulate.

4.3 Site Layout and Location

After numerous discussions, the location selected for the hydrogen refueling station is part of Xerox's existing maintenance facility at 737 Hawaii Avenue. The site, though modified by Xerox, will enable the hydrogen vehicle fleet to coexist with Xerox's existing propane fueled vehicles, and reside within the same security and refueling area. Full tractor-trailer access twenty-four hours a day, seven days a week are a prerequisite to ensure minimum cost and safe delivery operations. The attached site plan [Figure 5] overviews the site; more detailed scale drawings and layout for permitting purposes will be completed upon contract signature.

4.4 Site Preparation

Site preparation for gaseous hydrogen distribution systems are not extensive. Xerox will be required to pour two (2) concrete footing for the two 12-pack receiver modules; excavate and recover trenches for stainless steel piping for the distribution of hydrogen from the receivers to the fueling pumps; install bumper posts and fencing for safety and security; provide utility connections and hookups for electrical equipment, etc.; and provide for proper grounding for tie-ins.



)G. M7
STORAGE CONTAINER
PROPANE TANK
GASOLINE TANK
MAINT. STORAGE
DIESEL TANK
AMMONIA TANK
FUELING STATION
FUTURE STORAGE

5.0 Fueling System Operation

Refueling the utility vehicles with hydrogen gas from the "Partial Fill" fueling system will be a safe and straightforward operation. Maintaining a fueling log where each refueling is recorded will help to insure fueling uniformity and safety. The process would be done in the following step-by-step procedure (refer to the P&ID drawing):

1. Position the vehicle along side of the fueling post (assume refueling will be at the "Vehicle #1" position) and shut off the ignition.

2. Record the date, time, and pressure gauge readings for Bank "A" (17), Bank "B" (18), and the vehicle tank on the fueling log. Note whether there are any significant drops in receiver pressures since the last refueling. If there were, this may indicate that a leak has occurred someplace in the system which should be immediately investigated with the assistance of Praxair Customer Service.

3. Check to make sure that the following valves have been left in their normal standby positions:

Valves	Position
15 & 16	OPEN
19 & 20	CLOSED
25 & 26	CLOSED
31 & 32	VENT

4. Remove the fueling hose from its stored location on the fueling post and pull the hose toward the vehicle.

5. Connect the grounding clamp (35) available at the end of the fueling hose to the vehicle grounding stud adjacent to the vehicle fueling receptacle.

6. Connect the fueling nozzle (33) onto the vehicle fueling receptacle.

7. Switch the 3-way fueling valve (31) from the "VENT" posi tion to the "FLOW" position.

8. Open the hose isolation valve (25) to prepare for transfer of gas from the 12-Pack modules to the vehicle.

9. Open Bank "A" supply valve (19) to begin fuel flow to the vehicle.

10. Monitor the fueling hose pressure gauge (27) until no further increase is detected indicating that pressures have equalized with the vehicle tank.

11. Close Bank "A" supply valve (19).

12. Open Bank "B" supply valve (20) to begin fuel flow to the vehicle.

13. Monitor the fueling hose pressure gauge (27) until no further increase is detected indicating that pressures have equalized with the vehicle tank.

14. Close Bank "B" supply valve (20).

15. Close the hose isolation valve (25).

16. Switch the 3-way fueling valve (31) from the "FLOW" position to the "VENT" position to release gas trapped between the fueling valve and the vehicle fuel line check valve and vent it safely to the atmosphere.

17. Remove the fueling nozzle (33) from the vehicle fueling receptacle and replace the receptacle dust cap.

18. Disconnect the grounding clamp (35) from the vehicle grounding stud and replace the fueling hose back on the fueling post.

19. Record the final pressures in Bank "A" (17), Bank "B" (18), and the vehicle tank on the fueling log with the time for completing the transfer.

6.0 Safety Features

The design of the fueling facility places safety first among its requirements. Since this high pressure system will be operated on a daily basis by Xerox personnel with procedures that require making and breaking transfer connections and operating a series of valves, it is mandatory that a reliable, fool-proof supply system be provided.

One hazard that must be addressed is equipment overpressurization. The 12-Pack receiver modules are ASME pressure vessels that are protected by approved safety relief valves. As mentioned previously, each module will operate independently and have its own set of dual safety relief valves. The piping at the fueling post will also have overpressure protection to insure that it is safe even if a connection were somehow made to a vehicle with excessive tank pressure (greater than 2200 psig).

Emergency isolation of the hydrogen supply is provided locally at each hose as well as remotely positioned shutdown valves that isolate both module supply lines in a single motion. These provide a means of cutting off flow of gas quickly should a situation develop where a leak is evident at the fueling connection.

The hose breakaway system provides protection from a large hydrogen release should a driver forget and try to drive away while a transfer is in progress. The breakaway system is built around a quick release coupling that checks the flow on each side should it become separated.

Check valves are installed in each module supply line to eliminate backflow of higher pressure gas into the receiver modules. This could occur through an improper sequencing of the valves during a fueling operation or, possibly, if the fueling nozzle were connected to a source of higher pressure gas.

A vent stack will be provided at the receiver piping manifold to permit safe discharge of hydrogen into the air at a sufficiently high elevation to minimize personnel exposure should the discharge ignite at the end of the stack. The stack will accommodate release of hydrogen from the receiver relief valves and from purging operations during facility commissioning and tube trailer refills.

A site grounding system will be provided as previously described in Section 4.2.4 to eliminate potentially dangerous static discharges at locations that might possibly encounter a flammable mixture of hydrogen and air.

<u>CAN/Xerox Solar Hydrogen Plant</u>
<u>Maintenance Schedule</u>

This maintenance schedule refers to the Solar Hydrogen Production Plant and Vehicle Filling Facility at Xerox Corporation, Building M-7, 737 Hawaii Ave., El Segundo, CA 90245. The plant is designed to be fully automatic and require little maintenance, however since this is a prototype plant it will be necessary to monitor operation on a regular basis for a period of time and respond to any problems that may arise.

This schedule has been designed to help the maintenance person identify problems before they cause problems and respond to fault conditions or equipment breakdowns. The schedule refers to the "Instruction Manual for a Stuart Photovoltaic Hydrogen Generator Unicell-Cluster" throughout. This instruction manual should be kept in the electrical room at all times for reference. The maintenance person should become familiar with the contents of this manual.

As part of a daily or weekly walk around, the following items should be checked:

1. The MAIN POWER should be operational at all times. This is indicated by the red ON light on the control panel. If the light is OFF, then the plant may have been shut down by a fault condition. Fault conditions are discussed later on.

2. All fault condition lights on the control panel should be extinguished. If the alarm horn is sounding then a fault has occured. The fault may or may not shut down the plant depending on the severity of the fault. The actual fault will be indicated by a flashing red indicator. Refer to discussion later on on how to clear a fault.

3. The PVA meters on the control panel should indicate voltage above 12 volts and current above zero in daylight conditions. Current value will increase with increasing intensity of sun.

4. When the PVA current is above 200 amps, the battery charging system should be operating. The battery charger is wall mounted behind the control panel. There is no need to go back in this area, however from outside the sliding door, just note if the charging current is greater than zero. If there is no indication on the meter then the charger may not be working. This would need to be reported since the batteries would go flat within 48 hours.

5. Periodically check the main pressure in the nitrogen tank behind the MAIN DISCONNECT. If the tank pressure reads less than 200 PSI then replace with a new tank.

6. Check that the hydrogen purity is good. This is indicated by the oxygen analyzers, OI207 and OI208. Both should read well below 1.0 on their digital indicators (typically around 0.1).

7. Check that the gasholder is filling with hydrogen (the gasholder bell will slowly rise towards the ceiling). Check that the compressor comes on when the gasholder is full and the gasholder bell goes down, The compressor should stop when the bell is right down.

8. Check the compressor for the following:
   a) Crankcase oil level (at back of machine). Refer to Compair handbook for filling instructions.
   b) Oil pressure on front dial is around 69 bar when compressor is running.
   c) Regularly drain condensate as per instruction manual, Section 11, pg. 13.
   d) Final stage pressure should exceed 2000 PSI when running.
   e) Maintain compressor as per Compair handbook (Section 11).

The following is a description of the faults that will display on the control panel, their probable cause and recommended action.

1. Feed Water Low Level - There is not enough feed water in the head tank. Check that all valves are open and that water source at cabana is working. Refer to Section 6.
2. Oxygen Analyzer #1 or 2 1% level - Hydrogen purity is poor, gas will vent. Check to see if other faults have occured. Refer to Section 7D.
3. Oxygen Analyzer #1 or 2 2% level - Hydrogen purity is very poor, plant has shut down. Same checks as above.
4. Water Seal Level High - Water may overflow from water seal so plant has shut down. Ensure supply valve is turned off. Refer to Section 8.
5. Cell Level High - One of the cells has too much liquid and will overflow into recirc. Turn off feed water to that cell for day or two. Check that feedwater bowl float is not stuck. Refer to Section 6.
6. Cell Level Low - One of the cells has too little liquid. Check that feedwater valve is open and bowl float is not stuck. If not rectified, plant will shut down within 24 hours.
7. Cell Bank Temperature High - Plant has shut down. Check cell liquid levels. Refer to Section 7E.
8. Compressor Oil Pressure Low - Compressor will shut down. Refer to Section 11 and Compair handbook.
9. Compressor Discharge Temperature High - Same as above.
10. Main Inverter Fault - Compressor motor controller has shut down. Turn key to disable and back to enable. If fault persists, call Kenetech for service.

11. Ground Level High - A ground fault has occured in the electrical system and plant has shut down, most likely compressor AC feed. Check for shorts to ground.
12. Air Cylinder Pressure Low - Nitrogen tank is close to empty or nitrogen gas feed line is broken.
13. Dewpoint High - Moisture content of hydrogen gas at output is too high. Check dryer maintenance, Section 11.
14. Gasholder Venting - Compressor has not come on when gas holder is full. Check other faults.
15. PLC Battery Low - Battery voltage is low. Check charging system. If charging system is down, then operate battery charger from a 120VAC supply until fixed. Refer to Section 4.

Another fault which is not indicated on the control panel, but will shut down the plant, is high hydrogen levels inside the plant. The annunciator for the gas detection system is inside the cabana. If an alarm is indicated, contact Xerox to reset. Upon starting up the plant, check for leaks with soap sud solution.

When a fault condition is sounding the alarm, note the fault by the flashing red light. Press the Alarm Silence button to silence the horn. If the fault light stays steady on after pressing the Alarm Reset button, then the fault still persists and must be investigated.

If the plant will not re-start after correcting a fault, press the Control Panel OFF button then ON. Reset the annunciator.

The following is a list of contacts for help with problems:

a) Xerox - Contact: Jens Hansen, (310) 333-9431
b) UCR - Contact: Kent Johnson, (909) 781-5786 Jim Heffel's #
c) Electrolyser - Contacts: Bill Stewart, (416) 621-9410
   Matthew Fairlie
d) Kenetech - Contact: Mike Behnke, (510) 455-6012, Ext. 269
e) CAN - Contacts: James Provenzano, (310) 450-2121
   Paul Staples

Praxair -

Cal/EPA

California Environmental Protection Agency

Air Resources Board

Haagen-Smit Laboratory
9528 Telstar Avenue
P.O. Box 8001
El Monte, CA
91734-2301
(818) 575-6800

Reference No. A-96-235

Pete Wilson
Governor

James M. Strock
Secretary for Environmental Protection

JUL 2 6 1996

Mr. James J. Provenzano
Executive Director & Project Manager
Clean Air Now
1222 Lincoln Blvd.
Santa Monica, CA 90401

Dear Mr. Provenzano:

This is in response to your June 17, 1996, letter requesting a permit to perform experimental testing under the provisions of Section 43014 of the California Health and Safety Code.

Experimental permit, Executive Order No. C-347, is enclosed. This experimental permit is valid for one year from the date of signature and is not transferable. If your experimental program continues beyond the allowed time period, you will have to reapply for an extension of the enclosed permit. You may make copies of this experimental permit for each vehicle to retain in the vehicles. At the termination of your experimental program, the vehicles must be rebuilt to California certified configuration or shipped out of California.

If you should have any questions, please contact Ms. Aimee Trapp, Associate Air Pollution Specialist, at (818) 575-6703.

Sincerely,

John Kowalski, Chief
Certification Branch

Enclosure

State of California
AIR RESOURCES BOARD

EXECUTIVE ORDER C-347

Relating to Experimental Permits
For Vehicle Emission Control Devices

CLEAN AIR NOW

Pursuant to the authority vested in the Air Resources Board by Section 43014 of the Health and Safety Code which allows it to issue permits for the testing of experimental motor vehicle pollution control devices installed in used motor vehicles, or for the testing of experimental and prototype motor vehicles which appear to have very low emission characteristics; and

Pursuant to the authority vested in the undersigned by Section 39515 and Section 39516 of the Health and Safety Code and Executive Order G-45-9 (3)(k);

IT IS ORDERED AND RESOLVED: That Clean Air Now is hereby granted this experimental permit for field testing of three (3) 1993 through 1994 model year Ford Ranger trucks modified to operate using hydrogen fuel in the vehicles listed below. The original vehicles have been modified from a 2.3L configuration to a 2.9L configuration. The evaporative and exhaust gas recirculation systems have been removed.

This permit shall be kept in the glove compartment of each vehicle.

Vehicle Manufacturer: Ford
Vehicle Model Year/Model: 1993/Ranger
Vehicle VIN/License Plate Number: 1FTCR10A1PPA96692 4T27196
Operator Xerox Corporation

Vehicle Manufacturer: Ford
Vehicle Model Year/Model: 1993/Ranger
Vehicle VIN/License Plate Number: 1FTCR10A3PPA96693 4T27195
Operator Xerox Corporation

Vehicle Manufacturer: Ford
Vehicle Model Year/Model: 1994/Ranger
Vehicle VIN/License Plate Number: 1FTCR10A3RUA75783 4X28846
Operator City of West Hollywood

This permit is valid for one year from the date of signature.

Clean Air Now shall maintain a record of the vehicles identifying the specific test programs. This record shall be maintained for the duration of the test program and made available at reasonable times to the Air Resources Board.

Upon termination of this permit, the above vehicles must be rebuilt to California certified configuration or shipped out of California. No vehicle in this program shall be resold to an ultimate purchaser for operation in California prior to the completion of the certification procedures by the Air Resources Board.

Executed at El Monte, California this 26th day of July 1996.

John Kowalski, Chief
Certification Branch

June 17, 1996

Mr. John Kowalski, Chief
Certification Branch
Mobile Source Division
California Air Resources Board
9528 Telstar Avenue
El Monte, CA 91731-2990

Dear Mr. Kowalski:

This letter is to serve as application for obtaining an experimental permit under the provisions of Health and Safety Code Section 43014. The permit requested is for three 2.3L Ford Ranger pickup trucks modified to use pure hydrogen gas.

1. The modified trucks are part of the Clean Air Now Solar Hydrogen Vehicle Project, at Xerox Corporation in El Segundo, CA. The project is funded by the White House Technology Reinvestment Project, under US Department of Energy instrument no. DE-FC36-94GO10039, the Mobil Source Air Pollution Reduction Review Committee, under SCAQMD contract no. AB2766/C94049, and all the private project partners. (Please see enclosed Information Kit)

A. The purpose of the project and related engine modification is to demonstrate a practical application of non-polluting solar generated hydrogen used as a transportation fuel. The Xerox Corporation will operate 2 vehicles within their Maintenance department, and the City of West Hollywood will operate the 3rd in their Environmental Services Department.

B. The trucks are of an enlarged (2.9L) modified stock 4 cylinder, spark ignited, internal combustion engine design. The fuel delivery system is modified to handle the gaseous fuel using an electro-mechanical constant volume fuel injection system in line with a gas regulator, and enhanced feedback sensors and engine mapping. The air delivery system consists of a roots-type supercharger with intercooler, providing up to 4lbs of intake boost. The low-end performance (torque) is improved over the original gasoline engine, with minimal loss in high-end performance. All other driving characteristics mimic those of regular gasoline powered vehicles.

2. The Energy Technology Engineering Center, a Rocketdyne administered US. DoE facility, has performed an overall vehicle safety analysis and a non-stock components safety analysis. Both resulted in safe to operate ratings. The University of California at Riverside College of Engineering - Center for Environmental Research and Technology (CE-CERT) has performed emissions and performance testing on all three vehicles. Initial results indicate that no measurable carbon-based emissions are produced, oxides of nitrogen are one tenth that of a gas powered vehicle, and thermal efficiencies are in the 22% range. Further longitudinal testing is required and a Cold start CVS-75 Federal Test Procedure on truck #3 is currently being performed at CE-CERT.

Monitoring and feedback from the participating entities will track driveability, economy, and performance criteria during the project period. Periodic emission testing will be conducted as deemed pertinent to the acquisition of CARB certification and the performance evaluation of the overall hydrogen program. All three trucks will be in everyday use by the City of West Hollywood and Xerox Corporation. Direction and documentation will be performed by Clean Air Now or its assigned agent(s). Reporting is planned to continue through 1997.

3. Most major engine and exhaust based emission control components were removed. The three-way catalyst was removed because it becomes inoperative with the use of low temperature burning hydrogen fuel. All noxious fume control equipment is no longer needed due to the non-toxic nature of hydrogen gas and its combustion byproducts (heat & water). Recirculating equipment is not needed due to the carbonless nature, purity, and uniformity of hydrogen fuel

4. Truck #1: 1993 Ford Ranger pickup truck; lic. #: 4T27196; VIN: 1FTCR10A1PPA96692.
Truck #2: 1993 Ford Ranger pickup truck; lic. #: 4T27195; VIN: 1FTCR10A3PPA96693.
Truck #3: 1994 Ford Ranger pickup truck; lic. #: 4X28846; VIN: 1FTCR10A3RUA75783

The retrofit engineering for all three trucks was sponsored by the project funded entity, Clean Air Now. Even though the trucks are part of the funded project, trucks #1 & #2 are owned by, and registered under, the *Xerox Corporation, Site Services West*, and truck #3 is owned by, and registered under, the *City of West Hollywood.*

5. It is Clean Air Now's intention to have these trucks and their configuration certified by the end of the permit period so that they may continue to operate on the streets of California. These trucks are in practical service as demonstration fleets. We are proposing and working to expand the application and awareness of hydrogen powered vehicles. Work will continue as needed, and as practicable, to obtain a certifiable configuration for our hydrogen internal combustion power plants. If circumstances require, the trucks will be sold or donated to an out-of-state entity.

Thank you for your time and consideration.

Sincerely,

Original on letterhead signed

James J. Provenzano
Executive Director & Project Manager

cc. Aimée Trapp

Air Resources Board: Aftermarket Parts Section
9528 Telstar Avenue

Post-It™ brand fax transmittal memo 7671	# of pages ▸ 1
To James Provenzano	From Aimee Trapp
Co.	Co. ARB
Dept.	Phone # (818) 575-6703
Fax # (310) 472-5456	Fax #

DATE: Ju

TO: Ja

CO: Cl

FROM: Ai

PHONE: (

g cover page

Mr. Provenzan

Here are the questions I have on your June 17 letter:

1. What is the engine displacement of the original vehicles. (It is unclear whether the 2.9L is before or after the cylinders are bored.

2. What is the engine displacement after modifications.

3. Specify the emission control equipment removed such as air injection reaction (AIR) system, exhaust gas recirculation (EGR) system, positive crankcase ventilation (PCV) system, or the evaporative emissions (EVAP) system. Your statement in item 3 was unclear about what specific components will be removed and/or disabled.

4. Please specify whether your contract with DOE requires any emission testing and whether that testing is required to be according to the CVS-75 federal test procedures.

5. Provide the dates of the DOE contract, beginning and ending.

6. Provide information on any testing program you plan to do in addition to the DOE testing.

7. This is not critical for the permit. I am curious about the supercharger and intercooler you add on. Is the hydrogen injected after the supercharger and intercooler. That's the way the description sounded and I was just curious.

Please be advised that the ARB requires certification testing be done at a recognized laboratory. I can provide a listing if you like. As of this date CE-CERT is not on the list, so they would have to submit information to get on the list before we could accept test data from that lab.

Thanks for your help.

Aimee Trapp

James Provenzano
From: James Provenzano
Sent: Thursday, June 20, 1996 1:04 PM
To: 'Aimee Trapp'
Subject: Clean Air Now Experimental Permit Application

Dear Aimee,

Thank you for responding so quickly. I sent John Kowalski a copy of CE-CERT's interim report on the trucks' emission and performance tests. If you can't get a copy, I will send one along when I get back July 5th.

Answers:

1&2. The original engine was a 2.3L 4 cyl. Ford. The modified engine is now a 2.9L 4 cyl. spark ignition hydrogen fueled clean burning power plant.

3. There was no original AIR system on the Ford model we used. I spoke to the retrofit engineer to get clarification on all this. The EGR system was removed and the EVAP system was removed because these systems are not applicable to pure, non-evaporative hydrogen, gaseous fuel delivery systems. The PCV system and the catalytic converter (I misrepresented this in the application) remain on the vehicles.

4. The DOE contract does not call for any specific vehicle emission testing protocol. We included testing in our scope of work because of our desire to be comprehensive. We have fulfilled the contract obligations with the Interim Report I have sent along to your office.

5. DOE contract period started Aug. 11, 1994 and current end date is Aug 1, 1996. We will probably go for a no-cost extension to allow us time to acquire more data. The contract with Xerox Corp. run to May 1997. We have applied for add-on funding from the DOE.

6. We have performed one FTP CVS-75 test, and we plan to perform a series of tests as deemed necessary to optimize the emission characteristics of the vehicles.

7. The hydrogen is injected at the cylinder intake port, after the blower and intercooler. The configuration is optimized to reduce pre-ignition, which is a parameter concern with hydrogen systems.

8. I have notified CE-CERT regarding application to your recognized laboratory list.

Thanks so much. Let me know of anything else you need. I will try and address them before I leave tomorrow.

Best,

James

STATE OF CALIFORNIA PETE WILSON, Governor

AIR RESOURCES BOARD
HAAGEN-SMIT LABORATORY
9528 TELSTAR AVENUE
EL MONTE, CA 91731-2990
PHONE: (818) 575-6800

Reference No. E-93-053

September 3, 1993

Board of Directors
Clean Air Now
1416 Abbott Kinney Boulevard, Suite 112
Venice, CA 90219

Dear Board of Directors:

The California Air Resources Board (ARB) would like to thank you for the opportunity to review your Executive Summary entitled, "The Xerox-CAN Plan For a Solar Powered Hydrogen Generating Facility and Hydrogen Powered Vehicle Fleet". After reviewing your plan and discussing program details with Mr. Paul Staples, Executive Director-Clean Air Now (CAN), the ARB believes the Xerox-CAN Plan could be useful in providing further emission data from hydrogen vehicles. CAN's use of photovoltaics and solar energy to produce hydrogen through electrolysis also promises to provide useful information on the viability and economics of this process.

Since the ARB has little data on hydrogen vehicles, emission testing of one of your vehicles can be provided at the appropriate time. Similarly, since the ARB has little experience with hydrogen conversion kits, staff would appreciate receiving information on the Ford Ranger conversions. It should be noted, however, that since a hydrogen-powered conventional vehicle such as the Ranger would likely exhibit NOx emissions, and as it deteriorates could exhibit excess oil usage leading to HC emissions, such a design could not qualify as a zero emission vehicle (ZEV).

Looking toward the future, however, the ARB envisions the possibility of a hydrogen production process/hydrogen vehicle combination which might qualify for ZEV credits. Whereas electric vehicles produce emissions during electricity generation at the powerplant and some additional emissions during battery recycling, the hydrogen vehicle/fuel system must consider all possible emissions throughout the full fuel cycle in order to determine the potential for ZEV credit. For instance, any emissions resulting from the energy required to generate hydrogen fuel must be counted. Additionally, the deterioration of any hydrogen engine and any associated emissions must also be included in determining ZEV capability. For example, assuming hydrogen could be produced from an emission free process, a constant speed lean burn hydrogen turbine auxiliary power unit used in a hybrid electric vehicle might qualify as a ZEV. This would be because the turbine emissions could be near zero, and no deterioration in emission performance would be likely. In summary, if a hydrogen vehicle concept can demonstrate emissions from the full fuel cycle comparable to those associated with battery powered electric vehicles, the ARB would consider providing ZEV credits.

The ARB hopes CAN will be successful in its efforts to evaluate clean hydrogen technologies. Should you have any questions or would like to discuss this matter further, please have your staff contact Mr. Juan Osborn, Advanced Engineering Section, at (818) 575-6998.

Sincerely,

K. D. Drachand, Chief
Mobile Source Division

Energy Technology Engineering Center
Rocketdyne Division
Rockwell International Corporation
PO Box 7930
Canoga Park, CA 91309-7930
818.586.5326
Operator for U.S. Department of Energy

Rockwell *Aerospace*
Rocketdyne

February 5, 1996 In reply refer to: ETEC DRF 95-0067

James Provenzano
Clean Air Now
1222 Lincoln Blvd.
Santa Monica, CA 90401

Subject: **Trip Report of Visit to Xerox to Test Clean Air Now (CAN) Hydrogen Fueled Pickup Trucks**

Dear James:

On January 29, 1996, ETEC engineer Dennis Larson visited the Xerox site in El Segundo, CA to perform an initial checkout and limited service test on two CAN Ford Ranger pickup trucks that had been recently retrofitted for hydrogen service. Since the Xerox Ford Ranger pickup truck which had been previously tested at ETEC in June, 1995, was available, it was also reinspected and test driven.

The initial checkout consisted of visually inspecting the two new CAN Ford Ranger pickup trucks to determine if they met the general requirements of the retrofit design for hydrogen service and to verify that the design was implemented in a safe and workmanlike manner. Both pickup trucks were found to have been retrofitted in accordance with the general requirements of attached Figure 1, which was the same as the initial Xerox Ford Ranger pickup truck. The work had been done in a very professional manner and no outstanding safety concerns were observed.

Service testing was limited to performing a refueling operation and test driving each pickup truck a few miles at speeds up to 40 mph. The refueling operation went very smoothly. Connection of the grounding cable and attaching the CGA fitting took very little time. A placard of the detailed refueling operation attached to the refueling station is very easy for the operator to follow. Refueling is currently limited to approximately 2,500 psig, which certainly limits the distance the vehicle can be driven prior to refueling. A new system is being installed that will be capable of refueling to pressures up to 3,500 psig that will increase the vehicle's range.

During test driving, both vehicles ran very well and did not make the pinging and clattering sounds that were experienced during initial service testing of the original Xerox Ford Ranger pickup truck. Both vehicles exhibited good acceleration in all four gears and in general they performed similarly to a gasoline fueled vehicle.

Inspection of the Xerox Ford Ranger pickup truck indicated that the electronic pressure ratio regulator needs to be reattached to its support bracket. During refueling it was observed that ground/fuel cover linkage was sticking due to rust. Lubricating with either LPS or WD-40 will solve this problem. Also, one of the fuel tank manual shutoff valves was leaking at the valve seat. Although, this was not a safety concern since the fuel feed valve was functioning properly and was being used for fuel tank isolation, it does prevent having the capability of being able to isolate one fuel tank from the other.

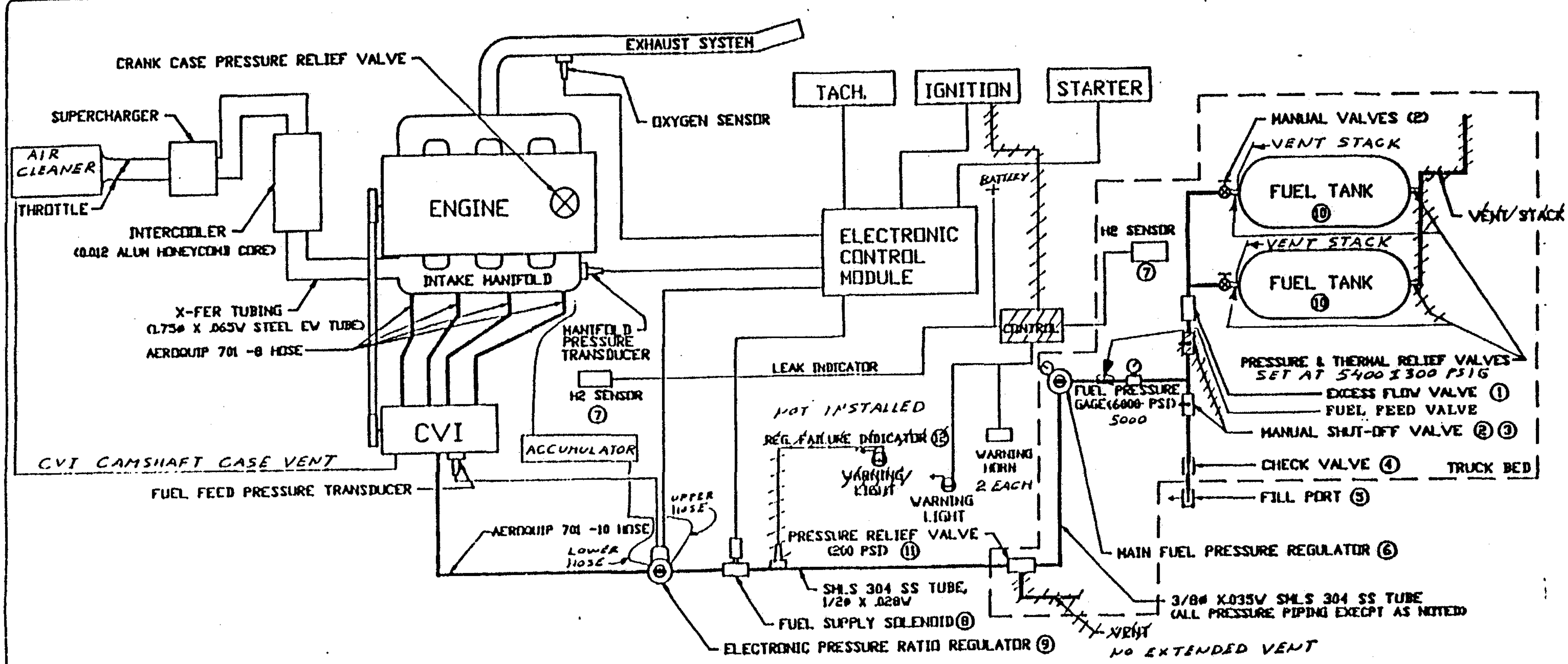
The Xerox Ford Ranger pickup truck was also test driven up to speeds of 40 mph. Its performance was similar to that of the two new CAN Ford Ranger pickup trucks. In general, the performance of all three hydrogen fueled vehicles was satisfactory.

If you should have any questions regarding this letter please call me at (818) 586-5258, anytime.

K. T. Knudsen

K. T. Knudsen
ETEC General Programs

Attachment



NOTES:

E.C.M. SEQUENCING START-UP:

1. IGN. SW. --- ON
2. ENGINE CRANKING .5 SEC.9approx)
3. IGN. SYS.--- ON (CRANKING)
4. FUEL --- ON TILL START

E.C.M. SEQUENCING SHUT-DOWN

1. IGN. SW. --- OFF
2. FUEL --- OFF
3. ENGINE SPEED < 100 RPM
4. IGN. SYSTEM --- OFF

COMPONENT SPEC.

1 CHEM-TECH EFV-250(B494) (ZERO FLOW IN CLOSED POS.)
2 NUPRO B-4P4T4
3 WHITEY SS83KS6
4 NUPRO SSDCHS6-1 DOUBLE CHECK
5 STANDARD CGA-350 CONNECTOR
6 TESCOM 20-1032-2915 REGULATOR (125PSI MAX.OUT)
7 CCI CONTROLS 7707 H2 DETECTOR (7907)
8 ADVANCED FUEL COMPONENTS MODEL 121 SOLENOID VALVE
9 NORGREN 11-008-130 REGULATOR (400 PSI MAX. IN)
BUZMATIC SPC1R-0E5-0A100-S12 DOME LOADER
10 COMDYNE 85710020 AF TANK (3.704 CU.FT. VOL.) (65710020)
ALUM./FIBERGLAS.3600 PSI RATED (NGV-2)
11 200 PSI RELIEF VALVE (APPROX.0.25SQ IN FLOW AREA)
12 T.I.-KLIXON-20PS-SERIES-SWITCH-3500PSI-BURST UL-RECOGNISED(FILE-SA995)-CSA-CERTIFIED(FILE-LR24821)

OPTIONAL SOLENOID OPERATED EMERGENCY FUEL CUT-OFF SYSTEM CONTROL LOGIC

				EMERGENCY SHUT-OFF VALVE LOGIC												
	IGN.SV	PR.SV.	OPEN	CLOSED	IGN.SV	PR.SV.	OPEN	CLOSED	IGN.SV	PR.SV.	OPEN	CLOSED	IGN.SV	PR.SV.	OPEN	CLOSED
ON	X				X	X				X						
OFF		X							X				X	X		
EM. VALVE			X					X				X			X	

TOLERANCES: .XX ± .010 .XXX ± .005 FRACT. ± 1/64 ANGLE ± .5 EXCEPT AS NOTED	ADVANCED MACHINING DYNAMICS
REV.	TITLE FUEL SYSTEM SCHEMATIC
FIN.	DRAWN W.J.K. DATE 2-26-95
	APPROVED DATE
HEAT TREAT	MATERIAL SPEC.
DWG. NUMBER H2FSYS	APPLICATION XEROX-CANI H2 FUELED FORD RANG

Figure 1. Fuel System Schematic

ENERGY TECHNOLOGY ENGINEERING CENTER

OPERATED FOR THE U.S. DEPARTMENT OF ENERGY
ROCKETDYNE DIVISION, ROCKWELL INTERNATIONAL

No. 019-TR-0003 Rev. NC
Page 1 of 26
Orig. Date 07/06/95
Rev. Date

TEST REPORT

TITLE: XEROX-CAN H_2 FUELED FORD RANGER TEST REPORT

- APPROVALS -

Originator D A Larson 7-10-95
D. A. Larson

Program Manager R Rovang 7-10-95
R. Rovang

DRR 23560UKD

REV. LTR.	REVISION	APPROVAL/DATE

Form 735-A-6 Rev 6-91

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FIGURES

TABLES

1.0 SUMMARY AND CONCLUSIONS

An initial check of the vehicle, indicated that the vehicle retrofit installation for gaseous hydrogen service met the general requirements of the retrofit design. Any deviations from the retrofit design are shown in the marked-up fuel system schematic, Figure 1. These deviations did not, in general, adversely impact the safety features of the vehicle and in many instances actually improved the design. However, several potential safety issues were encountered. The H_2 sensors, as installed, were not operable, requiring rewiring and replacement of one H_2 sensor module in order to make the hydrogen detection system functional. Location of the CVI made the fluid level check plug unaccessible for removal and inspection. Also, the H_2 CGA fill port has left-hand threads and the fill port attachment has right-hand threads, therefore, the fill port attachment could become loosened during the refueling operation.

No safety issues resulted from the fuel starvation-restart tests, stall-restart tests, and failed oxygen sensor tests. Although there was small backfiring while the engine was running with the sparkplug wires removed, there were no large unsafe explosions due to the presence of hydrogen during restart. The electronics control module (ECM) sequencing successfully prevented the accumulation of unsafe amounts of hydrogen that could cause exhaust line detonation during start-up.

Initial service testing indicated that the engine needed some additional adjusting and tuning in order for it to operate properly. At times, when the engine was under high torque and while it was being accelerated, the engine

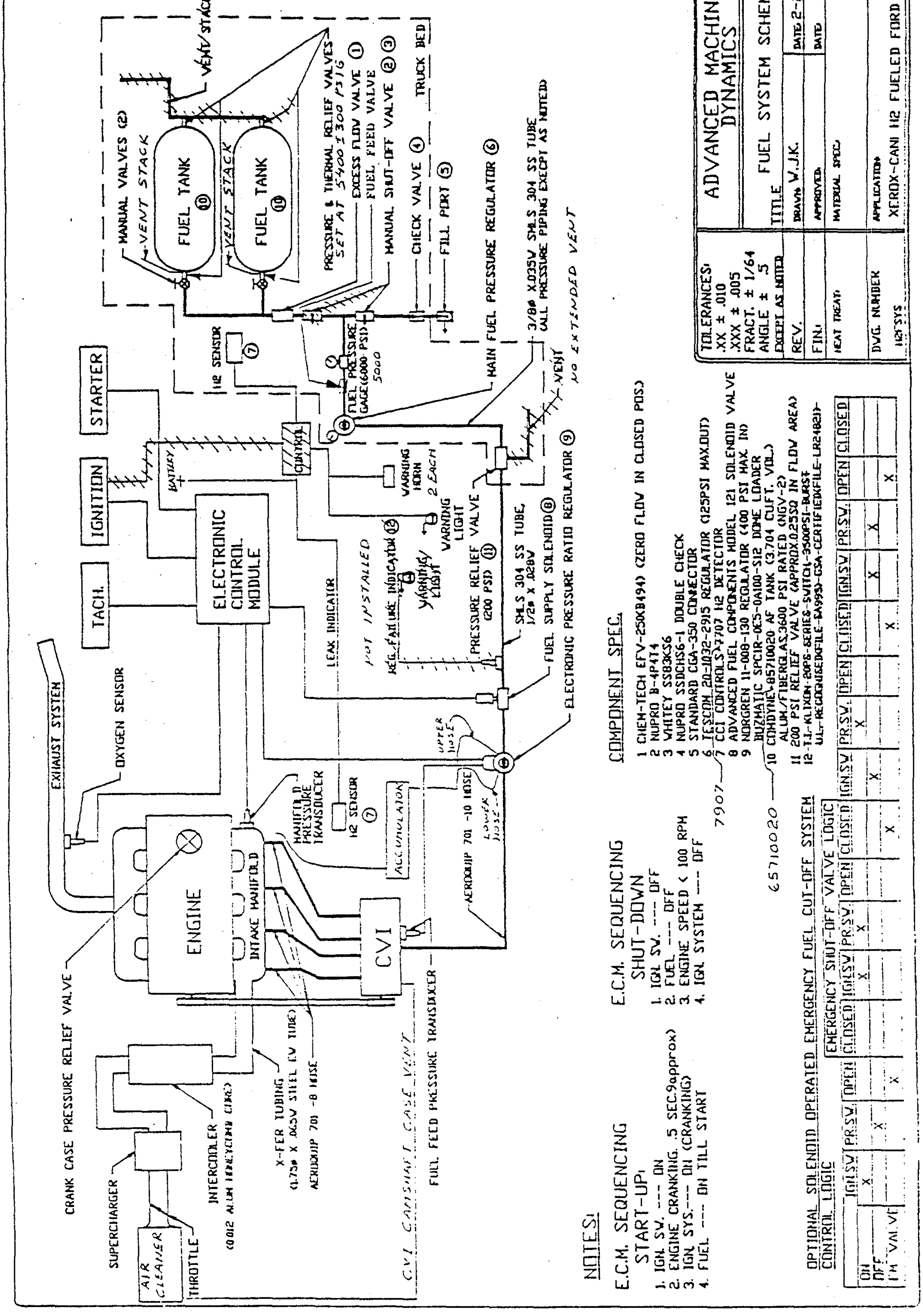

Figure 1. Fuel System Schematic

made a rather loud pinging and clattering sound. In general, the vehicle ran very sluggish during initial service testing and the average fuel consumption was 7.04 miles/lb hydrogen which is equivalent to only 14.73 miles/gal. gasoline. There also appeared to be an engine oil leak, since a quart of oil had to be added after only 223 miles of service testing. Oil leaks were indicated near the engine-transmission interface.

After the CVI and timing was adjusted, a final service test was performed. During final service testing, the engine ran very well and did not make the pinging and clattering sounds that were experienced during initial service testing. There was good acceleration in all four gears and in general the vehicle performed similarly to a gasoline fueled vehicle.

2.0 INTRODUCTION

The goal of the Xerox-CAN project is to demonstrate the use of solar-generated hydrogen as an alternate clean fuel for utility transportation vehicles. This Project utilizes state of the art, though "off-the-shelf," technology including photovoltaic electricity generation, water electrolysis for production of hydrogen, fuel storage and pumping facilities, and an internal combustion hydrogen fueled engine. Hydrogen production, storage, and fueling systems are being installed in the Xerox facility in El Segundo, CA, for this demonstration. A Ford Ranger pickup truck has been modified to use hydrogen fuel in normal operations at the Xerox plant.

ETEC is providing systems engineering and test services to the project; including safety assessment of the vehicle hydrogen system and initial checkout and verification of the vehicle safety features.

This report presents the result of tests which were conducted at the Santa Susana Field Laboratories (SSFL). The vehicle was checked out and tested in accordance with Reference 1, "Xerox-CAN H_2 Fueled Ford Ranger Test Plan."

3.0 TEST RESULTS

3.1 INITIAL CHECKOUT TESTS

The objectives of the initial checkout tests were to perform a top level systems analysis of the vehicle retrofit design and to verify that the design was implemented in a safe and workmanlike manner. Also, the functional readiness of the vehicle and the operability of the hydrogen related safety devices were checked out.

The vehicle was inspected to determine if the retrofit was in compliance with Advanced Machining Dynamics, Fuel System Schematic dated February 26, 1995. The vehicle retrofit met the general requirements of the retrofit design; however, there were some deviations which are shown in Figure 1. The fuel tank pressure and thermal relief valves were not installed opposite of the fuel tank manual shutoff valves and were not manifolded together for venting through a common vent stack. Instead, these relief valves were installed on the same end of the fuel tanks as the fuel tank manual shutoff valves and positioned between the fuel tanks and the fuel tank manifold shutoff valves. Individual vent stacks had been installed on these relief valves prior to final vehicle service testing.

The fuel feed valve was installed between the fuel pressure gage and the main fuel pressure regulator rather than between the excess flow valve and the pressure gage. This is actually a better location for the pressure gage since the fuel tank pressure can be read when the fuel feed valve is closed. Also, the installed 5000 psig fuel pressure gage should have been a 6000 psig pressure gage. This does not impact the anticipated operation since the Rocketdyne H_2 Lab refueling station was limited to 3750 psig by a relief valve and the Xerox refueling station is being designed with a 3600 psig relief valve.

The 200 psi pressure relief valve, downstream of the main pressure regulator, did not have an extended vent. This pressure relief valve was located in an area where it vented directly into the truck bed just below the H_2 sensor. This is actually an improved design since any large leakage or venting would be detected by the H_2 sensor.

The regulator failure indicator warning light was not installed. This was not considered immediately critical since the 200 psi pressure relief valve and the H_2 sensor in the truck bed provide the same function. If the regulator failed, the relief valve would become overpressurized and would vent hydrogen which would be detected by the H_2 sensor in the truck bed.

A low pressure hydrogen accumulator and vent lines were added between the electronic pressure ratio regulator and the intake manifold. This improves the safety of the retrofit since the hydrogen venting from the electronic pressure ratio regulator now vents directly into the intake manifold and is burned in the combustion chamber rather than venting into the engine compartment.

A CVI valve body vent line was added between the CVI valve body and the air cleaner. This is also an improvement since any hydrogen that leaks past the CVI valve seals is vented through the air cleaner and is burned in the combustion chamber rather than venting into the engine compartment.

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 were operable when the vehicle was delivered. No warning light or warning horn signal occurred on either of the H_2 sensors when flooded with hydrogen. After discussion with both Advanced Machining and CCI Controls, Inc., the supplier of the H_2 sensors, it was determined that the sensors should not be installed as shown on the Fuel System Schematic. The H_2 sensors should be wired directly to the battery rather than to the ignition. By being wired directly to the battery, a hydrogen leak would be detected before the ignition is turned on, which is an improved safety feature. After rewiring the H_2 sensors directly to the positive battery cable, the sensors still were not operable. It was determined that the H_2 sensor ground was not the same as the battery chassis ground. After rewiring the H_2 sensors to the battery chassis ground, both the H_2 sensors became operable except that the H_2 sensor in the truck bed operated intermittently. Troubleshooting indicated a loose positive connector in the sensing module which caused the hydrogen alert red light to go off intermittently. Advanced Machining Dynamics supplied ETEC with a new H_2 sensor which was installed and checked out by ETEC. The hydrogen leak detection system is now operating as designed by CCI Controls, Inc. The H_2 sensor light system is somewhat ambiguous in that it has a steady red indicator light to indicate that the system is operating properly and a pulsating red light and beeping horn to indicate the presence of hydrogen.

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 the fuel feed valve. Personnel from the Rocketdyne H_2 Lab were consulted and made an effort to tighten fittings while the line was still pressurized. The leakage was reduced to just a very small fizz at both Swagelok fittings. With both fuel tank manual shutoff valves closed and the fuel feed valve closed, (isolating the leaks) the fuel pressure gage located in the line with the leaks indicated an 8% pressure decay during a 24-hr period. There was a consensus between Advanced Machining Dynamics, ETEC Engineering, and the Rocketdyne H_2 Lab that the two leaks were too small to impact any of the testing to be done at ETEC. These leaks had been repaired prior to final vehicle service testing.

An inspection was performed on the CVI installation. Visual inspection of the CVI indicated that it was properly aligned and firmly mounted to the engine bracket even though only three out of four 1/4-in. high strength mounting bolts had been installed. Location of the fourth mounting bolt hole prevented the bolt from being installed. The three bolts seemed to be sufficient to maintain both proper belt tightness and CVI alignment. The fourth mounting bolt was installed prior to final vehicle service testing.

The CVI was located in an area where the engine shielded it from the exhaust system to prevent overheating. This location, however, prevents the CVI fluid level from being checked, since the level check hole plug is not accessible for removal and inspection. Following assurances made by Advanced Machining Dynamics that the CVI had been properly filled prior to installation and that there was no evidence of leaking fluid, safety testing was performed without checking the CVI fluid level. This situation also needs to be addressed before the vehicle goes into routine service.

3.2 H_2 REFUELING EVALUATION

The purpose of this task was to evaluate 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 (.825-in.-14LH EXT THD) fill port for hydrogen service. The other end of this CGA-350 fill port screwed into a 1/4-in. NPT port that attached to the hydrogen tank lines. The vehicle was also modified to accept a TWECO weld ground cable connection adapter which was located directly below the fuel fill cover. This ground cable connection adapter grounded directly to the truck frame and the CGA-350 fill port. There is a mechanical linkage between the ground cable connection adapter and the fuel cover. This linkage prevents the fuel fill cover from being opened without first connecting the ground cable. Therefore, the vehicle is 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 as shown in Figure 2. A total of seven refueling operations were successfully performed without any problems or apparent damage and wear

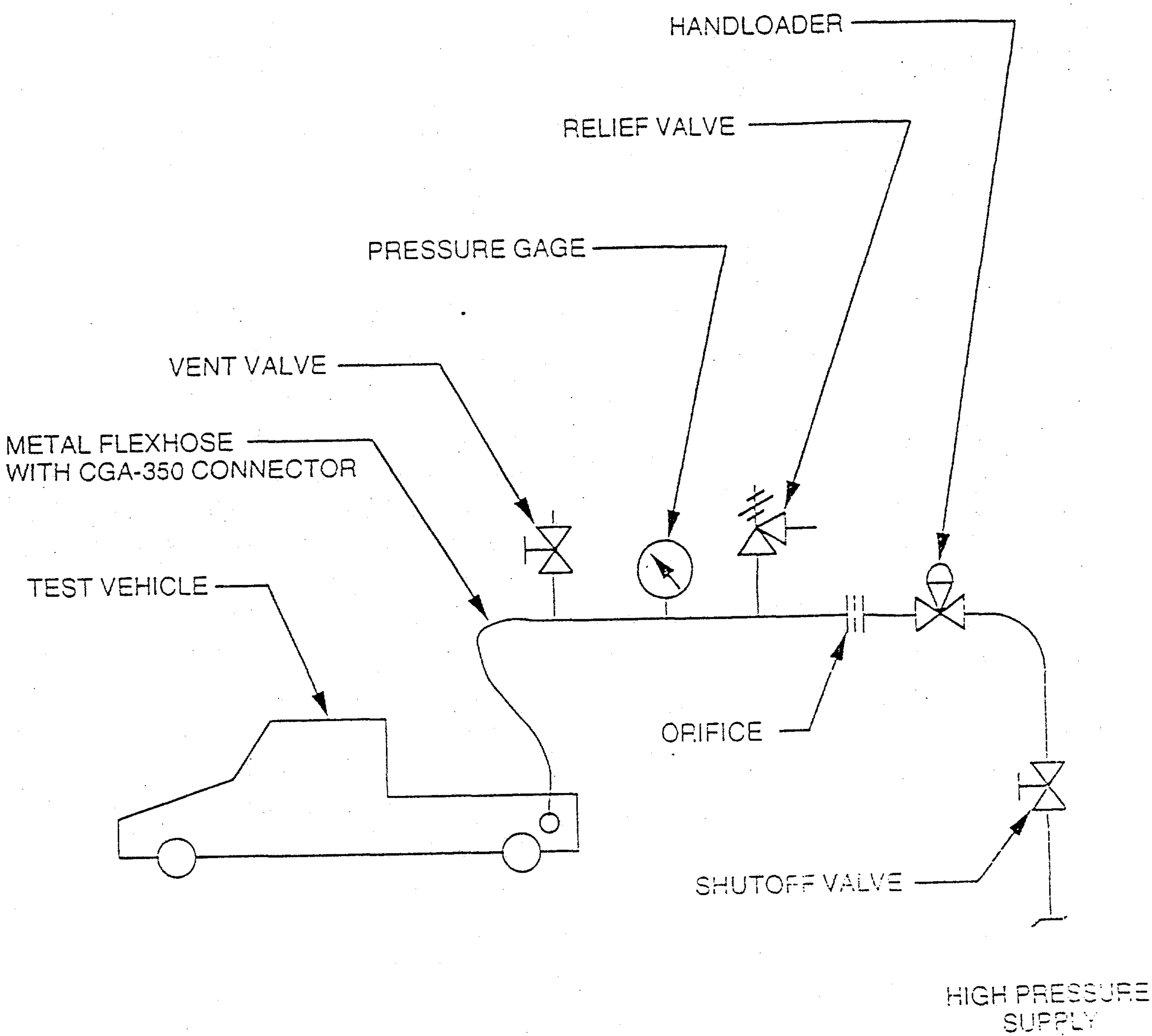

Figure 2. H_2 Fueling Station

to the CGA-350 fitting. The only concern with the refueling operation is that the CGA-350 fitting has left hand threads and the NPT fitting has right hand threads. If the CGA-350 fill port is not supported by a wrench, the NPT connection could become loose while tightening the CGA-350 connection on the flex hose. This could cause the NPT connection to loosen and leak hydrogen excessively during the refueling operation.

3.3 SAFETY TESTS

The objective of the safety tests was to assess the safety issues which, although not considered normal operation, are expected to be encountered during the life of the vehicle. Generally, these were situations where a mixture of hydrogen and air can be present in the exhaust manifold such as during vehicle stalling, loss of ignition in one or more cylinders, and oxygen sensor failure. These tests were also verification of the ECM sequencing for start-up and shutdown.

In order to comply with Reference 3 concerns for projectile protection, blast screens were placed in front of the vehicle's grill and a blast screen was also draped over the closed hood. All test personnel wore the following protective clothing: hard hat with face shield, safety goggles, heavy long-sleeve fire-retardant coveralls, boots, and leather gloves. The vehicle was equipped with two dry chemical Class ABC fire extinguishers. One extinguisher was placed in the truck cab and the other extinguisher was placed in the truck bed. All the safety testing was performed with the vehicle stationary with the hood closed and the engine usually running at an idling speed.

3.3.1 Fuel Starvation-Restart Safety Tests

The objective of the fuel starvation-restart tests was to determine if any restart problems existed as a result of the engine running out of fuel rather than a normal ignition shutdown. This test also verified the proper ECM sequencing for start-up and shutdown. These tests were performed by closing the fuel feed valve with the engine running and allowing the engine to run out of fuel. The fuel feed valve was then opened and the engine was restarted immediately. A total of five fuel starvation-restart tests were performed. The engine restarted immediately each time. There were no problems or delays due to fuel starvation. The engine started just as normal after fuel starvation as it did without fuel starvation. No safety issues were identified based on these fuel starvation-restart tests.

3.3.2 Stall-Restart Safety Tests

The objective of the stall-restart tests was 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 first series of stall-restart tests was performed with all the sparkplug wires connected. With the engine running and the emergency brake securely set, the truck was put into 5th gear and the clutch was slowly engaged until the engine stalled. The engine was then immediately started. These tests were repeated a total of four times. There was no noticeable difference between a restart during these tests and a normal start-up. There was no backfire during the restart due to accumulation of hydrogen in either the engine or the exhaust system. The ECM sequencing start-up step that cranks the engine for approximately 0.5 seconds appears sufficient to purge the system of hydrogen prior to ignition.

The next series of stall-start tests was performed with the front sparkplug wire disconnected. The engine started immediately; however, there were small backfires. This was most likely caused by unburned hydrogen being discharged from the cylinder with the disconnected sparkplug wire into the exhaust system causing the small detonations. Even though the engine was running on only three cylinders it still idled. The vehicle had to be put into 5th gear and the clutch slowly engaged in order to stall the engine. After each stall, the engine restarted immediately and continued making the small backfires. There were no large pops or bangs, just small backfires. This test was repeated four times. There was no noticeable difference between any of these tests. The sparkplug wire was then reconnected and the engine started immediately and it did not backfire. The engine ran and idled the same as it had done prior to these tests.

The last series of stall-restart tests was performed with two sparkplug wires disconnected. Both the front sparkplug wire and the third sparkplug wire from the front were disconnected for these tests. The engine once again started immediately; however, this time it made very rapid backfires. The magnitude of the backfire was approximately the same as when the engine was running on only three cylinders with one sparkplug wire disconnected. With two sparkplug wires disconnected, the engine stalled at idling speed. Even though the engine stalled, it restarted immediately each time. Again, there were no large pops or bangs, just small rapid backfires. A total of five tests were completed with no noticeable difference between any of the tests. After the two disconnected sparkplug wires were reconnected, the engine restarted immediately without any backfiring. The engine ran and idled the same after these tests as it had before the tests were performed.

3.3.3 Failed Oxygen Sensor Safety Tests

The failed oxygen sensor 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. These tests were performed after the engine had been warmed up as indicated by the heat gage. The oxygen sensor module had been designed with an on/off switch. The failed oxygen sensor was simulated by turning the switch off. With the oxygen sensor switch off, the engine was started and run for a few minutes then the engine was shut off. This was repeated for a total of five cycles. 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 then the oxygen sensor was turned off while idling, the engine stalled. This was changing from a closed-loop control of the air/fuel ratio (oxygen sensor on with adjustable fuel pressure ratio) to open-loop control of the air/fuel ratio (oxygen sensor off with old fixed fuel pressure ratio). Although the engine stalled when the sensor was turned off (failed oxygen sensor), it did not create a fuel system safety hazard. Obviously, there are safety hazards associated with stalling an engine in traffic if this vehicle were to be used on public roads.

3.4 SERVICE TESTS

The objectives of service tests were to assess the general operability of the hydrogen fueled vehicle and to get a very preliminary indication of any degradation in performance which may result in subsequent hydrogen safety issues. Initial service testing was performed on a network of mountainous roads with downhill grades of up to 12.5% and upgrades of up to 12.5% within the ETEC and SSFL complex.

After completion of the initial service testing, the vehicle was transported to Hydrogen Consultants, Inc., in Littleton, Colorado, for CVI adjustment and general tuneup. The vehicle was then made available for final service testing at XEROX El Segundo.

3.4.1 Initial Service Tests

From the very beginning of the service testing, the vehicle ran very sluggish. 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. It did not seem to make any difference whether the acceleration took place when the road was relatively level or when the grade was either uphill or downhill. Since the engine did not make this strange sound continuously, it was probably caused by the engine not being adjusted and tuned for hydrogen service while under relatively high torque. None of these strange sounds were detected during the safety tests which were performed while the vehicle was stationary and the engine idling under very low torque. Although most of the initial service testing was performed at speeds below 35 mph with the vehicle in the first three gears, when the road was clear and safe, the truck was accelerated up to 47 mph. The vehicle seemed to run quite well at 36 mph in 3rd gear and 45 mph in 4th gear.

After only 58 miles of service testing, the vehicle stalled due to the throttle cable popping out of the throttle cable guides. This was temporarily fixed by reinstalling the cable into the guide and securing it in-place with wire ties. The throttle cable guide was repaired prior to final vehicle service testing.

Because of engine restart concerns due to condensation forming in the combustion chamber and on the sparkplug 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. After the first four tests there was no evidence of steam or exhaust being discharged from the exhaust pipe. After the fifth test, steam started to be discharged from the exhaust pipe. The exhaust continued to steam after the sixth test for about 30 sec, then it changed to steam and water. The water stopped after about 1.5 minutes and the exhaust was once again just steam. It continued to steam for about 2 minutes before the exhaust became clear. Even though there was a large amount of condensation formed during these tests, none of the condensation prevented the engine from restarting. Although there was no need to remove and dry any sparkplugs, checks were made to remove and dry any sparkplugs, checks were made to determine the ease of removal. The front sparkplug required only a standard sparkplug wrench while the others would require a socket wrench with a universal joint. Examination of the removed sparkplug showed it to be very clean.

A series of initial service 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. Twice it stalled at stop signs and once while trying to accelerate uphill. The vehicle definitely needs the oxygen sensor on and operating in order for the engine to run properly.

A quart of oil had to be added to the engine, after only 223 miles of initial service testing. Although there may be some oil consumption because the engine had just recently been rebored, the loss of oil is probably due to an oil leak. There seems to be oil coming from or near the engine/transmission interface as indicated by oil on the transmission housing and the location of oil spots on the floor beneath the truck.

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. The refueling data is shown in Table 1.

The density was calculated using the Beattie-Bridgeman equation of state in Reference 4.

The Beattie-Bridgeman equation of state is

$$P = \frac{R_u T}{\overline{v}^2}\left(1 - \frac{C}{\overline{v}T^3}\right)(\overline{v}+B) - \frac{A}{\overline{v}^2}$$

where

$$A = A_o\left(1 - \frac{a}{\overline{v}}\right) \text{ and } B = B_o\left(1 - \frac{b}{\overline{v}}\right)$$

$$\overline{v} = Mv \qquad Density(\rho) = 1/v$$

When P is in psia, $\overline{v}$ is in ft^3/lb mol, T is in °R, M is in lb/lb mol, and R_u = 10.73 psia $\cdot ft^3$/lb mol$\cdot$ °R, the five constants in the Beattie-Bridgeman equations are as follows:

Gas	A_o	a	B_o	b	C
Hydrogen	744.510	-0.08105	0.3357	-0.6982	4.708×10^4

This data and the heat values from Reference 5 were used to calculate the fuel consumption information shown in Table 2.

Hydrogen consumed (lb) = $\rho_i V_i - \rho_f V_f = V(\rho_i - \rho_f)$
Since $V_i = V_f = V$ = volume of both tanks = 2 (3.704) cu ft
V = 7.408 cu ft
then hydrogen (lb) = 7.408 $(\rho_i - \rho_f)$

where ρ_i = density prior to refueling

ρ_f = density after refueling

Miles = miles driven between each refueling

Mile/lb H_2 = miles/hydrogen consumed (lb)

$$\text{Equivalent } \frac{\text{Mile}}{\text{gal. gasoline}} = \frac{\text{Mile}}{\text{lb } H_2} \; \frac{HVG}{HVH_2} \; (\rho_G)$$

where HVH_2 = Hydrogen heat of combustion (high heat value), Btu/lb

HVG = Gasoline high heat value, Btu/lb

ρ_G = Density of gasoline, lb/gallon

From Reference 5

Hydrogen heat of combustion (high heat value) = 61,031 Btu/lb H_2

Gasoline high heat value = 20,750 Btu/lb gasoline

Density of gasoline = 6.152 lb/gal.

$$\text{Then equivalent } \frac{\text{miles}}{\text{gal. gasoline}} = 2.092 \; \frac{\text{miles}}{\text{lb } H_2}$$

$$\text{Average miles/lb } H_2 = \frac{\text{Total miles}}{\text{Total hydrogen consumed}}$$

$$\text{Average equivalent } \frac{\text{miles}}{\text{gal. gasoline}} = 2.092 \text{ (average miles/lb } H_2)$$

During initial service testing, the average mileage rate was 7.04 miles/lb hydrogen. This is an equivalent average mileage rate of 14.73 miles/gal. of gasoline. Contributing factors for this low mileage rate are, engine not properly tuned, mountainous test road, low speeds, some testing with oxygen sensor off.

3.4.2 Final Service Tests

Final service testing of the vehicle, after a CVI adjustment and general tuneup by the CVI manufacturer (Hydrogen Consultant, Inc.) consisted of test driving the vehicle approximately 5 miles on the surface streets at the XEROX El Segundo complex. The vehicle started immediately and test driving commenced without allowing the vehicle to warmup. There was good smooth acceleration in all four gears and there was no coughing or lunging during acceleration. Also, the engine did not make any pinging and clattering sound during acceleration that was experienced during the initial service tests. The vehicle was driven at speeds up to 50 mph. The general driveability of this hydrogen fueled vehicle, after the CVI adjustment and general tuneup, was similar to a gasoline fueled vehicle. Since the vehicle was driven such a short distance and it was not refueled, no fuel consumption comparison could be made between initial service tests and final service tests.

Table 1. Refueling Data for Initial Service Tests

Date	Both Tanks Pressure (psig)	Trip Odometer (miles)	Tank Temperature (~°F)	Density (~lb/cu ft)
04/24/95	2400	NR	75	NC
05/01/95	1060	6.6	75	NC
05/01/95 Refuel 1	3000	6.6	75	.9275
05/01/95	440	47.2	75	.1568
05/02/95 Refuel 2	3375	47.2	65	1.0420
05/02/95	150	101.2	75	.0573
05/03/95 Refuel 3	2190	101.2	73	.7071
05/03/95	400	131.1	80	.1419
05/04/95 Refuel 4	3400	131.1	60	1.0574
05/04/95	700	171.1	60	.2510
05/05/95 Refuel 5	3450	171.1	55	1.0795
05/05/95	500	222.2	60	.1822
05/08/95 Refuel 6	3600	222.2	55	1.1182
05/12/95	2060	240.0	75	.6671
05/12/95 Refuel 7	3490	240.0	75	NC

NR = not recorded
NC = not calculated

Table 2. Fuel Consumption Analysis for Initial Service Tests*

Refueling Cycle	Hydrogen Consumed (lb)	Miles Driven	Miles/lb H_2	Equivalent Miles/gal. Gasoline
1-2	5.709	40.6	7.112	14.88
2-3	7.295	54.0	7.402	15.48
3-4	4.187	29.9	7.141	14.94
4-5	5.974	40.0	6.696	14.01
5-6	6.647	51.1	7.688	16.08
6-7	3.342	17.8	5.326	11.14
Total	33.154	233.4		
Average			7.040	14.73

* This fuel consumption analysis is for the initial service tests prior to the CVI unit being adjusted by the manufacturer. No fuel consumption analysis was made for the final service tests since the vehicle was only driven approximately 5 miles and was not refueled.

4.0 RECOMMENDATIONS

Based on the tests performed at ETEC, the basic configuration and safety features incorporated in the hydrogen vehicle design appear to be sound. Safety issues, such as filling the exhaust manifold with unburned hydrogen, were simulated and found to be benign. The ECM start sequence provided adequate purge to clear hydrogen from the lines prior to ignition.

The major concern with the vehicle, as initially tested, was its poor driveability and acceleration under load. Since the vehicle started and idled well, the problem appeared to be with the pressure regulator control or timing advance. These issues were resolved during subsequent adjustments by the manufacturer.

The following recommendations should also be implemented to improve the reliability of the hydrogen fueled Ford Ranger.

a. Install two pressure gages in or on the dash to indicate the pressure in each hydrogen tank or maintain a daily logbook and record the tank pressure. This will provide an indication to the operator of the amount of available fuel in the tanks.

b. Place placard on truck dashboard explaining how the H_2 alert display and horn function.

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Energy Technology Engineering Center

Contractor to the U.S. Department of Energy
Rocketdyne Division, Rockwell International

No. 019-TN-0003 Rev. New
Page 1 of 28
Orig. Date September 19, 1995
Rev. Date ______

DRR 25698

TITLE: SAFETY EVALUATION FOR UNRESTRICTED USE OF THE H2 FUELED CAN FORD RANGER

APPROVALS

Originator: Kenneth M. Sprouse

REV. LTR.	REVISION	APPROVAL/DATE

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ABSTRACT

This safety evaluation shows that Clean Air Now's (CAN's) hydrogen fueled Ford Ranger Truck should be capable of safely performing service operations at the Xerox Corporation's El Segundo facilities under expected normal operating conditions. Conditions for safe operation require that: (1) the truck be operated within posted speed limits on Xerox property and connecting surface streets, (2) all truck refueling personnel be properly trained in hydrogen safety, and (3) all maintenance work be performed by qualified engineers and technicians familiar with the design of the truck's fuel system. Due to cost constraints; the results obtained and presented in this report should be considered preliminary. Areas requiring further analysis are identified.

CONTENTS

1.0 INTRODUCTION

The hydrogen fueled Clean Air Now (CAN) Ford Ranger truck represents a significant advancement in the development of ultra-low air pollution vehicles. By firing with hydrogen, this truck eliminates air pollutant emissions from: carbon monoxide, CO, and unburned hydrocarbons, HCs, while significantly reducing emissions of nitrogen oxides, NOx. These are the three primary air pollutants which lead to unhealthful air quality in the nation's metropolitan cities. The only expected emission is thermal NOx produced from the air's oxygen and nitrogen at elevated temperatures (above 2,500°F). In the CAN Ford Ranger, this pollutant is controlled by running a lean-burn (oxidizer rich) engine where bulk combustion temperatures are kept as low as reasonably achievable.

The U.S. Department of Energy (Energy Technology Engineering Center, ETEC) was requested by CAN to evaluate their truck's design in terms of performance and safety. This truck was subsequently delivered to the ETEC laboratory located to the west of Canoga Park, CA and tested on facility roads. In performing this testing, a number of documents were written (Refs. 13 through 16) detailing the truck's test plan, safety issues, and final test results, among other things.

As part of this program, ETEC was also requested to perform a safety evaluation on this hydrogen fueled Xerox-CAN Ford Ranger truck for unrestricted use. This report, which documents this evaluation, centers on two areas. First, the report evaluates the safety margins in various non-stock truck components to determine whether these components will rupture under off-design pressure excursions due to engine back-fires. Second, the report begins the investigation into failure modes and effects analyses (FMEAs) -- currently identifying a number of single-point failures which could lead to loss-of-life.

2.0 SUMMARY AND CONCLUSIONS

The Xerox-CAN Ford Ranger truck appears well suited as a demonstration vehicle for accelerating the introduction of clean hydrogen burning cars and trucks into the nation's fleets. Analysis and operating experience shows this truck to be safe under normal operating conditions. There appears to be sufficient instrumentation, controls, and safety devices located on the truck to maintain reasonable safety margins in its operation. Calculations on a number of critical non-stock components show that these components should be safe (i.e., will not burst) under postulated high pressure engine back-fire conditions.

The truck appears safe even under a number of single point failures (e.g., timing belt slips or breaks, a leaking valve or fitting, etc.). Perhaps the biggest safety concern with this truck is how it will perform under various road collision scenarios. Under these off-normal accident conditions, the possibility does exist that a high pressure hydrogen line will be severed or the high pressure hydrogen tank crushed or punctured. Such component failures will certainly lead to the rapid high release of hydrogen gas. Depending upon complicated physical and chemical processes occurring during the accident, this hydrogen gas could: (1) dissipate harmlessly into the environment, (2) mix and burn with air as an ambient pressure diffusion flame with consequences similar to gasoline/air fires, or (3) mix and detonate with air producing a high pressure (15 atm) shock wave capable of destroying structures and injuring people at extended distances from the original crash location.

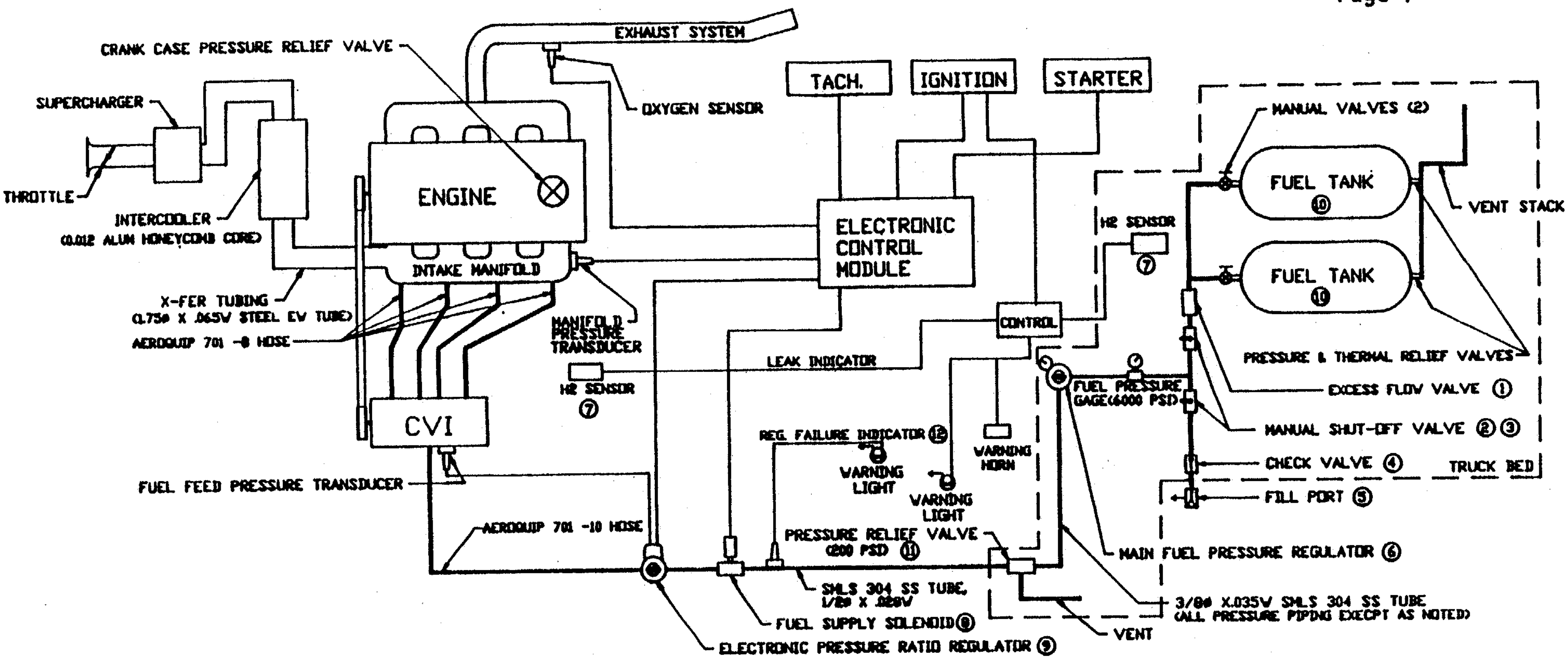
Further study should be performed in the area of FEMAs under postulated vehicle road collisions. More effort should also be given to the prevention of storage tank rupture through the use of shrapnel shields and crush resistant cages. Destructive impact testing of the hydrogen tanks along with over pressure testing of the truck's air intercooler and constant volume injector (CVI) should also be performed to quantitatively determine actual safety margins.

3.0 GENERAL TRUCK DESCRIPTION AND EXPECTED TRUCK OPERATIONS

The hydrogen fueled CAN truck is a 1993 Ford Ranger light duty pick-up truck (with a standard 4-cylinder engine and 5-speed manual transmission). All components on the pick-up are factory equipment except the truck's fuel/air feed systems which have been modified for hydrogen operation. The modifications to the engine's fuel and air feed systems are shown in Figure 1. Basically, the gasoline tank and liquid fuel feed lines have been removed and replaced by a gaseous hydrogen storage and delivery system. On the air feed system, a supercharger and air intercooler have been added.

The Ranger's hydrogen feed system stores hydrogen in two lightweight aluminum/fiberglass pressure vessels. These tanks are mounted to the cargo bed of the Ranger (immediately behind the cab) and are capable of being filled to a pressure of 3,600 psia. A pressure regulator immediately downstream of the hydrogen tanks is set to supply hydrogen to the truck's fuel supply solenoid at a constant 200 psia pressure. Just downstream of the fuel supply solenoid is the Ranger's hydrogen trim pressure regulator. This regulator is automatically controlled by the truck's Electronic Control Module (ECM). The ECM senses the pressure in the engine's intake manifold (among other parameters such as oxygen exhaust concentration, engine speed, etc.) and trims the hydrogen pressure at the upstream side of the truck's Constant Volume Injector (CVI) to a predetermined value above the engine's intake manifold pressure. The CVI is designed to ensure that the specific volumetric flow of hydrogen (in units of ft^3/revolution) to each of the engine's cylinders is constant. More will be said about the CVI in Section 4.2.

The Ranger's air feed system uses a supercharger to boost the air pressure above ambient conditions at the engine's intake manifold. At moderate engine speeds, the supercharger has been designed to supply air to the intake manifold at approximately 20 psia although vendor data shows this supercharger capable of producing 30 psia at high speed off-design conditions. Like the CVI, the supercharger is driven by belt pulley's from the engine's crankshaft. An air intercooler (located between the supercharger and intake



NOTES:

E.C.M. SEQUENCING
START-UP:
1. IGN. SW. --- ON
2. ENGINE CRANKING .5 SEC.9approx)
3. IGN. SYS.--- ON (CRANKING)
4. FUEL --- ON TILL START

E.C.M. SEQUENCING
SHUT-DOWN
1. IGN. SW. --- OFF
2. FUEL --- OFF
3. ENGINE SPEED < 100 RPM
4. IGN. SYSTEM --- OFF

COMPONENT SPEC.

1 CHEM-TECH EFV-250(B494) (ZERO FLOW IN CLOSED POS.)
2 NUPRO B-4P4T4
3 WHITEY SS83KS6
4 NUPRO SSDCHS6-1 DOUBLE CHECK
5 STANDARD CGA-350 CONNECTOR
6 TESCOM 20-1032-2915 REGULATOR (125PSI MAX.OUT)
7 CCI CONTROLS 7707 H2 DETECTOR
8 ADVANCED FUEL COMPONENTS MODEL 121 SOLENOID VALVE
9 NORGREN 11-008-130 REGULATOR (400 PSI MAX. IN) BUZMATIC SPC1R-0E5-0A100-S12 DOME LOADER
10 COMDYNE 05710020 AF TANK (3.704 CU.FT. VOL.) ALUM./FIBERGLAS.3600 PSI RATED (NGV-2)
11 200 PSI RELIEF VALVE (APPROX.0.25SQ IN FLOW AREA)
12 T.I. KLIXON 20PS SERIES SWITCH, 3500PSI BURST U.L. RECOGNISED(FILE SA995) CSA CERTIFIED(FILE LR24821)

OPTIONAL SOLENOID OPERATED EMERGENCY FUEL CUT-OFF SYSTEM
CONTROL LOGIC

				EMERGENCY SHUT-OFF VALVE LOGIC												
	IGN.SW	PR.SW.	OPEN	CLOSED	IGN.SW	PR.SW.	OPEN	CLOSED	IGN.SW	PR.SW.	OPEN	CLOSED	IGN.SW	PR.SW.	OPEN	CLOSED
ON	X				X	X				X						
OFF		X							X				X	X		
EM. VALVE			X					X				X			X	

TOLERANCES: .XX ± .010 .XXX ± .005 FRACT. ± 1/64 ANGLE ± .5 EXCEPT AS NOTED	ADVANCED MACHINING DYNAMICS
	TITLE FUEL SYSTEM SCHEMATIC
REV.	DRAWN: W.J.K. DATE: 2-26-95
FIN:	APPROVED: DATE:
HEAT TREAT:	MATERIAL SPEC:
DWG. NUMBER H2FSYS	APPLICATION: XEROX-CANI H2 FUELED FORD RANGER

Figure 1. Engine Feed System Process & Instrumentation Diagram (P&ID)

manifold) is also included in the air feed system to remove the heat of compression from the inlet air stream.

Refueling of the Ranger with gaseous high pressure hydrogen occurs through standard hydrogen fittings (i.e., a CGA-350 connector) in which the off-truck fitting has been modified with metal wings for hand service (i.e., no wrenches required). Electrical grounding of the Ranger's body metal to the filling station's connector is also provided. This grounding is designed to prevent electrical sparks in the area of the Ranger's fueling port which could ignite any surrounding hydrogen/air mixtures due to leaks.

The CAN Ranger is primarily expected to be operated as a service truck on Xerox's El Segundo property and neighboring surface streets. Maximum velocities of this truck and other area vehicles should be well below 40 mph. This truck is not expected to be driven at speeds approaching 60 mph on nearby freeways and interstates. These low speeds reduce the risks associated with collisions.

4.0 SAFETY MARGINS IN NON-STOCK TRUCK COMPONENTS

The Ranger has a number of non-stock components which are not found on light duty passenger vehicles. Because of the hazards associated with hydrogen fires, explosions, and detonations; the following truck components have been singled out for additional analysis: the air intercooler, the constant volume injector, the hydrogen fuel tanks, and their associated interconnecting lines and valves.

Gaseous hydrogen fuel systems present hazards not commonly found in today's liquid gasoline powered vehicle fleet. First, hydrogen/air diffusion flames are usually invisible to the naked eye during daytime unless there is sufficient particulate matter in the air for illumination. Hence, the risk of unwittingly walking directly into a burning flame is significantly increased. Second, gaseous hydrogen/air mixtures can detonate with additional destructive consequences. Detonation over-pressures approaching 15 times initial pressure have been observed for stoichiometric mixtures (see, e.g., Ref. 17). These blast pressures can destroy nearby structures and personnel while causing other detrimental effects at extended distances (e.g., damaged ear drums, cuts from flying shrapnel, glass, etc.).

Although gaseous hydrogen possesses these additional hazards, it does mitigate other acute risks. First, unconstrained open air flames at ground level are greatly reduced due to the buoyancy effects of hydrogen. Any open air fires will rapidly rise into the atmosphere rather than continue burning on the ground as is the case with spilled gasoline. Second, the risks associated with delayed accident ignition following uncontrolled fuel escape is eliminated due to gaseous hydrogen's buoyancy and high diffusion coefficient -- non-flammable conditions are achieved much faster following a hydrogen spill than a gasoline spill.

Ensuring reasonable safety margins with hydrogen replacement fuel in non-stock Ford Ranger components is probably the key to successful operation and service with this truck.

4.1 AIR INTERCOOLER

The Ranger's air intercooler is shown in Figure 2. It is composed of approximately 40 thin rectangular aluminum sheets having a thickness, δ, of approximately 0.013-in. On one side of each sheet is high pressure (up to 30 psia) super-charged air while on the other side is ambient pressure (approximately 14.7 psia) cooling air. The gap between sheets on the high pressure side is approximately 0.25-in. while on the ambient pressure side the gap is 0.375-in. Heat transfer fins are located in the gaps and structurally connect the thin aluminum sheets together. The heat transfer fins are in the shape of an accordion bellows -- the distance, L, between alternating ridges is approximately 0.200-in. These ridges behave structurally like pivot points for supporting the aluminum sheets. The intercooler is made primarily from 3003 aluminum with no temper.

The intercooler's largest tensile stresses will occur on the ambient pressure side of cooler's thin aluminum sheets at fin contact points. These tensile stresses are produced by the differential hydraulic pressure existing across the aluminum sheets. Under normal operating conditions these differential pressures will be below 20 psid and produce negligible tensile stresses in the thin aluminum sheets. However, under backfire conditions these differential pressures can be significantly higher and could lead to failure of the intercooler.

4.1.1 Estimated Feed System Backfire Pressures.

The maximum feed system backfire pressure is the hydrogen/air detonation pressure, P_d, at the stoichiometric mixture ratio. This pressure can be estimated from the following equation (see, e.g., Ref. 1):

$$\frac{P_d}{P_o} = 1 + \alpha(\gamma - 1)\left\{1 + \left[1 + \frac{2\gamma}{\alpha(\gamma^2 - 1)}\right]^{1/2}\right\} \qquad (1)$$

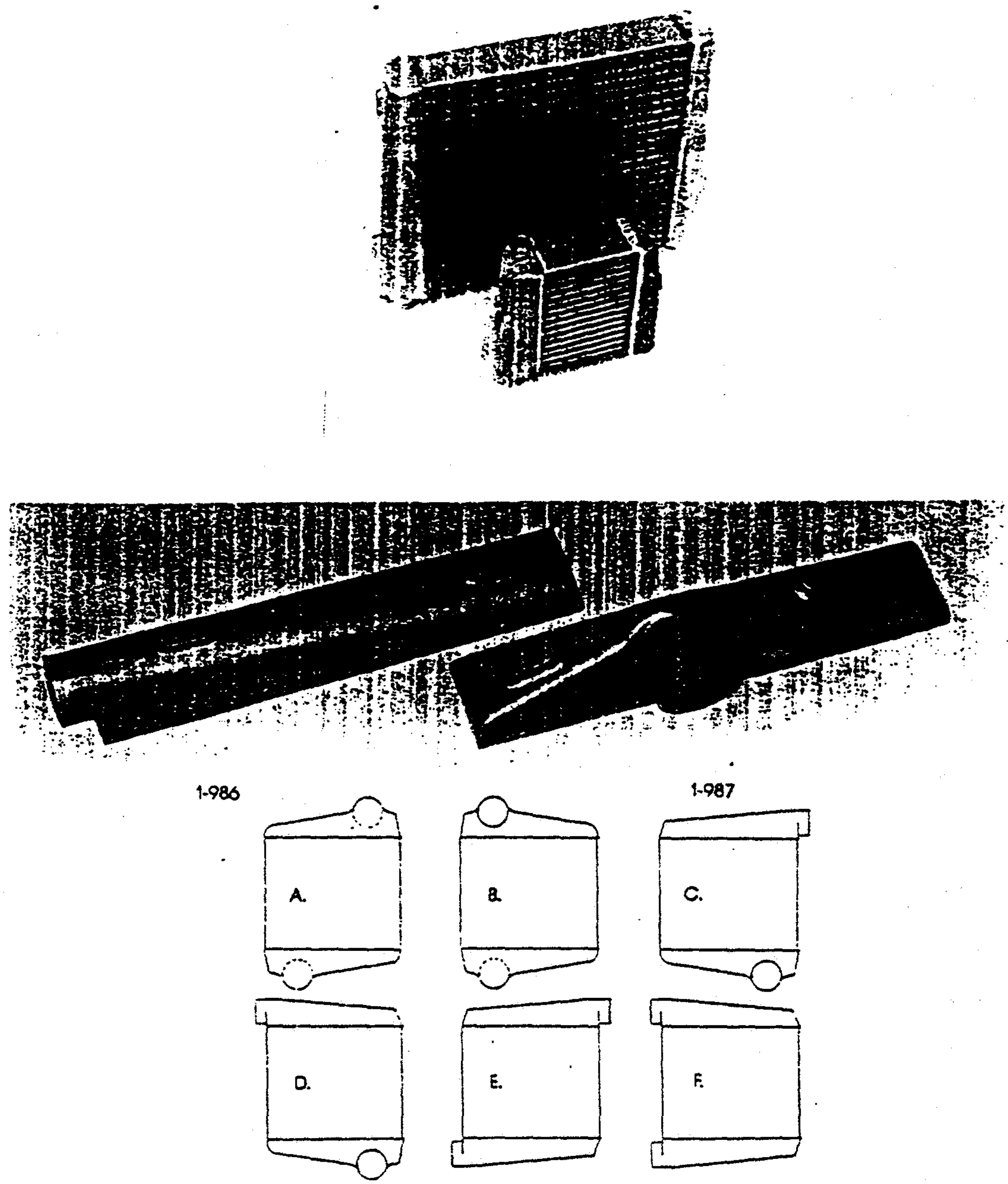


Figure 2. Air Intercooler

where P_0 is the Ranger's initial intake manifold pressure before detonation (Pa), γ is the ratio of specific heats (c_p/c_v) in the gas, and the parameter α is defined by:

$$\alpha = \frac{q\rho_0}{P_0} \tag{2}$$

where ρ_0 is the initial pre-mixed gas density before detonation (kg/m^3) and q is the total specific chemical heat released in the detonation (J/kg) -- lower heating value (LHV) basis.

For stoichiometric hydrogen/air detonations, the LHV heat release q is approximately 0.818 kcal/gm and the ratio of specific heats γ is about 1.4. If the pressure before detonation is 30 psia (i.e., maximum supercharger boost pressure) and the temperature downstream of the intercooler is 300°K, Equations 1 and 2 will provide a detonation pressure of about 730 psia. However, for purposes of this report, an experimentally measured pressure increase of 15 to 1 (see, e.g., Ref. 17) will be used instead, since Equation 1 doesn't adequately account for changes in the specific heat and molecular weight of the high temperature burnt gases. This effectively reduces the maximum detonation pressure to 450 psia.

It is highly unlikely that gaseous hydrogen will travel from the engine's intake manifold to the air intercooler via the air feed system. This is because the engine's ECM is programmed to ensure that the engine is always cranking prior to opening the fuel supply solenoid -- as seen in Figure 1. Hence, backfire detonations in the engine's intake manifold are expected to produce non-reacting shock waves which travel to the intercooler from the manifold. The pressure behind the shock wave as it reaches the intercooler is expected to be substantially less than these stoichiometric hydrogen/air detonation pressures. This pressure can be determined from the following three conservation and state equations (see, e.g., Ref. 2):

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho v)}{\partial z} + \rho v \frac{\partial(\ln A)}{\partial z} = 0 \qquad (3)$$

$$\rho\left[\frac{\partial v}{\partial t} + v\frac{\partial v}{\partial z}\right] + \frac{\partial P}{\partial z} = 0 \qquad (4)$$

and:

$$\frac{P}{\rho^{\gamma}} = \text{constant} \qquad (5)$$

Equations 3 and 4 are the conservation equations for gas continuity and gas momentum respectively. Equation 5 is a combined conservation of energy equation and gas equation of state for non-reacting isentropic gas flow. The variable ρ is the gas density (kg/m^3), the variable v is the gas axial velocity along a streamline (m/s), the variable t is the time, the variable z is the axial position along the streamline (m), the variable P is the gas pressure (Pa), and the variable A is the streamline cross-sectional area. These equations present a series of 3 equations to solve for the following 3 unknown dependent variables: ρ, P, and v. It should be noted that these equations assume non-reacting adiabatic frictionless gas flow.

These 3 equations can be best solved using the method of characteristics numerical solution technique (see, e.g., Ref. 3). However, due to program constraints, a simpler methodology will be used which assumes the backfire gas pressure behind the shock front is a function of only the radial position of the front, and that the pressure and temperature behind the shock front remain uniform. Thus, the backfire pressure behind the shock front, P_b (in Pa) is estimated solely from Equation 5 above as:

$$P_b = P_d \left[\frac{V_d}{V}\right]^{\gamma} \quad (6)$$

where the variable P_b is the effective backfire pressure behind the shock wave (Pa), the variable V_d is the volume within the intake manifold which detonates (m^3), and the variable V is the total volume behind the shock wave (m^3).

The total volume within the Ford engine's intake manifold is estimated to be approximately 100 in^3. The total volume of the hydrogen/air feed systems downstream of the CVI and air intercooler (including the intake manifold) is further estimated to be approximately 170 in^3. Using these values, Equation 6 shows that the backfire pressure at the air intercooler from a detonation involving the entire intake manifold is about 215 psia. For a detonation involving only half the volume of the intake manifold, the backfire pressure would be reduced to approximately 80 psia.

4.1.2 Tensile Stresses In Intercooler Walls.

For a rigidly supported thin flat plate subjected to a uniform pressure differential across its thickness, δ; the maximum tensile stress, s, in the plate can be estimated from the following equation (see, e.g., Ref. 4):

$$s = \frac{\Delta P \ L^2}{2 \ \delta^2} \quad (7)$$

The variable ΔP is the hydrostatic pressure differential across the intercooler's thin sheets (Pa), the variable L is the distance between fin supports along the thin sheet (m), and the variable δ is the thickness of the sheet (m). Equation 7 assumes the sheet supports to be infinitely long and supported on only one side. However, the sheets are actually supported on both sides by braised fins which are perpendicular to one another. Since at the time of this report, data on the fin/sheet brazing compound and process are unknown; it was decided to use Equation 7 above as a conservative estimate. The tensile stress equation for a thin square sheet having sides L by L should be used in place of Equation 7 once the integrity of the fin/sheet brazing connections are confirmed.

Using the values for fin spacing, L, sheet thickness, δ, and blast pressures, P_b, given above, it can be shown from Equation 7 that the intercooler's maximum tensile stress, s, is estimated to be 25,000 psi for backfires where the engine's entire intake manifold has been filled with a stoichiometric mixture of hydrogen/air. When the intake manifold is only half filled with a stoichiometric mixture of hydrogen/air, the backfire pressure at the air intercooler is reduced significantly to approximately 10,000 psi. From Ref. 4, the ultimate tensile stress for 3003 aluminum with no temper is given as 16,000 psi. Hence, there is no margin for safety if the engine's intake manifold fully participates in the detonation and a safety factor of 1.6 when half the intake manifold volume detonates.

Under normal operation, there should be very little volume inside the engine's intake manifold having hydrogen/air mixtures near stoichiometric. Hence, it would appear that the air intercooler is safe for Ranger truck service. It is expected that filling the engine's entire intake manifold with hydrogen/air mixtures could occur only if the CVI timing belt fails or is installed incorrectly. Even under CVI timing belt failures the chances of completely filling the intake manifold with hydrogen/air mixtures is somewhat remote -- half the volume is probably more reasonable.

4.2 CONSTANT VOLUME INJECTOR (CVI)

The Ranger's CVI is shown in Figure 3. It consists of a series of four chambers (each chamber having dimensions approximately 3-in. by 2-in. by 1.25-in. high). Each cylinder on the Ranger's engine is fed from one of these CVI chambers. All chambers on the CVI have two internal valves to isolate

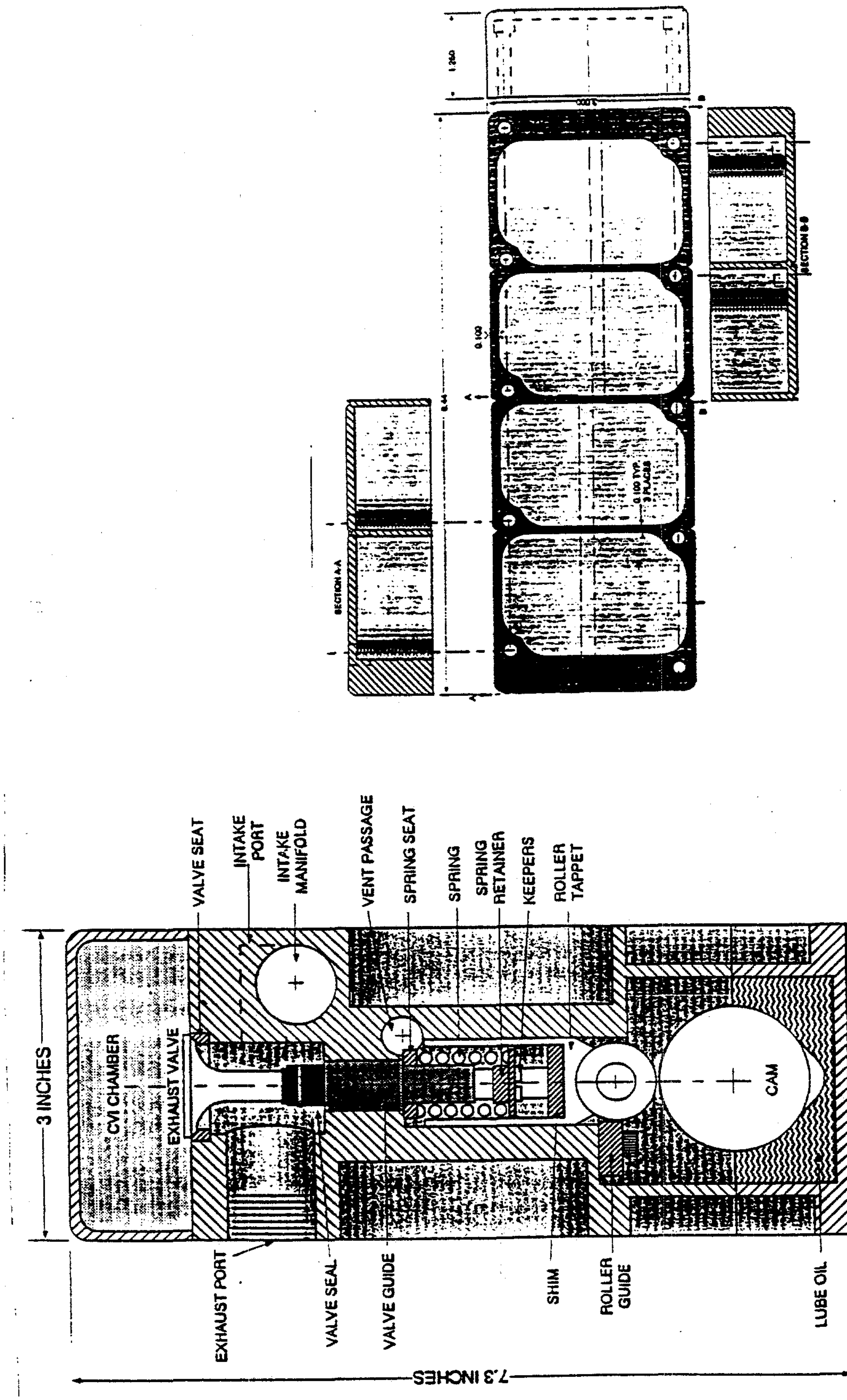


Figure 3. Constant Volume Injector (CVI).

each chamber from the upstream hydrogen feed supply system and the downstream engine intake manifold at the correct timing sequence. The walls of the CVI chambers have a minimum thickness, δ, of approximately 0.100-in. The four CVI chambers are machined from a single block of solid aluminum. The machined chambers are subsequently bolted to the top of the CVI body.

The CVI's maximum largest tensile stresses will occur on the edges of the CVI chamber's top and side walls. This maximum tensile stress, s, can by estimated by the following equation (see, e.g., Ref. 4).

$$s = \Delta P \left[\frac{L^2}{2\delta^2} + \frac{h}{\delta(1 + 2h/b)} \right] \qquad (8)$$

where the variable ΔP is again the hydrostatic pressure differential across the wall, L is the shortest side dimension of the CVI chamber's rectangular top (m), the variable b is the longest dimension of the CVI chamber's rectangular top (m), the variable h is the height of the CVI chamber (m), and δ is the minimum thickness of the chamber walls. Equation 8 assumes the hydrostatic pressure on the chamber's side walls is reacted out only through the chamber's top rather than through the top and base anchor bolts.

Using values for L, b, h, and δ of 2-in., 3-in., 1.25-in., and 0.10-in. respectively, Equation 8 shows that detonations from an engine intake manifold completely filled with a stoichiometric hydrogen/air mixture can produce tensile stresses on the CVI's chamber wall to 44,000 psi. If the intake manifold is only half filled with a hydrogen/air mixture, the maximum tensile stress on the chamber wall is estimated to be 17,000 psi. For these calculations the CVI was assumed to see the same backfire pressures calculated earlier for the air intercooler in Section 4.2.1.

Assuming the CVI's chamber is made from 6061-T6 aluminum which has an ultimate tensile stress of 45,000 psi, the above results show that the CVI is marginally safe under backfire events when the intake manifold is completely filled with a stoichiometric hydrogen/air mixture. This component will be safe whenever the intake manifold has less than half its volume filled with a hydrogen/air mixture. Hence, it would appear that the CVI (like the intercooler above) is safe under normal operating conditions. Safety issues will arise whenever the CVI's timing belt is not functioning properly. However, the probability of completely filling the engine's entire intake manifold with a stoichiometric hydrogen/air mixture (even under these off-design conditions) appears relatively remote.

4.3 HYDROGEN FUEL TANKS

The Ranger truck has two compressed hydrogen fuel tanks located in the forward section of its cargo bed. These fuel tanks are standard lightweight aluminum/fiberglass wrapped pressure vessels originally designed for compressed natural gas (CNG) storage. Each tank has a volume of 3.7 ft^3 and is rated for 3,600 psia gas pressures under ambient temperature environments. The manufacturer of the truck's tanks (Comdyne 1 Inc., West Liberty, OH) has obtained an U.S. Department of Transportation (DOT) exemption (DOT-E 10256) which allows these pressure vessels to be: (1) filled with compressed hydrogen rather than natural gas, and (2) connected dynamically to the fuel feed system of a vehicle rather than as statically stored cargo. This exemption does require reinspection and hydrostatic retesting of these tanks every 3 years.

Based upon this information, these non-stock truck components should have sufficient safety margins for normal transportation operation. Hydrostatic burst testing shows that these pressure vessels have sufficient over-pressure safety margins (at least 1.5) at the tank's maximum 3,600 psia service pressure -- when there are no mechanical impacts or large applied external compressive forces. The American Gas Association Laboratories (Cleveland, OH) has also developed standards and test procedures for vehicle natural gas storage tanks (Ref. 5) which further include requirements for their cycling, burst, and impact testing. It is expected that the Ranger's hydrogen fuel tanks also meet these stringent standards. Recently, other tank manufacturers (e.g., Refs. 6 and 7) are disclosing their data on fiberglass metal lined vessels which appear to demonstrate reasonable safety margins on various standardized government tests.

However, determining how these pressure vessels will perform under a full range of expected and unexpected compressive forces and projectile impacts -- such as occur in vehicular collisions or other highway related accidents -- is not fully clear. No attempt is made here to perform these complicated impact/compression analyses or experiments other than to point out that, like gasoline vehicle storage tanks, these gaseous fuel pressure vessels will lose their packaging contents if hit with sufficient force in sufficient concentration. Furthermore, whether their contents (i.e., hydrogen) ignite subsequent to impact depends upon complicated physical mass transport, and chemical kinetic processes.

4.4 FEED SYSTEM PIPING AND VALVES

As seen in Figure 1, there are numerous ancillary components associated with the non-stock hydrogen/air feed systems. Most of the valving appears adequate for high pressure hydrogen service. However, due to the number of fittings involved in connecting these valves, pressure regulators, gauges, etc. to the feed lines; the margin of safety regarding inadvertent hydrogen leaks due to loose fittings could be significant. Maintaining numerous leak tight fittings on a continuously vibrating vehicle could be problematic. It is recommended that as many of these fittings be welded to the interconnection piping as reasonably feasible.

The safety margins for rupture in all hydrogen tubing upstream of the CVI should be excellent since: (1) it is doubtful combustible mixtures of hydrogen/air will ever occur in these locations, and (2) any engine backfire shock waves reaching these locations will be minimal. However, the X-fer tubing (connecting the engine's intake manifold with the air intercooler) and the Aeroquip 701 hose (connecting the engine's intake manifold with the CVI) may see significant elevated pressures (over nominal) due to engine backfires. Should half the engine's intake manifold contain a stoichiometric mixture of hydrogen/air during detonation, the static backfire pressure at these hose/manifold connections will be (using Equation 6) approximately 170 psia. The safety margin in the X-fer tubing under this backfire condition is 1.5 based upon a burst pressure of 250 psia (Ref. 8) and should be considered safe. Although burst pressure data on the Aeroquip 701 hose has not yet been obtained, it is expected to be higher than the X-fer tubing due to its smaller diameter.

Should the full volume of the engine's intake manifold contain a stoichiometric mixture of hydrogen/air during backfire detonation, it can be expected that these hoses will see the full 450 psia detonation pressure near the intake manifold connections. Under these conditions, it is likely the X-fer tubing will rupture before the backfire shock wave reaches either the truck's intercooler or CVI. This tube rupture may effectively act as a burst diaphragm -- protecting both the truck's air intercooler and CVI from failure as determined previously under full volume intake manifold detonations. As stated above, these full volume engine intake manifold detonations are considered to be highly unlikely.

5.0 FAILURE MODE AND EFFECTS ANALYSIS

Failure mode and effects analyses (FEMAs) are the usual methodology for developing safe hardware in the context of acceptable risk. For example, the U.S. National Aeronautics and Space Administration (NASA) has developed standard methodologies for performing these studies which are conducted concurrently with the system design effort (see, e.g., Ref. 9). The major thrust of the FEMA is to produce a "critical items list" (CIL) for those system components which could cause a "loss of human life" if they inadvertently fail. For critical failure modes, the CIL must provide the specific rationale to justify the retention of the critical item in the system. That rationale is oftentimes provided by probabilistic and economic analyses that are presented in cost/benefit terminology. At this time the following discussion will only be concerned with those hardware failures in which a possibility exists that the subsequent effects may be the loss of human life. Detailed cost/benefit rationales for retaining critical components -- which (1) use probabilistic fault trees for reaching different effects, and (2) estimate, in dollars, the value of a human life or the benefits of reduced pollution -- will not be performed. Failures and effects will be identified and discussed only in general qualitative terms.

5.1 ENGINE BACK FIRES

In all cases the critical component leading to engine backfires is expected to be the failure of the engine's CVI timing belt. This timing belt -- which is made from rubber rather than metal chain -- is probably capable of operating an average of 120,000 miles before breaking under normal conditions. Assuming a hydrogen fueled vehicle fleet to average 12,000 miles per year and that 10 percent of the vehicle owners will not replace these belts before driving 120,000 miles (normal maintenance should require replacement at about 60,000 miles), it can be expected that a timing belt failure may occur at an average frequency as high as 0.01 failure/year·truck.

Fortunately, the detrimental effects of breaking a CVI timing belt (i.e., high pressure backfires into the fuel/air feed systems) are expected to be minimal as shown above. As long as less than one-half of the engine's intake manifold volume contains a stoichiometric mixture of hydrogen/air, the backfire over-pressures should be effectively contained within the feed system hardware without rupture and shrapnel generation. However, the possibility exists that a CVI timing belt failure could fill up more than half the engine's intake manifold volume (even though very remote) and lead to hardware disassembly. Hence, under typical FEMA analysis, the CVI timing belt should be placed on the truck's CIL with subsequent justifying (cost/benefit) rationale for retention of the current rubber design.

5.2 VEHICLE COLLISIONS

Some recent studies (Refs. 10 and 11) are beginning to assess the effects associated with the rapid release of high pressure hydrogen from vehicle fuel tanks during uncontrolled road collisions and impacts. The effects of these tank failures include: ruptured ear-drums (caused by high pressure non-reactive gas venting), and significant human injury (caused by high pressure detonations).

Attempting to assess the fuel tank's collision failure rate and the probabilities of the tank's contents (upon escape) subsequently reacting with air in various combustion modes is a highly complex task. First, the approximate g-loads on the fuel tank assembly during rapid changes in acceleration must be estimated. For example, head-on collisions at 60 mph could produce de-accelerations to the fuel tank assembly on the order of 12 g's. Such high accelerations subsequently lead to forces capable of shearing tank hold-down bolts and process piping. Even if the tank hold-down bolts and piping remain intact, other ancillary vehicle components (e.g., body framing, engine, transmission, etc.) may impact the tank and crush or pierce its walls causing rapid high pressure hydrogen release. Failure of the tank assembly under these conditions requires further study.

The effects of rapid high pressure hydrogen release (should it occur) are also quite varied. Whether this gas will ignite in air or simply dissipate as a harmless invisible cloud is a function of complex chemical kinetic and physical processes. Although these processes are amenable to detailed analysis and testing (see, e.g., Refs. 1, 12, 18, and 19), initializing vehicle accident geometries and component disassembly processes at the time of rapid hydrogen release is problematical. Determining whether an ignition source (e.g., a spark from impacting shrapnel) will be present at the right hydrodynamic conditions (e.g., hydrogen/air mixture ratios and gas velocities) depends upon variables that are specific to the type of accident (out of thousands of possible scenarios) involved.

It is suggested that a number of baseline accident scenarios be developed to bracket the possible high pressure hydrogen tank failure modes. For each failure mode identified, a probability effects tree with supporting analysis should be identified to determine the expected consequences of the high pressure hydrogen release.

5.3 HYDROGEN LEAKAGE (FILLING OPERATIONS & TRUCK STORAGE)

System failures due to leaking hydrogen could be problematical for a gaseous storage and feed system containing so many valves and pipe fittings. Indeed, a number of small hydrogen leaks were initially detected on the Ford Ranger truck at the time of original receipt by ETEC. As mentioned earlier, some thought should be given to making as many tube fittings (as practical) completely welded fittings rather than mechanical fittings (e.g., Swage lock). In high vibration environments -- such as a vehicle transportation system -- mechanical fittings have a known tendency to work loose.

The Ranger's female hydrogen filling receptacle is a fitting requiring special attention. This is primarily because the fitting is to be connected and disconnected repeatably during the vehicle's life. Depending upon truck usage, this fitting may be connected and disconnected to a filling station's feed nozzle as frequently as once per day. In a high pressure hydrogen environment, such fittings usually need constant servicing and maintenance in order to prevent all possible leaks.

Fortunately, the effects of such feed system leak failures should be rather minimal. First, hydrogen leak rates through tube fittings should be relatively small thus making flammable hydrogen/air mixtures in the vicinity of the truck difficult to achieve. The main danger from these leaks is if they occur in an unventilated enclosure (e.g., a residential garage) where flammable mixtures have an opportunity to build up. However, if the Ranger is always kept outdoors or in well ventilated areas, fire and explosion effects from hydrogen fitting leaks should be essentially non-existent. Second, igniting these oxidizer rich hydrogen/air mixtures is generally more difficult than stoichiometric or fuel rich mixtures.

6.0 RECOMMENDED FUTURE SAFETY EFFORTS

Additional safety related efforts should be considered -- especially if this hydrogen fueled Ford Ranger begins to see wide spread road use. Safety improvements in the design should be possible with additional analysis and testing.

Both the air intercooler and CVI chamber should be hydrostatically pressurized to failure. This destructive testing should be relatively inexpensive to perform and provide quantitative burst pressures for determining required component safety margins. Additionally, the added cost of procuring (and developing, if necessary) air intercoolers and CVIs capable of surviving a worst case internal pressure of 450 psia should be assessed. It should also be determined whether hydrogen feed system piping and valves can be connected by welded fittings instead of mechanical ones.

Detailed FEMA studies should be performed in the area of vehicle collisions assuming such collisions and other road impacts will occur and therefore must be reasonably understood. A number of representative collision scenarios should be baselined along with the hydrogen feed system components expected to fail under each scenario identified. The numerous effects produced from these component failures should be listed and those component failures which lead to possible loss of human life identified and placed on a "critical items list" for subsequent analysis. The causal connection between hydrogen feed system component failure and loss of human life should be firmly established for each collision baseline. For example, if all fatalities would have occurred without the subsequent failure of a hydrogen feed system component, then that component (even though it failed) should not be included on the critical items list.

From a safety standpoint, the hydrogen fueled CAN truck is a good first-of-a-kind demonstration vehicle. It should be reasonably safe to operate in its intended service environment as long as the procedures developed by the truck's integrator (Advanced Machining Dynamics) are strictly followed. Under no circumstances should this truck's hydrogen fuel feed system be modified or repaired without the direct supervision of Advanced Machining Dynamics or a qualified and licensed professional engineer (PE).

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Addendum Regarding Ford Ranger Hydrogen Conversions

Summary of Emissions Characteristics

A Ford Ranger pickup truck was converted for use of hydrogen fuel by UCR CE-CERT (University of California, College of Engineering, Center for Environmental Research and Technology), with the aid of Bill Kaiser of Kaiser Engineering and the "CVI" (Constant Volume Injection) product of Hydrogen Components Inc. This truck used a turbocharger and an automatic transmission. Subsequently, Kaiser converted three more Ranger trucks for Clean Air Now (CAN). This addendum discusses the emission characteristics of these trucks.

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

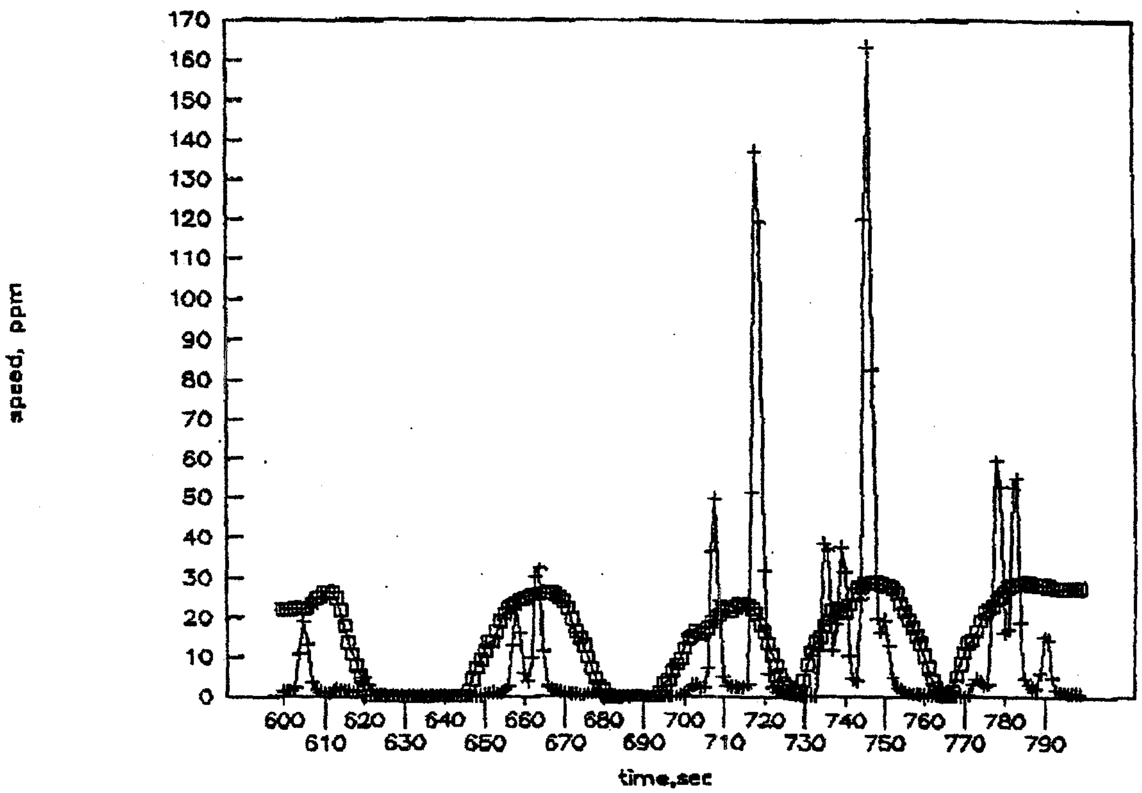
The three CAN trucks, although expected to be identical, do operate notably differently. This became evident in constant speed dynomometer tests done in conjunction with CE-CERT. The NOx tests varied depending on the truck, with the best of these vehicles maintaining below 35 ppm NOx at full throttle 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, operating with a richer mixture, had higher NOx test values.

A single FTP75 test procedure was run on the high performance truck, CAN2. Total gram per mile results were: (as compared to the ULEV standard and proposed EZEV standard):

	CAN2	ULEV 50K mi	100K mi	EZEV
CO	0.052 g/mi	1.7	2.1	0.17
HC/NMOG	0.003	0.04	0.055	0.004
NOx	0.299	0.2	0.3	0.02
Total	0.36	1.94	2.455	0.194

It is evident that the hydrogen fueled truck handily meets any of the standards for CO and HC, but the NOx is excessive even for the low milage ULEV standard.

Noting that the FTP NOx emissions were more than would have been expected from constant speed tests, we obtained second by second records of the FTP test. A sample follows.[1] If we eliminate the peaks, the NOx emissions are reduced by a factor of eight. We believe that these emissions are due to the momentary enrichment of the hydrogen mixture to the engine. This, if verified, is a weakness of the presently used engine control unit. We expect that this can be remedied. Funding has been requested to carry out further tests and ECU (engine control unit) development. We believe that the total emissions can be reduced to a fraction of the total emissions allowed for the EZEV.



Tests of a development engine at Sandia Laboratories indicate that a hydrogen engine can meet all the requirements of the proposed California EZEV, even with an admixture of natural gas in the hydrogen.[2]

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[1] Two parameters are plotted, the vehicle speed in miles per hour - denoted by squares -and the NOx in ppm (parts per million, after a factor of 44 dilution) - denoted by +. Here we see simulated city driving with acceleration to near 30 mph, followed by slowing to a stop. NOx peaks are observed to dominate the NOx emissions, with these peaks occuring near times of reducing the throttle.

[2] P. Van Blarigan, Development of a Hydrogen Fueled Internal Combustion Engine Designed for Single Speed/Power Operation, *SAE Paper 961690*, presented at the SAE Future Transportation Technology Conference, Vancouver (August 1996)

FINAL REPORT

Evaluation of Supercharged Hydrogen Fueled

Ford Ranger Trucks

A CE-CERT Study done under contract to

Clean Air Now

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SUMMARY

The University of California College of Engineering Center for Environmental Research and Technology (CE-CERT) has completed a contract awarded by Clean Air Now (CAN) for test and evaluation of the three Ford Ranger trucks converted to hydrogen fueled operation under South Coast Air Quality Management District funding. This report describes the test protocol, and the results of the evaluation.

The following is a summary of the results:

1) Except for occasional misfires and a tendency towards an oscillatory instability at full throttle, the engines performed as expected within the range of 2000 to 5000 rpm.

2) Proper adjustment of the fuel injection control circuit is essential for proper engine performance.

3) Even with lean mixtures to reduce NOx production, engine power substantially exceeds that of the stock gasoline powered engine. Ultralean operation - with phi of 0.35 or less - causes substantial power reduction but allows NOx levels at or below 35 ppm over the full range of engine power and rpm.

4) Despite additional weight of the modified vehicle, the increased engine power allows the hydrogen fueled truck to accelerate like the stock vehicle even with lean operation. Ultralean operation - required only for the lowest NOx levels - results in reduced power and acceleration (as expected).

5) The trucks equipped with EDO fuel storage tanks had a range in excess of 140 miles.

6) Total emissions are less than those of a ULEV vehicle, but NOx reductions are still required. Federal Test Procedure (FTP) measurements of CAN2, the West Hollywood truck, show total hydrocarbons and NMHC (non-mentane hydrocarbons) each at 0.003 g/mi, CO at 0.052 gm/mi. and NOx at 0.299 grams/mile. Over 80% of the NOx emissions occur in sudden bursts which are thought to be related to instability of the engine control system.

7) While the overall operation of the vehicles was satisfactory, each of the three had distinct performance characteristics. The reasons for the differences are not fully understood at this time.

Improvements to the vehicles which could further improve performance are suggested herein. A program of preventative maintenance and periodic inspection is recommended.

I - Background

The Clean Air Now/Xerox Solar Hydrogen Powered Fleet project uses sun generated hydrogen to fuel a fleet of hydrogen fueled trucks. The trucks are converted Ford Rangers with 4 cylinder engines which have been bored and stroked to 2.9 liter displacement and use a supercharger to enhance airflow. The fuel control system is of the Constant Volume Injection (CVI) design. Contractors for the truck conversion include Advanced Machining Dynamics (AMD, Bill Kaiser), with Hydrogen Consultants Inc. (HCI, Frank Lynch) providing the CVI system. University of California at Riverside Center for Environmental Research and Technology (UCR CE-CERT) has contracted to evaluate the operation of the trucks.

The CE-CERT contract with CAN provides for the measurement of the following parameters:

T-IN	Air temperature between the outlet of the supercharger and the inlet to the intercooler, °F
T-OUT	Air temperature at the outlet of the intercooler, °F
T-EXH	Exhaust gas temperature, °F
T-TANK	Temperature in the hydrogen storage tank, °F
P-TANK	Pressure in the hydrogen storage tank, psi
VREG	Buzzmatic set point, being the signal from the CVI electronic controller which commands the Buzzmatic electronic pressure regulator, presented in psi commanded
P-IN	Hydrogen pressure at the inlet to the CVI volume, psi
MAF	Mass air flow, lb/min
H2F	Hydrogen mass flow, lb/min
MAP	Manifold air pressure, psi
VEGO	Voltage from the exhaust gas oxygen sensor, converted to equivalence ratio φ (phi)
TPI	Throttle position indicator

In addition, a single pressure sensor placed in an available spark plug hole was used to monitor the pressure inside the cylinder as the fuel is compressed and burned.

More detail on the sensors and the data acquisition system is given in Appendix A.

II - Description of the Trucks

The first conversion of a Ford Ranger truck to use hydrogen fuel and the CVI injection system was done by CE-CERT and HCI/AMD in 1994 under contract from the SCAQMD (South Coast Air Quality Management District). This UCR truck will be referred to herein as UCR1.

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 are used for short runs around the Xerox buildings, and on local streets. The truck converted for the City of West Hollywood uses the freeways to go to El Segundo for fuel until a West Hollywood fueling facility is installed. Whereas UCR1 has an automatic transmission, the CAN trucks use manual transmissions - allowing improved low speed acceleration. We will refer to these trucks as CAN1, CAN2 and CAN3. CAN1 and CAN3 are owned by the Xerox Corporation. CAN2 is property of the City of West Hollywood.

Due to concern over the limited low speed acceleration of UCR1, it was decided to substitute a supercharger for the turbocharger used on UCR1. These trucks were also bored and stroked to increase the displacement to 2.9 liters and the compression ratio to 11:1.

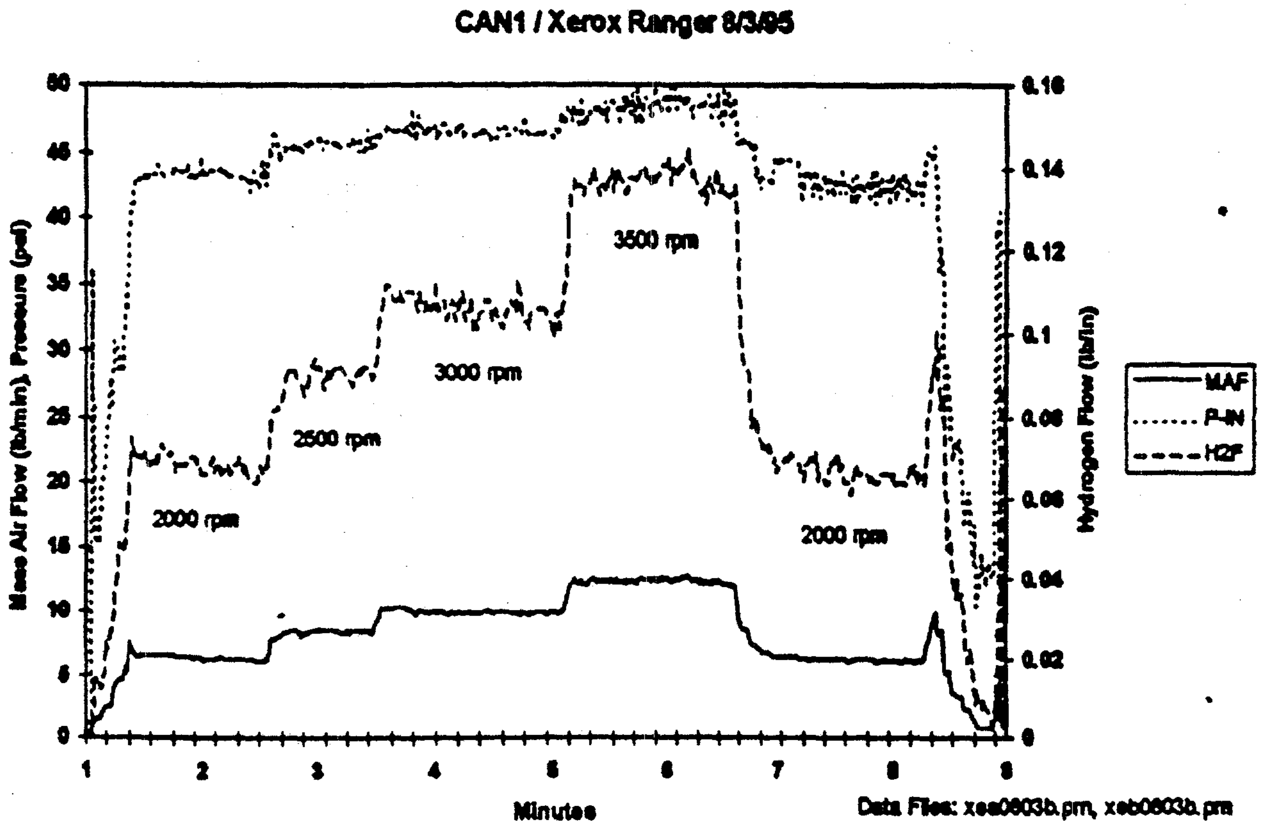

Figure 1 CAN mass air flow, hydrogen mass flow and hydrogen inlet pressure to the CVI induction unit as recorded for 9 minutes of operation at various engine speeds.

III - CAN1 DATA AND ANALYSIS

Figures 1 - 4 display engine data parameters as recorded for CAN1. After the first minute, the driver increased power to full throttle and controlled load by means of a hand held control which is cable connected to the dynamometer controller. Torque was varied to successively maintain each of several speeds:

2000 rpm	- from t=1.4 to 2.5 minutes
2500 rpm	- from t=2.9 to 3.4 minutes
3000 rpm	- from t=3.8 to 5.1 minutes
3500 rpm	- from t=5.2 to 6.5 minutes
2000 rpm	- from t=7 to 8.2 minutes

These rpm measurements were from a commercial tachometer and are cited only to offer a relative indication of engine speed.

The bottom line of Figure 1 shows the mass air flow in units of lb/min (left scale), the mass flow of hydrogen is given by the broken line (right scale), and P-IN (hydrogen pressure at the CVI inlet) is given at top (left scale).

Other parameters recorded during these test runs are illustrated in Figures 2 - 4.

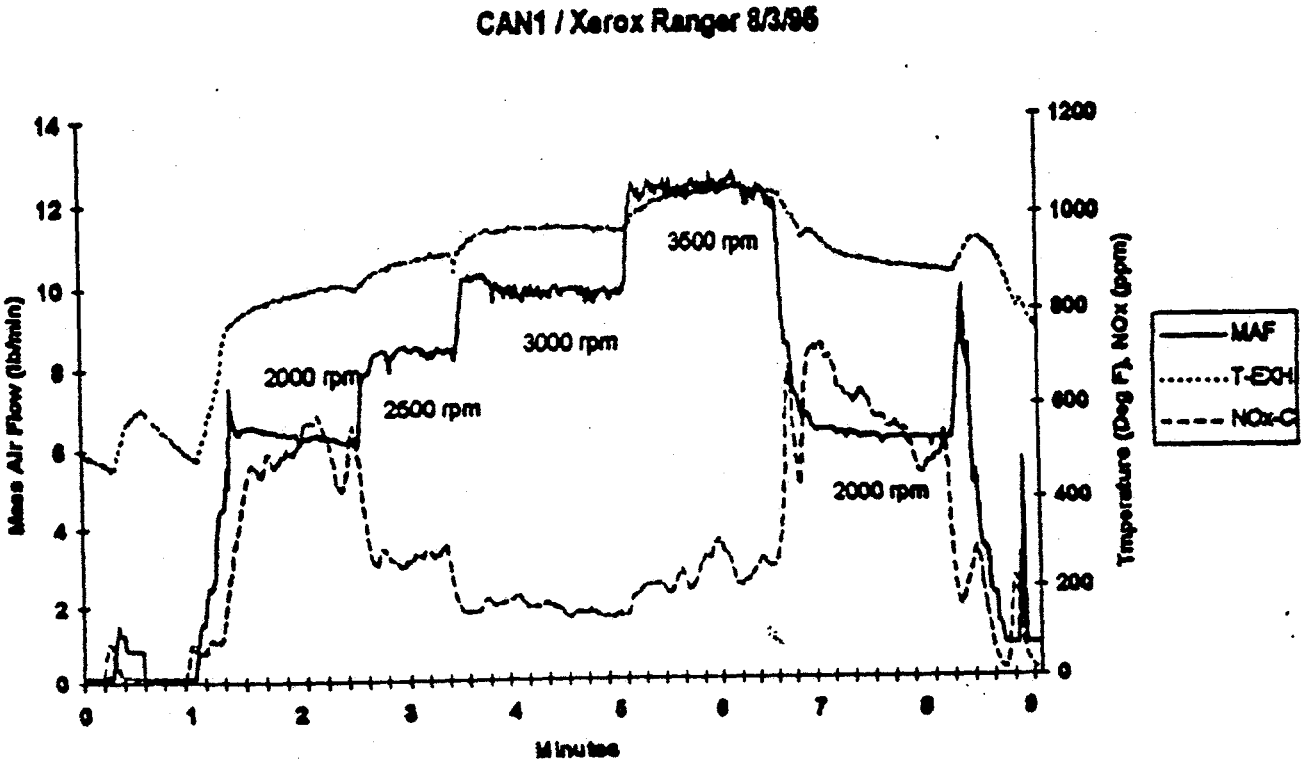

Figure 2 MAF, T-EXH and NOx for CAN1.

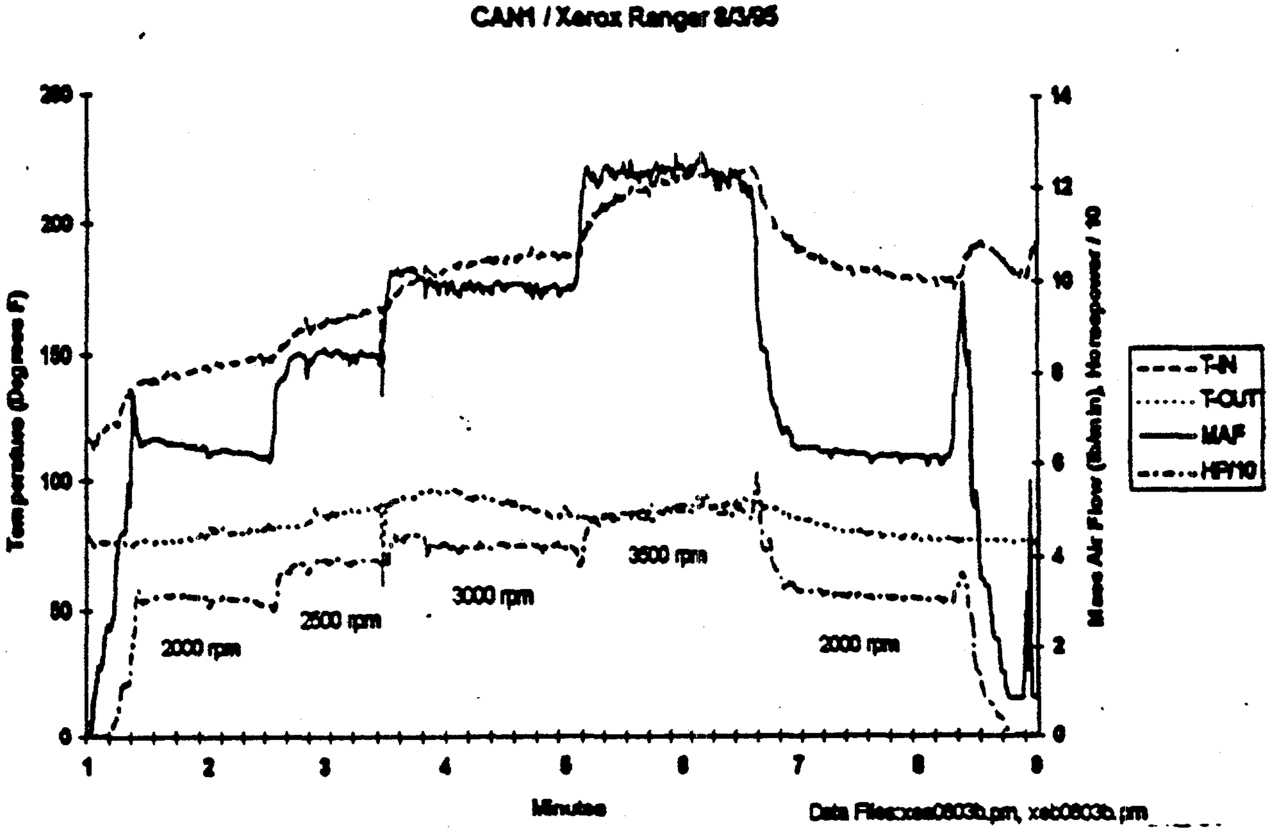

Figure 3 CAN1 MAF, HP, and intercooler inlet and outlet temperatures.

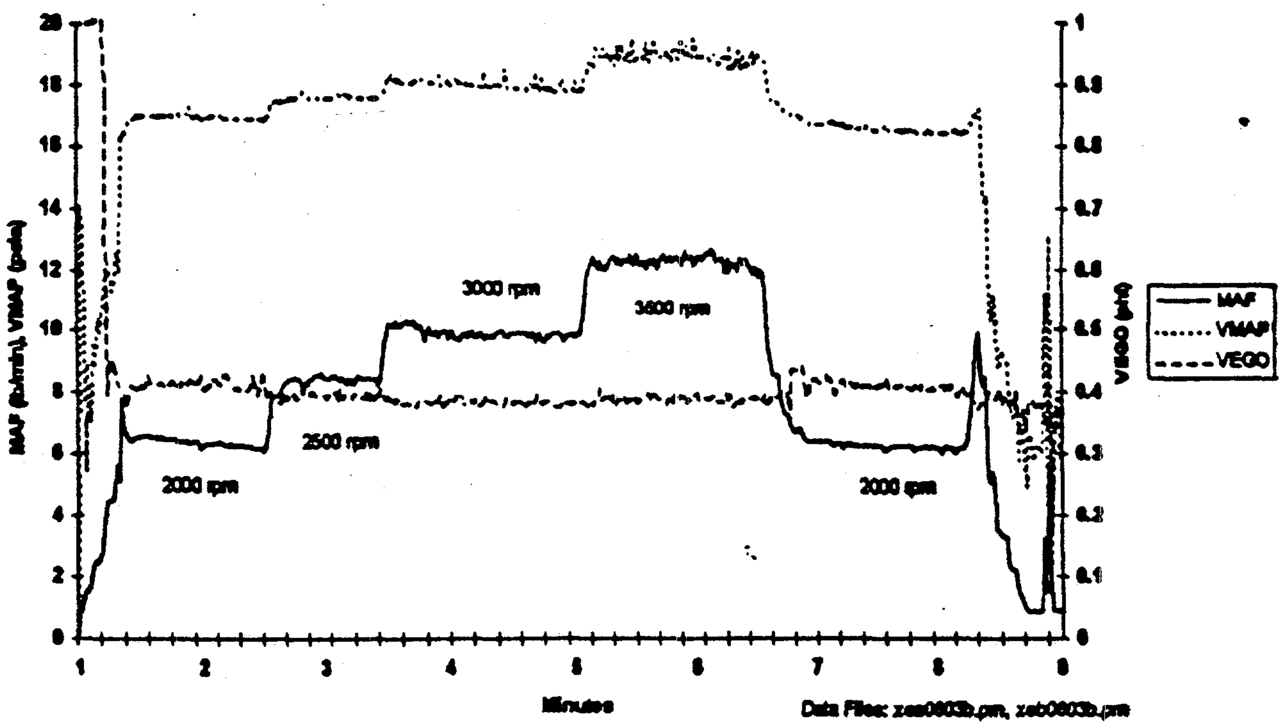

Figure 4 MAF, manifold air pressure MAP, and EGO sensor output expressed as phi.

The top curve of Figure 1 shows the inlet pressure of hydrogen fuel to the CVI increases slightly with rpm, with a peak pressure of approximately 48 psi at 3500 rpm. This pressure is automatically controlled by the CVI fuel control electronics driving the valve which controls the hydrogen pressure at the fuel distributor inlet.

Note the NOx data of Figure 2. The highest NOx levels are seen at the lowest rpm - 2000 rpm. The notable decrease in NOx with increasing rpm may be due to the fuel burn being later in the cycle at lower temperatures and pressures, as neither the ignition angle or the flame speed changes with increasing rpm. The slightly higher NOx value as the speed was returned to 2000 rpm (at t=7+ minutes) may be attributed to the warmer engine, as evidenced by the higher T-EXH.

We believe that the wide excursions in NOx, and the high average values of NOx (200 - 600 ppm) for this engine, relate to the tendency of the engine to have oscillations in power and mixture at full throttle, as will be shown later (Section III-A).

The intercooler effectiveness is illustrated in Figure 3, where the inlet temperature T-IN is reduced from over 200 degrees to outlet temperature T-OUT slightly above ambient. The exhaust gas temperature (Figure 2) and the horsepower to the road increase with rpm as expected - again, all these data are taken at full open throttle.

Figure 4 repeats the MAF curve, but this time with the manifold air pressure, MAP, and the exhaust gas oxygen voltage VEGO - converted to display as φ, the equivalence ratio - presented vs. time.

Comparing the mass flows as read from Figures 1 and 2 (at 3500 rpm), the air/fuel ratio is MAF/H2F=12.3/0.138=89, as compared to the stoichiometric ratio of 34.3. Thus the calculated equivalence ratio φ is 34.3/89=0.384. The desired "ultralean" operation has been attained.

The EGO sensor shows φ approximately equal to 0.40 at 2000 rpm, falling to approximately 0.38 at the higher engine speeds. This direct measurement of the exhaust gas oxygen content may be taken as confirmation of the value calculated from the measured fuel and air flows.

III-A Observed Unsteady Engine Operation

A fast response piezoelectric pressure sensor was used to sense the combustion chamber pressure in cylinder 4 of CAN1.

Figure 5 presents an oscillograph of the pressure in cylinder #4 as a function of time during full throttle operation of CAN1 at a nominal 3000 rpm. Each pulse represents the burn of a single charge of hydrogen. The separation of pulses represents 2 rotations of the engine, or approximately 40 ms. The highest pressure observed is approximately 750 psi.

The variation of pressure pulse height is most striking. The data suggests that either the mixture or the total charge inducted into the cylinder varies by more than a factor of two. The separation of maxima is some 10 to 16 firings, or 0.5 to 0.8 seconds. While taking

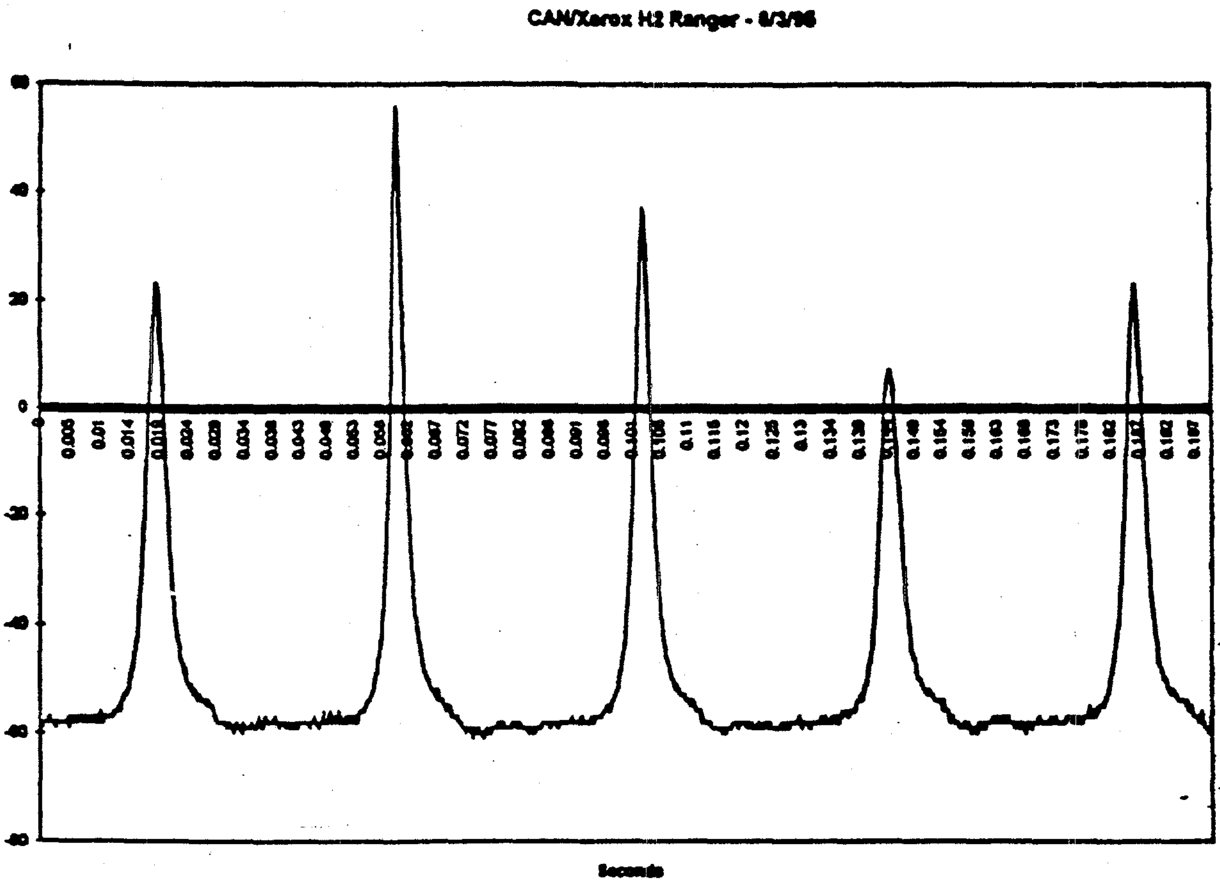

Figure 5 Time dependence of cylinder #4 pressure shows cycle to cycle variation.

these data (operating CAN1 at full throttle and at approximately 3000 rpm) it was also evident even from the sound of the engine, that the engine was surging, not running steadily. This surging also showed up in earlier measurements.[1]

This observation of varying peak pressure in the cylinder suggests a tentative explanation of the NOx data. With either the mixture or the total charge varying the time averaged NOx numbers would not be expected to be representative of the average charge. This is a result of the known exponential dependence (for lean mixtures) of NOx production on mixture and combustion temperature.

[1] Subsequent to the dynamometer testing CAN1 was modified to the same level of control system as on CAN2 and CAN3. Hence this discussion is somewhat academic, as the surging is not observed in the later versions.

For instance, if φ is varying by over a factor of two, say from .3 to .6, the amount of NOx produced at the high φ firings would grossly exceed that of firings at low and average φ. The average NOx level would greatly exceed that expected at the average φ. Thus, high NOx levels would result from unsteady operation.

The exhaust gas NOx is high, about 500 ppm, at the lowest engine speeds.[2] As was noted above, the high NOx levels, while correct for the operating conditions, appear to result from unsteady operation of the engine. The data shows a dramatic drop to less than 1/4 that value as the rpm is increased to 3000 rpm. Similarly, the data taken the following day is above 500 ppm at 2000, drops to 300 ppm at 2500 rpm and then to about 200 ppm at 3000 rpm before slowly climbing as the rpm are increased.

The unsteady operation appears to be an artifact of the CVI controller, and is a problem primarily at full throttle operation. Oscillation of control systems generally results when loop gain is high (sensitive response to input parameters), as this can overwhelm the damping in the system. This (CVI) controller is of fully analog design. The damping of the controller appears to depend on the settings of several potentiometers.[3] Due to the observation of these oscillations, the CVI settings were adjusted with the intent of setting for smooth running. Preliminary indications are that this has been more successful with trucks CAN2 and CAN3 than it was for CAN1.

III-B CAN1 Summary Data

All data for Figure 1-4 were taken on 8/3/95. Other data was taken at engine speeds including 4000 and 4500 rpm the prior day.

It is convenient to replot the data as a function of rpm. To do this we select a time interval, at each rpm, during which exhaust temperature and other slowly varying parameters are comparatively constant. We then take the data from a given instant during that interval for each parameter. This yields tables of the dependence of the various parameters on engine speed, which tables are then converted to figures.

As an example, Figure 6 shows horsepower and air and exhaust temperatures as dependent on rpm for CAN1. Note, again, the effectiveness of the intercooler in cooling the compressed manifold air.

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[2] Previous measurements, such as those of Das (*Int. J. Hydrogen Energy*, 16, pp. 765-775, 1991) suggest that for the conditions of the CAN engines at φ=0.4, approximately 100ppm of NOx should be expected. We note that the engines are quite different from that of Das, and thus this can be only a guideline.

[3] The manufacturer of the CVI system, Hydrogen Consultants International, provided no written detail regarding the controller. During a visit to the HCI facility in May, 1995, Bill Kaiser (of AMD, the manufacturer of the converted truck) was given a tutorial of how to make the adjustments.

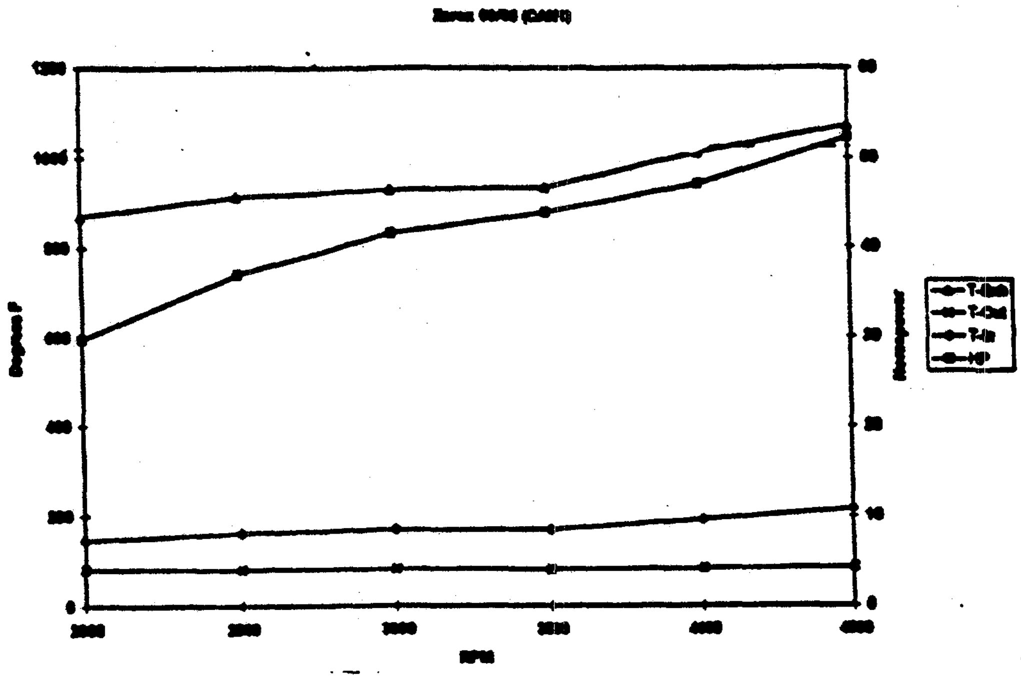


Figure 6 Summary HP, intercooler inlet and outlet temperatures and exhaust gas temperature as dependent on rpm at full throttle.

We term these plots of the engine parameters vs. rpm Summary Data, as they summarize the time plots and present the steady state operation of the engine. We again note that the rpm measurements are not precise. The temperatures were obtained with thermocouples and the power was taken from the output of the recently calibrated Clayton chassis dynamometer.

IV - CAN2 Data

The second truck, CAN2, is a black 1994 model short bed Ford Ranger fitted with the larger and lighter carbon composite tanks manufactured by EDO (of Canada). CAN2 has better drivability and performance compared to the other vehicles. This is probably the result of two factors: lower milage (the CAN2 engine had no on-road use prior to test, while CAN1 had a few hundred miles of ETEC testing prior to delivery to CE-CERT), and the CAN2 engine control parameters appeared to be better optimized compared to CAN1.

Preliminary CAN2 NOx measurements are much lower than those of CAN1, peaking at 100 ppm at 3000 rpm and falling to half that value at the high speeds. This could be attributed to less "seeking" (more steady combustion) than was apparent on CAN1, but further measurements are appropriate before drawing conclusions.

V - CAN3 Data

The third truck had performance characteristics very different than CAN1 or CAN2. Smooth and practically free of misfires, much like CAN2, it was much less powerful than either earlier supercharged truck. CAN3 was most certainly operating too lean at the time of our measurements (after delivery to Xerox it is reported that the mixture was enrichened and the performance was improved). CAN3, for instance, had exhaust gas temperature some 200 degrees below that of CAN2 and nearly 100 degrees below that of CAN1. Finally, the NOx levels are also dramatically lower. At 33 ppm, the highest NOx observed is a third that of CAN2 and some 5% the high results of CAN1.

A prescribed Federal Test Procedure (FTP) emissions measurement yielded 0.37 grams NOx for the turbocharged truck UCR1. (CO and hydrocarbon levels were negligible in comparison.) The CAN vehicles have not yet been FTP tested. However, comparing the similar steady throttle tests done with the CE-CERT chassis dynamometer on UCR1 and the CAN vehicles, one can estimate that:

1) For CAN2, the FTP NOx would be below 0.1 gm/mi,
2) For CAN3, as tested, the FTP NOx would be below 0.04 gm/mi.

One must realize that these are - essentially - the total emissions, as there is no carbon in the fuel. The steady throttle tests miss the emissions caused during increases/decreases of power level, and hence these estimated improvements over the UCR1 emissions are likely optimistic.

VI - Comparisons between CAN1, CAN2, and CAN3

After discussion of the data above, it is clear that the three trucks are very different. One would like to declare the differences to be entirely due to the differing settings of the CVI controller leading to differing mixture ratios. To do this, we must first attempt running all three trucks with identical controller settings.

In the next set of tests we will measure the settings of the CAN2 controller and attempt setting up the other two trucks to operate identically. Many of the static measurements will be repeated, and we will get FTP tests on one or more trucks.

VII - Comparing the Performance of the CAN Supercharged Truck with Others

Figure 7 illustrates the power curves of a stock gasoline powered Ford Ranger (4 Cyl.) as compared to UCR1 and CAN2 - as measured at CE-CERT. The CAN truck has clear advantage until one gets to the highest rpm!

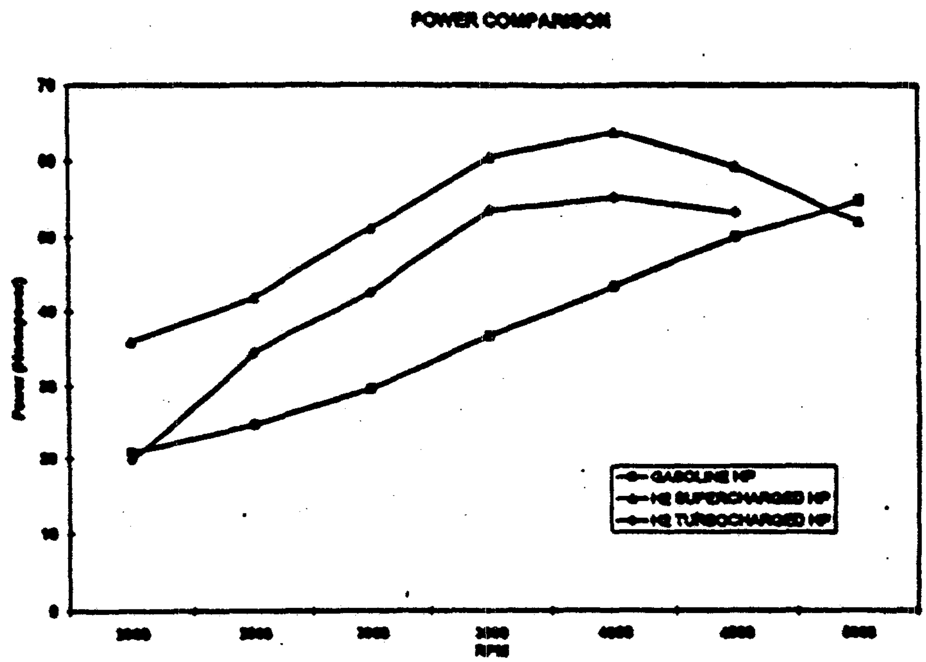


Figure 7 Comparing the HP of a stock gasoline fueled Ranger with the turbocharged and supercharged hydrogen fueled trucks.

Road tests were done only on CAN3. Lighter weight (like CAN2, due to the EDO tanks) than UCR1, it would easily beat the turbocharged truck off the start, but both would take over 25 seconds to accelerate from 0->60 mph! This is illustrated in Figure 8.

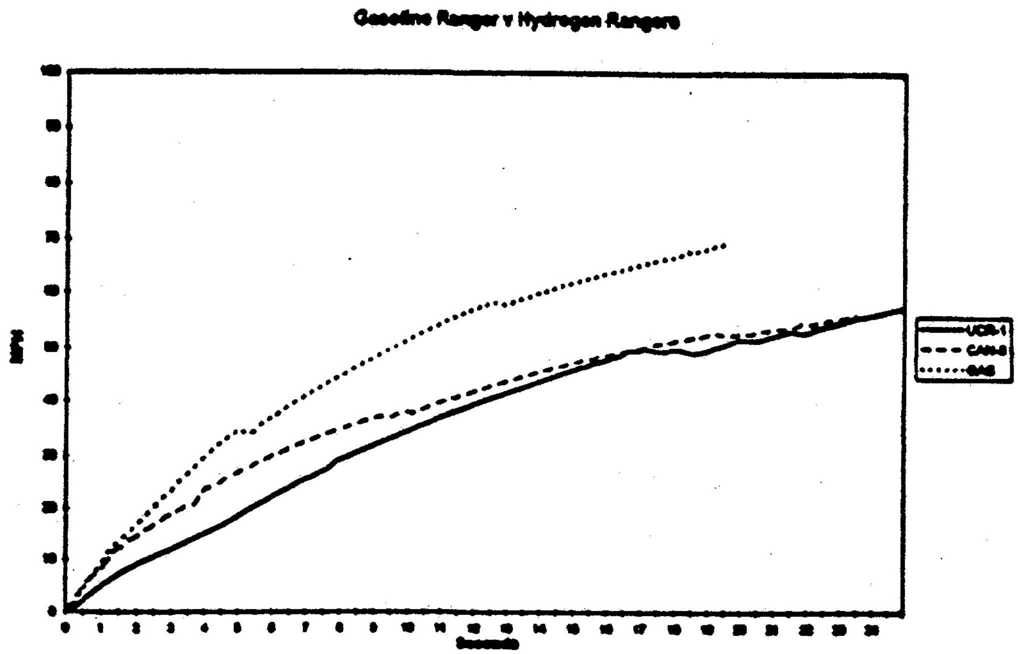


Figure 8. Acceleration of hydrogen powered trucks as compared to the stock Ford Ranger. CAN3 was operating ultra-lean at the time of this test. (CAN2 and CAN1 would show up better in this comparison, but no data is yet available.)

VIII - Federal Test Procedure Evaluation of CAN2

CAN2, the West Hollywood Ranger, was evaluated using the Federal Test Procedure (FTP75, 3 phase). In this procedure the vehicle is mounted on a chassis dynomometer, and a driver is given, by television screen, a set driving protocol representing city driving.
By use of the accelerator the car speed is controlled so as to follow that protocol. For three intervals (of between 3 and 4 miles) a bag sample of the emissions is collected for sampling. Figure 16 presents the results. The CO and hydrocarbons are very low, but the NOx (while it meets TLEV is above the ULEV standard.

CE-CERT

CHASSIS DYNO PROTOCOL — TEST CELL 1

TEST NO : H9606034
TESTNAME: FTP75 3 phase
TESTMODE: Gasoline conforming to regulations

COUNTRY : USA
CYCLE : FTP75

CONTRACTOR : Clean Air Now
OPERATOR : Dave Martis
DRIVER : Ross Rettig
DATE : 17.06.96 11:44

BASIC DATA

VEHICLE	: 94 Ford Ranger	VEHICLE MASS	lbs	: 3250
VEHICLE SPEC.	: 1FTCR10A3RUA75783	FUEL TYPE		: Hydrogen
ENGINE TYPE	: 2.8 liters	HEATING VALUE	BTU/lb	: 61031.0
ODOMETER	: 25607	DENSITY	kg/l	: 0.23500
TRANSMISSION	: 5 spd.	CARBON WEIGTH FRACTION		: 0.00000

ENVIRONMENTAL DATA		PHASE 1	PHASE 2	PHASE 3
AMBIENT TEMPERATURE	°F	71.5	74.1	73.9
AMBIENT PRESSURE	inHg	30.0	30.0	30.0
RELATIVE HUMIDITY	%	57.4	70.2	65.6
ABSOLUTE HUMIDITY	gr/lb da	65.6	88.4	81.9
HUMIDITY CORRECTION FACTOR	1	0.958	1.067	1.034
DILUTION FACTOR	1	197.4	206.6	207.5
VMIX CVS NORMALIZED TO 293.15°K	SF^3	2893.3	4954.6	2911.3
DISTANCE	mi	3.590	3.885	3.599
TIME	s	508.3	865.6	507.9

BAG ANALYSIS	THC ppm	CH4 ppmc	NOx ppm	CO ppm	CO2 Vol %
PHASE 1					
SAMPLE	1.69	1.98	9.04	3.93	0.07
BACKGROUND	1.34	2.34	0.04	2.12	0.06
CORRECTED	0.36	-0.34	8.99	1.82	0.01
PHASE 2					
SAMPLE	1.79	2.04	4.10	3.16	0.06
BACKGROUND	2.05	2.06	0.04	1.90	0.06
CORRECTED	-0.25	-0.01	4.06	1.27	0.01
PHASE 3					
SAMPLE	4.06	2.15	5.40	3.56	0.06
BACKGROUND	4.68	2.06	0.03	1.81	0.05
CORRECTED	-0.59	0.09	5.36	1.76	0.01

MODAL SAMPLE CORRECTION		THC		NOx	CO	CO2
PHASE 1	g					
PHASE 2	g					
PHASE 3	g					
DENSITY	g/l	0.5768	0.6709	1.9101	1.1647	1.8300

EMISSIONS		THC	NMHC	NOx	CO	CO2
PHASE 1	g	0.051	0.051	1.348	0.178	15.426
PHASE 2	g	0.000	0.000	1.162	0.214	21.236
PHASE 3	g	0.000	-0.005	0.873	0.173	12.469
PHASE 1	g/mi	0.014	0.014	0.375	0.050	4.297
PHASE 2	g/mi	0.000	0.000	0.299	0.055	5.466
PHASE 3	g/mi	0.000	-0.001	0.243	0.048	3.465
TOTAL	g/mi	0.003	0.003	0.299	0.052	4.676

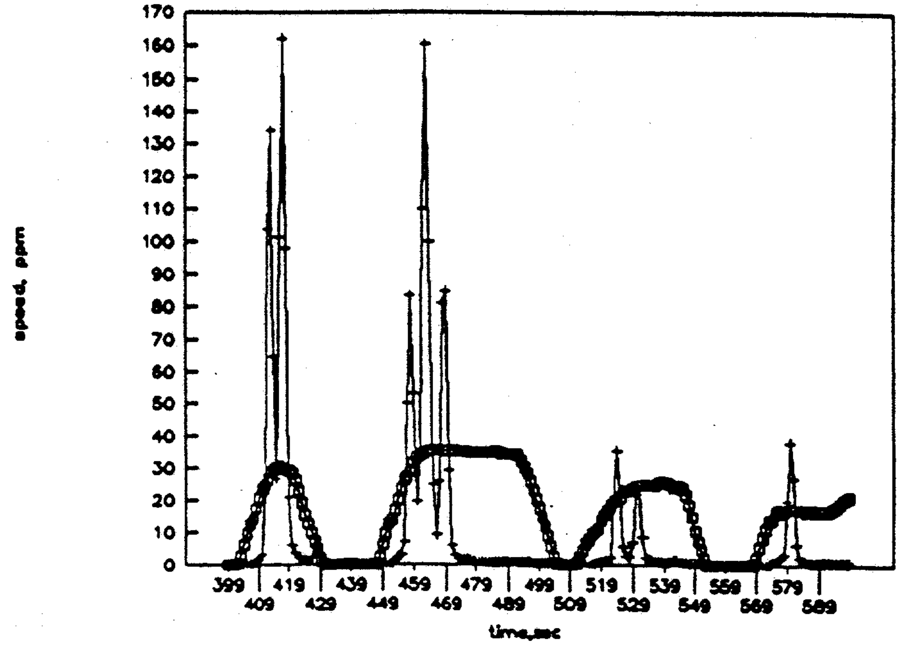
FUEL ECONOMY	mpg	l/100km	km/l
PHASE 1	0.00	-0.23	-0.23
PHASE 2	0.00	-0.17	-0.17
PHASE 3	0.00	-0.29	-0.29
TOTAL	0.00	-0.07	-0.07

CYCLE SUMMARY	DEVIATION mi	FAULTS 1	CRANK s	SOAK s
	0.1802	1.00	3.95	598.00

COMMENTS
BEFORE TEST: n=2, 308 cfm
AFTER TEST :

Figure 16 - Results of CAN2 FTP Test.

Figure 17 presents the time resolved record of the NOx production. The vast majority of the NOx is emitted in spikes of only a few seconds duration. It will be appropriate, at some later time, to seek the cause of these rather sporadic disturbances. It would appear that the control system for the hydrogen flow is at times making the fuel mixture richer than intended. If one can eliminate the spikes, the NOx emissions come down to about 0.05 gm/mi.



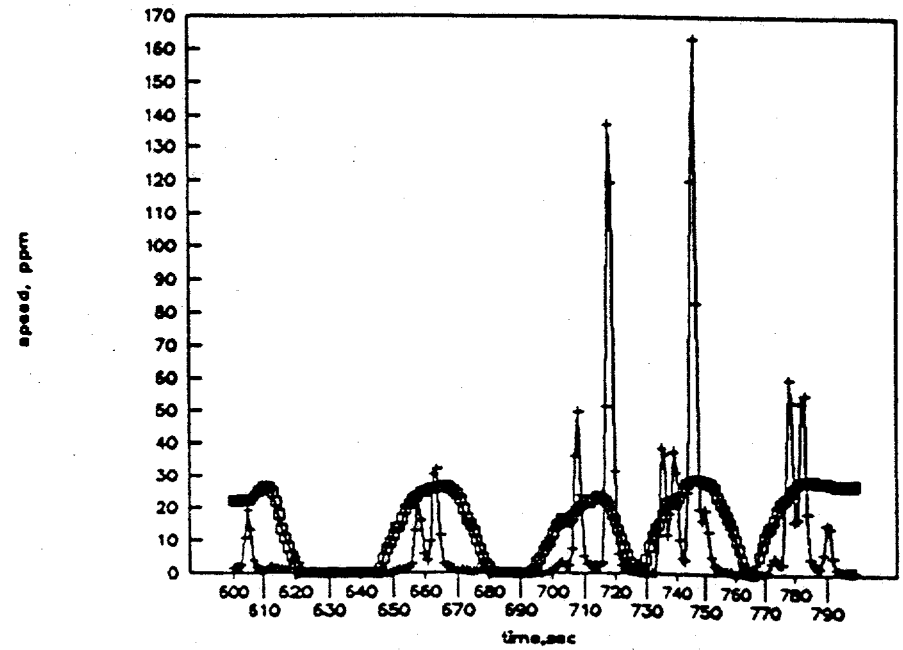


Figure 17 - Time records of the vehicle speed and NOx production for CAN2 FTP.

IX - Conclusions

The CAN trucks are certainly a successful adaptation of the UCR1 concept. Particularly notable are:

* acceptable driving characteristics, but for infrequent misfires,

* power and low speed acceleration acceptable to better than the stock version,

* The three trucks vary notably in performance. Part of this may be attributed to the CVI control system.

* Emissions are of carbon containing compounda are <u>much</u> less than those of a ULEV vehicle, but NOx remains above the ULEV limits. This also appears to result from control system limitations, rather than being inherent in the engine configuration.

* Programs of periodic followup with the drivers, and "inspection and repair as necessary" should be implemented. Further, it would be appropriate to repeat a test protocol similar to the one herein following a given milage (10,000?) or period of time.

Appendix A: Instrumentation and Data Acquisition System

The data collection system consists of sensors to measure the real-world phenomena, signal conditioning to modify the sensors' output into something easily measurable, and an acquisition device to convert the analog signals into digital numbers that can be stored and later analyzed and presented.

The sensors used are listed in Table A-1.

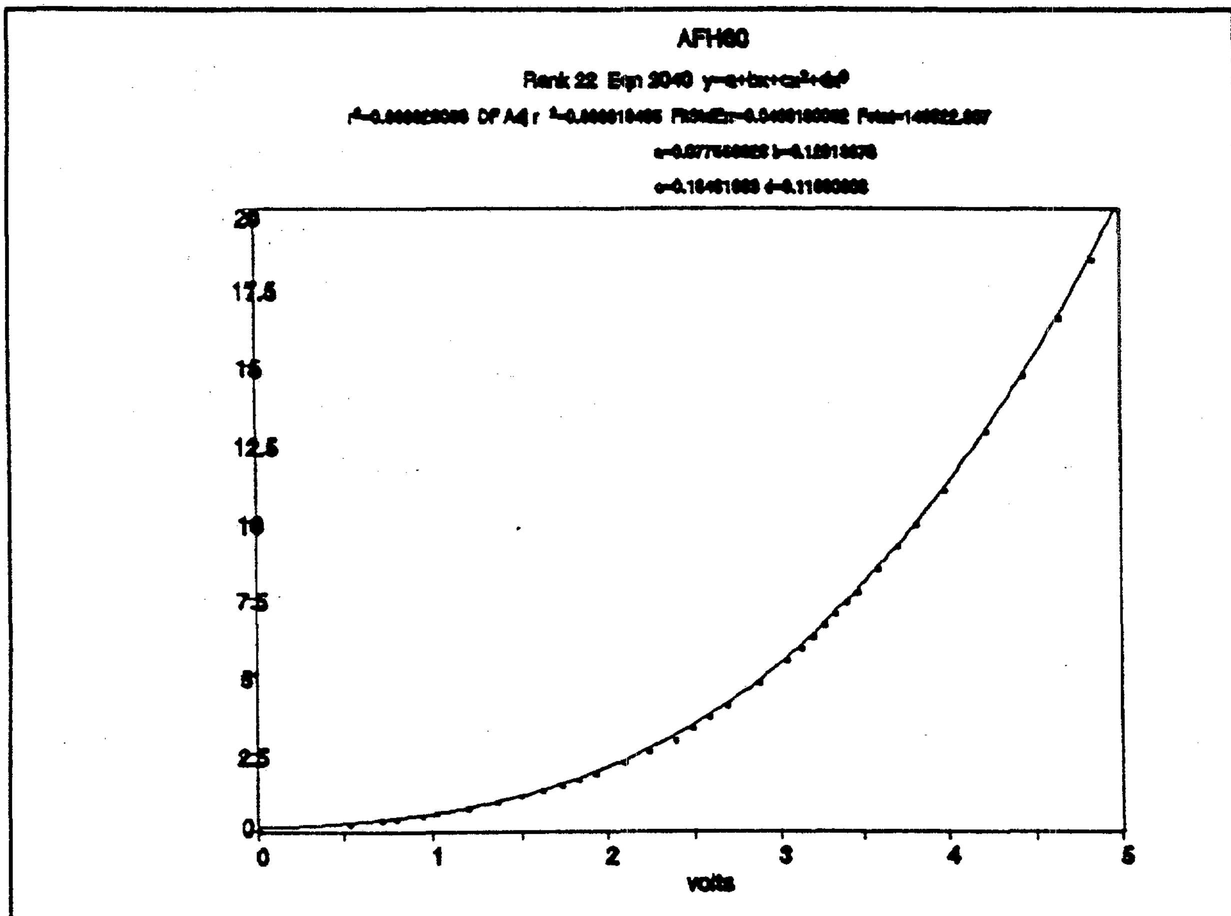
Table A-1 Summary of Data Parameters and Sensor Instruments

Data Point	Sensor	Range	Output
Mass Air Flow (MAF)	Ford AFH-60-01	0 to 500 kg/hr 0 to 18.375 lb/min	0 - 4.834 volts
Exhaust Gas Oxygen Sensor (VEGO)	NGK TL-7111-W1	0 to 20.96% O_2	3 - 4.21 volts
Horsepower (HP) Speed (SPEED)	Clayton 796E Chassis Dynamometer Clayton CSS/1200	0 to 200 Horsepower 0 to 128.25 MPH	0 - 5 volts 0 - 5 volts
Throttle Position (TPI)	Ford 9B989	0 to 100% (0-85°)	1.12 - 4.71 volts
Manifold Air Pressure (MAP)	Buzmatics, Inc. Model RPS-OA50	0 to 50 psia	0 to 5 volts
Control Signal (VREG)	HCI Control Unit	0 to 105 psi	0-5 volts
NO_x (NOX)	Thermo-Electron Model 10AR	0 to 2500 ppm 0 to 10000 ppm	0-10 volts
RPM	Vehicle Tach	0 to 7000 rpm	Driver: Visual in Vehicle
Calculated PHI-P, PHI-M	Equation based on H2 Flow and Mass Air Flow Sensors		
T-EXH, T-IN, T-OUT, ECT T-TNK	Type K Thermocouples	-328 to 2282 ° F	-6.458 to 54.845 millivolts
CVI Fuel-Inlet Pressure	Bourns Model ST3100-A005 Pressure Transducer	0 to 250 psia	0 to 50 millivolts

Data Point	Sensor	Range	Output
P-TNK	Bourns Model ST3200	0 to 5000 psia	0 to 50 millivolts
H2 Flow (H2FM)	MicroMotion CMF025M	0 to 80 lb/min (cal. to 0 to 0.80 lb/min)	4-20 ma.
H2 Flow (H2FP)	Porter 113-APAS	0 to 0.096 lb/min (0 to 500 SLPM)	0-5 volts

MAF

The air flow measurement uses the Ford Mass Air Flow (MAF) sensor as supplied for all Rangers. Mass air flow is measured (in all recent automobiles) and used as an input to control a normally aspirated IC engine. This hot-wire anemometer device was not removed during engine modifications (even though the HCI control unit does not use it). The flow calibration curve below was furnished by the Ford Chemistry Department. Signal conditioning is embedded within the instrument and supplies a high-gain voltage output which is proportional to flow.



AFH-60 calibration information from Ford is given in volts v. kg/hr. We have converted this to English units, as displayed in the curve fit. A device output of 4.834 volts indicates 500 kg/hr, which converts to 18.375 lb/min of air.

VEGO - Exhaust Gas Oxygen Sensor

The Exhaust Gas Oxygen (VEGO) sensor manufactured by the NGK Spark Plug Company was installed as part of the engine control system. The sensor works by comparing the oxygen content of the exhaust stream with the known oxygen content of ambient air. The output signal is roughly a linear analog of the difference. The sensor was calibrated using a premixed stream of air diluted with nitrogen, and the resulting data was fitted to give the equation

$$\%O = 16.454\ V - 47.98$$

or $$phi = 3.2848 - 0.783524\ V$$

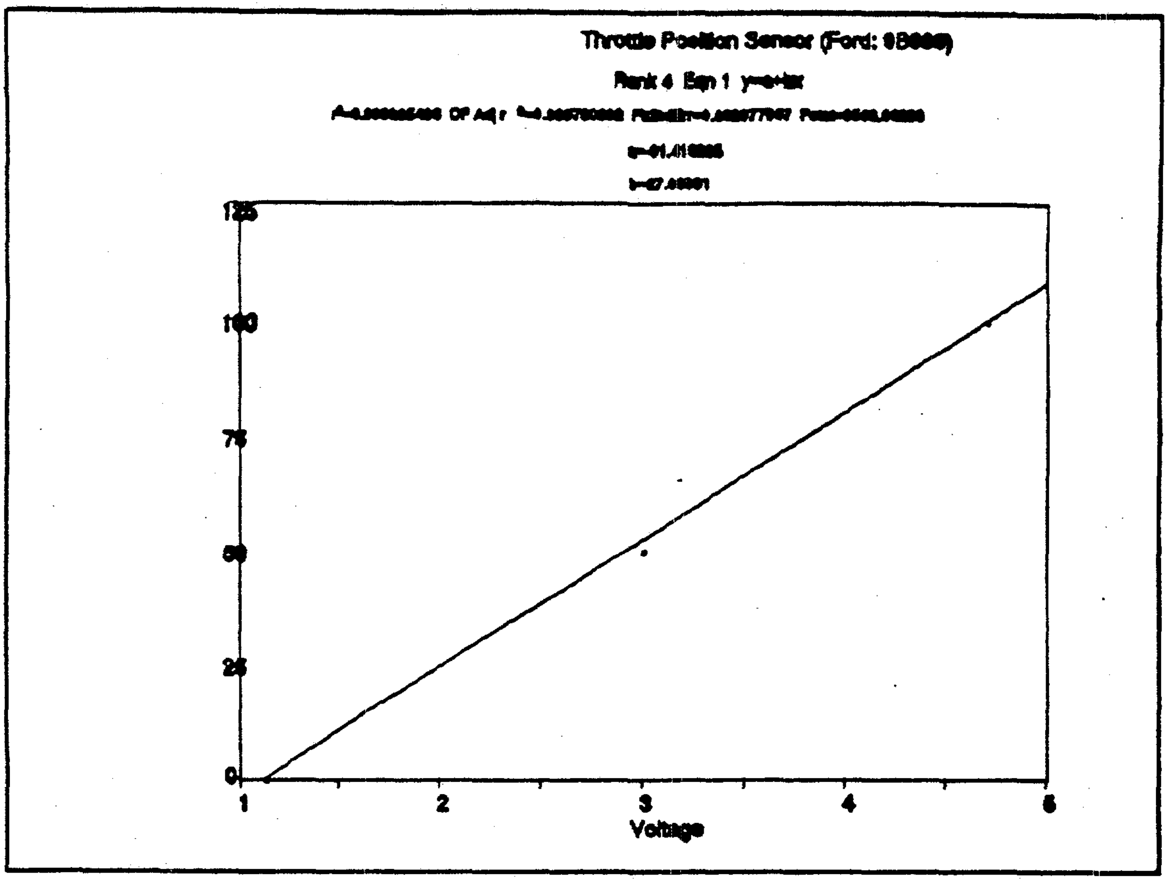
where V is the voltage from the sensor interface.

HP - Chassis Dynamometer

The device used to provide load for the test vehicle is a chassis dynamometer (796-E) manufactured by Clayton Industries. The dynamometer was refitted for this project with an electronics package that provides high-gain signals proportional to torque, vehicle speed, and horsepower. A load cell is used to determine torque; a pulser-wheel used to measure frequency which corresponds to vehicle speed (at the dyno rollers). The electronics package uses these signals to calculate horsepower and outputs the HP in addition to the other two.

TPI - Throttle Position Indicator

The Throttle Position Indicator is also a sensor found on stock vehicles. The device is essentially a potentiometer. A known voltage (5.0 volts dc in our case) is applied to the resistor and the voltage drop at the wiper is measured. The voltage is linearly proportional to the change in throttle position. To calibrate the TPI, a measurement was taken at 0%, another at 100%, and a y=ax+b equation was fitted. The calibration curve is shown in the following figure.



MAP - Manifold Air Pressure

The Manifold Air Pressure sensor was installed by HCI as an integral part of the engine control system. The sensor is an absolute pressure transducer manufactured by Buzmatics, Inc. with a range of 0-50 psia. The output signal is conditioned by on-board electronics and is directly proportional to pressure.

VREG - Hydrogen Pressure Command Signal

VREG is a control signal generated by the HCI control unit. It commands the pressure regulator to produce a given hydrogen pressure output, which then flows to the inlet of the CVI.

NOx - Measured Oxides of Nitrogen

NO_x was measured using an instrument that measures the chemiluminescent reaction of nitric oxide and ozone. NO_2 is converted to NO by thermal conversion of nitrogen dioxide to nitric oxide giving a total NO_x measurement. The unit is a Model 10AR, Chemiluminescent NO/NO_x Analyzer, made by Thremo-Electron Corp. To calibrate the unit a standard gas with a known concentration of NO/NO_x was introduced into the sample port.

A stainless steel probe was inserted in the tail-pipe of the test vehicle on the dynamometer to withdraw the sample through a heated line and moisture remover from Universal Analyzers. The resulting gas stream passed through teflon tubing to the thermal converter and then into the NO_x analyzer.

RPM - Engine Rotational Speed

Test Runs were made by selecting a predetermined Engine RPM. The test driver manually controlled throttle position (using the gas pedal) and dynamometer load (using a hand-held control pendant). Feedback to the driver was supplied by a Mallory Tachometer installed on the dash.

Phi - Equivalence Ratio

In addition to the phi value provided by the EGO sensor, a calculated phi (PHI) was produced using inputs from the fuel flow sensor and the mass air flow sensor. Phi was calculated by

$$\varphi = 34.33/afr$$

where afr is the ratio of the mass flow rate of air divided by the mass flow rate of fuel. In the case of hydrogen as the fuel, the air/fuel ratio is equal to 34.33 for a stoichiometric mixture.

Temperatures

Type K thermocouples were used for all temperature measurements. Voltages were recorded directly by the acquisition system and processed through NIST temperature tables. Cold-junction compensation was provided by the multiplexer input circuit (see Data Acquisition System).

Pressures

Fuel Inlet pressure and Fuel Tank Pressure were both measured using Silicon-on-Sapphire absolute pressure transducers from Bourns Instruments, Inc. The transducers output signal is linearly proportional to absolute pressure.

instrument. As this was expected to be troublesome, another hydrogen mass flowmeter, manufactured by Porter, was borrowed from HCI (Frank Lynch). This unit, unfortunately, was damaged in shipping and was later found to have a flow indication at variance with the MicroMotion meter. Further, its full scale flow limit was only 500 slpm, a third of what was needed for these measurements.

The Micromotion instrument interfaces to an electronic unit which can be set for a 0 to full scale range less than the full capability of the mass-flowmeter. With the aid of Micromotion staff, the instrument was set for a full scale mass flow of 0.80 lb/min.

The Micromotion instrument output is a 4-20 milliamp current, which passes through a 500 ohm resistor to convert the signal to a voltage. The signal has a notable noise level.

For most of the measurements, the Micromotion and the Porter were both used, being plumbed in series. The two instruments never agreed, and hence were both sent out for calibration. As the calibration result did not explain the discrepancy, we performed two calibration experiments with hydrogen as the flow gas at CE-CERT.

1) The small UCR1 hydrogen storage tank, reportedly of 1.6 cubic foot internal volume, was passed through a limiting valve and then to both the Micromotion and Porter instruments. The pressure and temperature of the tank were recorded, as were the measured flow rates.

2) A standard calibration orifice of 0.065 inch diameter was used as a flow standard, with the orifice downstream of the mass-flowmeters. In this case the flows were measured at mass-flowmeter pressures varying from 30 to over 100 psi.

The results from these two tests were generally consistent, with the conclusion that the Micromotion - although noisy - appears to be most accurate, generally indicating a flowrate from 0 to 15% higher than the true flow. The Porter consistently indicates a flow below the true flow. To correct the Porter measurements (approximately) multiply the indicated flow by 1.5.

All sensor output signals were routed first to their respective signal conditioning devices, where necessary, and then into the Data Acquisition System.

Acknowledgements

Special thanks to James Pakko, Jerry Jesion and Donald Lawrence at Ford Motor Company, and to Craig Nutter and Eric Nutter at Bourns, Inc. for their help in providing instruments and information.

Appendix B - INTERIM TEST RESULTS AND SUMMARY

1) The test results are summarized below in tables 1, 2 and 3.

Table 1: CAN1 Results

RPM	1900	2400	2700	2900	3500	4000
H_2FM	.059	.077	.089	.094	.113	.136
HP	30	37	42	44	47	52
MAP	16.89	17.52	17.75	17.96	18.74	19.15
MAF	5.96	7.64	8.87	9.64	11.32	12.89
NOx	658	711	221	144	183	322
T-IN	148	163	171	170	193	217
T-OUT	83	81	82	81	83	85
T-EXH	868	913	929	934	1012	1070.
VEGO	.411	.401	.395	.394	.378	.394

Table 2: CAN2 Results

RPM	2000	2400	2900	3400	4000	4500	4900
H_2FM	.0719	.0883	.1158	.1519	.1537	.1770	.1930
HP	36	42	51	61	64	59	52
MAP	17.8	18.58	19.41	20.75	21.56	22.55	23.13
MAF	7.15	8.55	10.69	13.81	15.94	18.22	19.63
NOx	52	69	123	91	42	59	50
T-IN	151	173	194	193	209	230	240
T-OUT	77	80	85	94	95	104	86
T-EXH	887	914	1014	1065	1108	1199	1217
VEGO	.434	.429	.434	.427	.426	.419	.436

Table 3: CAN3 Results

RPM	2100	2400	2900	3400	3900	4400	5000
H_2FM	.0885	.1138	.1352	.1582	.1827	.2188	.2531
HP	19	25	31	37	43	49	53
MAP	15.92	16.94	17.89	18.57	19.09	19.80	20.11
MAF	5.45	6.68	8.15	9.71	11.63	13.72	15.5
NOx	13	12	14	21	29	11	33
T-IN	144	145	154	168	180	181	204
T-OUT	69	70	71	76	81	77	89
T-EXH	756	811	834	880	931	944	1018
VEGO	.33	.33	.32	.32	.32	.32	.31

H_2FM	Hydrogen flow in lb/min
HP	Horsepower - transferred from truck to dynamometer
MAP	Manifold air pressure in psi
MAF	Mass air flow in lb/min
NO_x	NO_x in ppm
P-IN	Hydrogen pressure at CVI inlet in psi
TPI	Throttle position indicator in % open
T-IN	Intercooler air inlet temperature in °F
T-OUT	Intercooler air outlet temperature in °F
T-EXH	Exhaust gas temperature°F
VEGO	Exhaust Gas Oxygen (EGO) sensor signal

2) Initial evaluation of three hydrogen-powered Ranger Trucks has been completed. Data collected, summarized above, was taken at wide open throttle on a twin ride water brake dynamometer.

3) There is considerable variability in the performance and operation of the three vehicles. Of particular concern is: (a) the difference in the form of variation of HP as a function of RPM; and (b) the large variation in NOx emissions. The reasons for these differences have yet to be identified although variability in fuel metering and air/fuel control strategy appear to be likely reasons. It is recommended that further emissions and engine parameter measurements be taken to further identify reasons for performance variability.

4) In an attempt to further understand the variability and overall unreliable performance of one of the vehicles in-cylinder pressure measurements were made during steady state operations of one of the vehicles (CAN1). Typical data and discussion are in Section III-A of the body of this interim report. Of note is the large variability in peak incylinder pressure, which indicates erratic behavior of the CVI control system. In cylinder pressure measurements are recommended for all three vehicles.

FINAL REPORT CONTRACT # C94049

XEROX-CAN! HYDROGEN FUELED LEAN BURN - SUPERCHARGED FORD RANGER PICKUP TRUCKS

FEBRUARY 29, 1995

SUBMITTED TO

CLEAN AIR NOW!

PREPARED BY

KAISER ENGINEERING

William J Kaiser

WILLIAM J. KAISER
OWNER

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1.0 SUMMARY AND CONCLUSIONS

This is the final report on the conversion of three 1993 and 1994 Ford Ranger pickup trucks to operate on hydrogen fuel. This project was completed as part of the XEROX-CAN! Solar Hydrogen vehicle Project. These vehicles are to be used by Xerox and the City of West Hollywood as part of their respective fleets,using the solar hydrogen production facility at Xerox, El Segundo, Ca. as their fueling facility. This project was sponsored by the U.S. Department of Energy, the South coast Air Quality Management District, and the Mobil Source Air Pollution Reduction Review Committee.

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 Constant Volume Injection (CVI) system for delivering timed and metered quantities of hydrogen to each cylinder. Fuel metering is controlled fluidically with trimming by an electronic pressure regulator using exhaust oxygen feedback.

The emissions control system consists of an electronically trimmed fuel injection system with exhaust oxygen feedback,a positive crankcase ventilation system and an oxidation catalyst.The lean burn engine is held in closed loop control with a constant fuel-air equivalence ratio of less than 0.45 where oxides of nitrogen are very low. There are no other significant pollution emissions with hydrogen fuel. All information disclosed in this report regarding this control system (Constant Volume Injector) is proprietary to Hydrogen Consultants Inc., Littleton Co.

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. and a weight of 242# each. Subsequently, fuel storage was provided by two EDO Canada carbon fiber, 3600 PSI tanks having an internal volume of 5.64 cu.ft. each, mounted in the bed of each truck. This tankage uses approximately 50% of available bed space and allows a range of about 144 miles at a total weight of 202#. These tanks reduce weight by 58% and increase range by 52%.

The use of an intercooled supercharger instead of a turbocharger and increasing engine displacement to 2.85 liters provides low speed performance at least as good as stock despite operating at less than 50% of the chemically correct fuel-air ratio. The compact, light weight EDO fuel tanks allow the vehicles to be used as practical and useful truck. If regulations are changed to permit storage of gaseous fuels on board vehicles at pressures in the range of 5500 to 7000 PSI,increases in range and payload will make such vehicles very attractive and practical low emission transportation modes.

2.0 RECOMMENDATIONS

In the course of building and testing the three Xerox-CAN! hydrogen fueled trucks, some basic limitations of the CVI fuel injection system and fuel storage system have come to light which could be improved at a future time .The first is a consequence of using Manifold Absolute Pressure (MAP) as the primary parameter for metering fuel to the engine.

When an occasional misfire into the intake manifold occurs, the system interprets the increase in MAP as a signal to increase fuel flow. The resulting rich mixture is, much more likely to cause another bigger backfire. Therefore, once misfiring starts,it is likely to continue until the throttle is closed for a few seconds. If a Mass Air Flow (MAF) sensor is substituted, a backfire results in a decrease in mass air flow, and the system responds by reducing fuel flow which will reduce the possibility of further misfires. Since drastically increased emissions of oxides of nitrogen occur during these momentary rich mixtures, total emissions will also be reduced somewhat.

A second area which could benefit from further study is the final fuel pressure regulator. This regulator sets the fuel pressure fed to the CVI on the basis of manifold absolute pressure and exhaust oxygen feedback. As a result it sees a rapidly changing set point. Additionally, the CVI by its nature, is a pulsating non-steady load. While no significant problems have developed to date, long term durability of these regulators is of concern and may require additional development.

Additionally, the most significant limitation on practicality of hydrogen fueled vehicles, other than fueling facilities, is the ability to store adequate fuel on board. While the use of the current EDO carbon fiber fuel tanks does provide significantly more range than electric vehicles, cargo space and range are still limited compared to gasoline fueled vehicles. Technology is currently available to allow the storage of compressed gases safely at up to 6000 PSI, and could be developed to allow storage at 10,000 PSI or more. Because of its impact on vehicle payload and range,we feel that this is an area of great importance from both a technological and a regulatory standpoint.

Development of an approved self-grounding quick-disconnect fueling nozzle is also an important area for study. The current industry standard nozzle is manually connected to the vehicle by a threaded fastener which requires hand tightening. Additionally, a separate electrical grounding system is needed. While this system is adequate for trained operators, a simple-to-operate automatic system is needed to insure safety and acceptance by the public.

3.0 SCOPE AND PURPOSE

This task was undertaken as part of a technology demonstration project. This project is to show the feasibility of producing hydrogen gas from Solar energy and operating a fleet of gasoline fueled vehicles which have been converted to use hydrogen as fuel. The vehicles chosen for the demonstration were 1993 and 1994 Ford Ranger pickup trucks with 2.3 liter 4 cylinder engines and manual transmissions. The trucks are to be used as part of a fleet of maintenance and general use vehicles at Xerox Corp., El Segundo, Ca. and by the City of West Hollywood.

The goal of the vehicle conversion task assigned to Kaiser Engineering (formerly Advanced Machining Dynamics), Highland, Ca. was to produce a set of three trucks capable of operating on hydrogen gas produced from Solar energy at the Xerox, El Segundo facility. The trucks were to have a range of at least 65 miles when fueled to 3600PSI and to perform as near to stock production levels as possible. Modifications to enhance fuel tank crash protection, gas leak detection, and fire protection were also incorporated into the conversions. Engine and vehicle road testing to prove driveability and basic performance were to be accomplished. Detailed chassis dynamometer testing and emissions testing were to be done by University of California Riverside, College of Engineering Center for Environmental Research and Technology (CE-CERT). results of that task will by reported by CE-CERT in a separate document.

4.0 ENGINE MODIFICATIONS

Basic specifications of the 1993-1994 Ford 2.3 liter engine are as follows:

2.3 liter (140 cu.in.) displacement
4 cylinders
Naturally aspirated
Dual spark plug CD ignition
Multi-port electronic fuel injection
Exhaust oxygen sensor
Exhaust gas recycling
Three-way catalyst

Modification of the engines for Hydrogen operation begin with the installation of a new crankshaft and new pistons which change the bore and stroke to increase displacement to 2.85 liters. Pistons and bearings were fitted to minimum clearances to minimize oil contamination of the combustion process. A "gap-less second compression ring was used on each piston to minimize hydrogen "blowby" into the crankcase and to further reduce oil consumption. A high volume oil pump was installed to provide additional oil flow to lubricate the roots type supercharger.

Cylinder head modifications include intake and exhaust port changes to increase airflow capacity by 35 %. Since the fuel volume now accounts for 20 to 30% of the total volume flow, this is necessary to offset the air volume displaced in the intake system by gaseous hydrogen fuel. Stock inlet and exhaust valves were retained to maximize port velocities and minimize back-flow of hydrogen into the intake manifold during fuel injection. Combustion chambers were contoured and polished to improve air flow and reduce the possibility of pre-ignition due to hot spots. Minor changes to water flow passages were done to reduce local temperatures near the exhaust valves and the water thermostat was replaced by an outlet restrictor to provide increased water pressure in the engine and allow lower operating temperatures.

An Engine Electronics Compu-fire ignition system was installed into a Volkswagen distributer, modified to fit the Ford engine. This system allows a fixed spark timing to be set to any desired value. The compu-fire system produces a 100 mili-joule spark with a 40 kilovolt open circuit voltage. Triggering is by hall cell pickups with spark energy provided by two dual coils(waste spark technique).

Compression ratio was increased from 8.5 to 1 to 11.0 to 1 by increasing cylinder displacement while maintaining stock combustion chamber volumes. The increased compression is desirable since it increases basic thermal efficiency and improves power, particularly at low speeds. Increased oxides of nitrogen production were of concern; however, subsequent testing at CE-CERT indicated that this was not a problem.

a 70 cu. in. positive displacement roots supercharger manufactured by Fageol Superchargers of El Cajon, Ca. was fitted to each engine. The supercharger was used to help regain the power lost by deleting over half of the chemically correct fuel. Originally, the manifold pressure boost was intended to be set at 7.0 PSI above atmospheric, but due to rotational speed and flow limitations of the supercharger 4.0 PSI was all that was practical.

The engine crankcase ventilation system was modified to reduce oil "pull-over" into the intake system. Changes were also made to insure the removal of all water vapor. water vapor in the crankcase is the result of combustion products (water) leaking past piston rings into the crankcase. With hydrogen, this is a much bigger problem than with gasoline. The crankcase ventilation system also incorporates a large pressure relief valve in the cam cover. This is to insure no damage occurs if hydrogen were to leak into the crankcase and be ignited on engine start.

Horsepower produced by the modified engine is compared to the production gasoline fueled engine in Figure 1. This data was collected on the CE-CERT chassis dynamometer using a stock 1993 Ford Ranger pickup and the City of West Hollywood hydrogen fueled Ford Ranger. the hydrogen fueled truck was operated at 45% of the chemically correct fuel-air ratio. As shown in Figure 1, the low speed power is quite close to that of the gasoline vehicle, but the high speed power falls off faster in the hydrogen fueled vehicle. This is primarily due to the limited air capacity of the supercharger used.

5.0 CHASSIS MODIFICATIONS

To accommodate the modified engine, hydrogen fuel system, and"CVI" fuel injection 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 stock single row radiator was replaced with a two-row Modine radiator, located 1.5" aft of the original location. Engine intake air is 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 approximately 53#,to offset some of the weight of the new system.Hydrogen tanks,transversely mounted at the front of the truck bed, are protected by side impact structures. The first truck was fitted with aluminum/fiberglass tanks 19.4" in dia. and 38" long made by Comdyne Mfg., at the request of Praxair, one of the project team members. These tanks were protected by a tubular steel structure around the valve end of the tanks. Subsequent trucks were fitted with EDO Canada carbon fiber tanks of 18.5" dia. and 46.5" in length.

The EDO tanks provide an increase in fuel capacity of about 52% but require extensive bed modification. To accommodate the long tanks, it was necessary to truncate the rear wheel houses 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 is a reduction in weight of 280 lbs.,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 are also protected by these covers.

To insure safe conditions for refueling of the vehicles, an industry standard CGA350 refueling port is located behind the original fuel filler door in the bed side. A positive electrical grounding receptacle is located below and forward of the refueling door. The grounding cables at the Xerox refueling facility are equipped with a probe which mates to the grounding receptacle and when turned in the receptacle, will unlock the refueling door. This interlock is designed to prevent attaching or disconnecting a refueling hose to the truck without proper system grounding.

This refueling port and grounding interlock system was designed to meet the requirements set by Praxair Corp. for safety in the test fleet environment. For safe and easy use by the untrained public, a self grounding "Quick-disconnect" type of fueling system is needed. Such systems are now under study at the University of California, Riverside Center for Environmental research and Testing.

Additional safety equipment installed in each truck include Hydrogen leak detectors, hood vents to prevent leaked hydrogen from building up under the hood, and vent stacks on the fuel tank thermal pressure relief valves. The leak detectors were manufactured by CCI Controls of Southgate, Ca.. They provide a green "system on" light and an audible leak warning horn under the vehicle dashboard.

In the event of a fuel tank overpressure condition, built-in relief valves vent the excess pressure overboard. This hydrogen is vented into the vent stacks which carry it to a point above the cab roof and release it vertically. In this way, the possibility of a jet of burning fuel being directed toward personnel is eliminated.

6.0 CONSTANT VOLUME INJECTION

Hydrogen Consultants Inc. of Littleton Co. began development of the "CVI" system in 1980. This system was developed to meet the special needs of engines using hydrogen as a fuel. Due to the wide flammability limits of hydrogen, fuel-air mixing in the intake manifolding cannot be allowed. Therefore. the fuel must be injected into the engine as close to the intake valves as possible. Due to the very low density of gaseous hydrogen, electrically actuated valves with adequate flow capacity, speed, and reliability are not currently available. For this reason, the "CVI" system was developed using mechanical poppet valves and fixed volume metering chambers to meter the basic fuel charge to each cylinder, each cycle. Electronics are used only to "trim" fuel feed pressure to the "CVI" based on feedback from an exhaust gas oxygen sensor and a closed loop control circuit.

The Electronic Control Module (ECM) provides the necessary feedback signal from the exhaust oxygen sensor to the Electronic Pressure Ratio Regulator to trim the fuel pressure fed to the "CVI". The ECM also provides a startup and a shutdown sequence designed to minimize the possibility of hydrogen build-up in the engine before starting or after stopping. A schematic diagram of the complete Engine and Fuel System is shown in Figure 2.

A complete discussion of "CVI" operating principles,installation parameters, and maintenance procedures is given in APPENDIX A of this report. Schematics and block diagrams detailing principles of operation and functional relationships of the system are also presented. This information is proprietary to Hydrogen Consultants Inc., Littleton Co..

7.0 VEHICLE TESTING

Upon completion of Xerox vehicle #1, it was taken to Hydrogen Consultants Inc. plant in Littleton Co. to conduct a series of road and chassis dynamometer tests. The purpose of these tests was to fine tune the Constant Volume Injection System parameters and to subjectively evaluate vehicle road performance. No emissions tests were performed at that time.

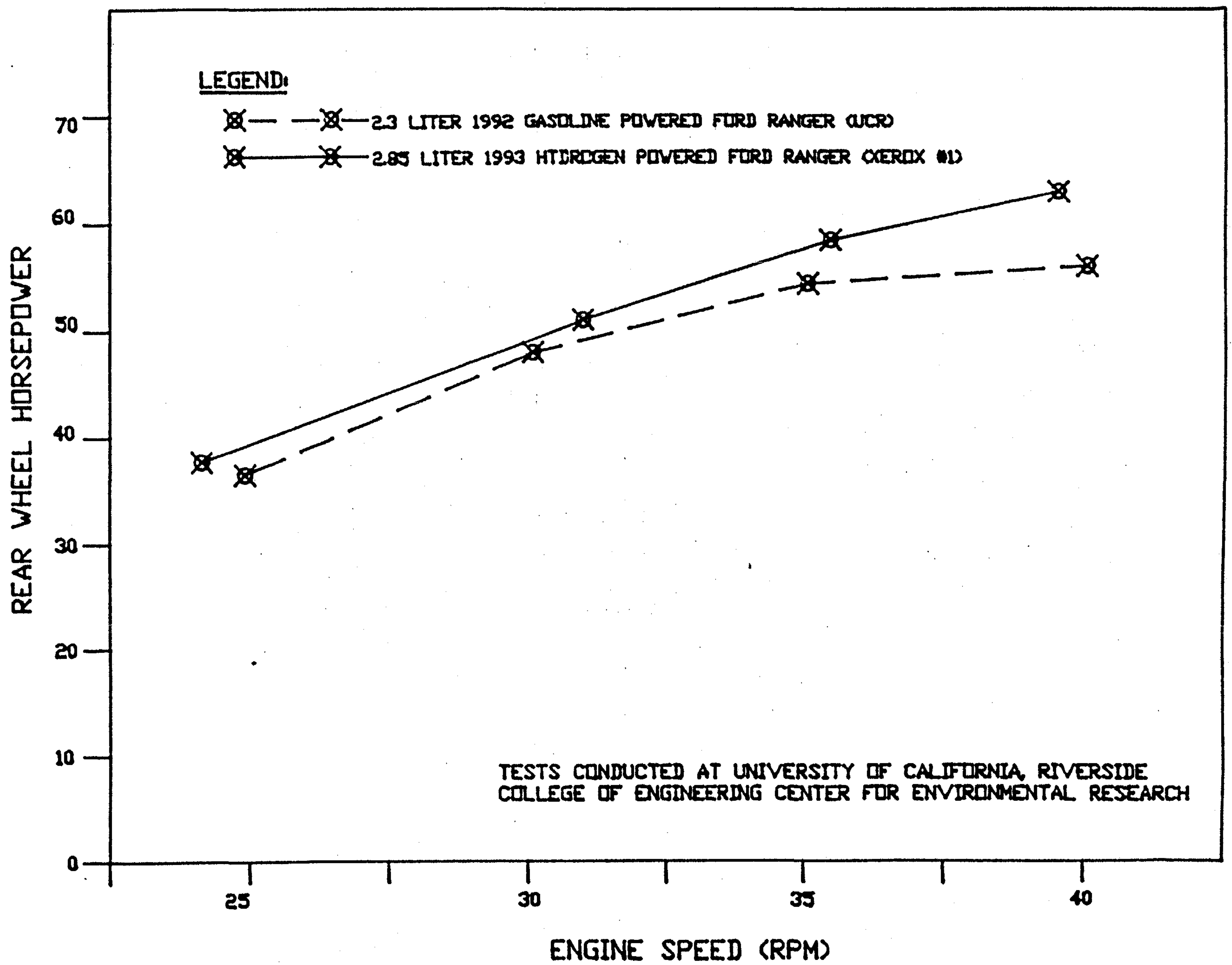
Dynamometer tests showed that acceptable engine operation could be achieved over the required engine speed range of idle to 5000 revolutions per minute (RPM). Power output was consistent with the data taken later at CE-CERT. During these tests, control system parameters were varied to determine optimum settings for this and subsequent vehicles. Procedures for tuning the system after installation were also established in these tests.

Once control system tests were completed, subjective road tests were conducted on the streets of Littleton, Co.. Typical city streets in hilly terrain with normal traffic were used. Acceleration away from stop lights and passing performance was found to be quite close to what is expected from small gasoline fueled vehicles. Cruising speeds from 30 to 50 miles per hour could be maintained, even on moderately steep hills, without difficulty. A total of 87 miles were driven during these tests and calculations indicated an average fuel mileage of 22 to 23 miles per gallon (gasoline equivalent).

It should be noted that this testing was done at an elevation of approximately 5000 Ft.. Sea level and lower altitude performance is significantly better.

Road testing of each subsequent vehicle was conducted on surface streets and freeways in the San Bernardino and Riverside, Ca. areas. Results of these tests were essentially the same as for Xerox #1 vehicle.

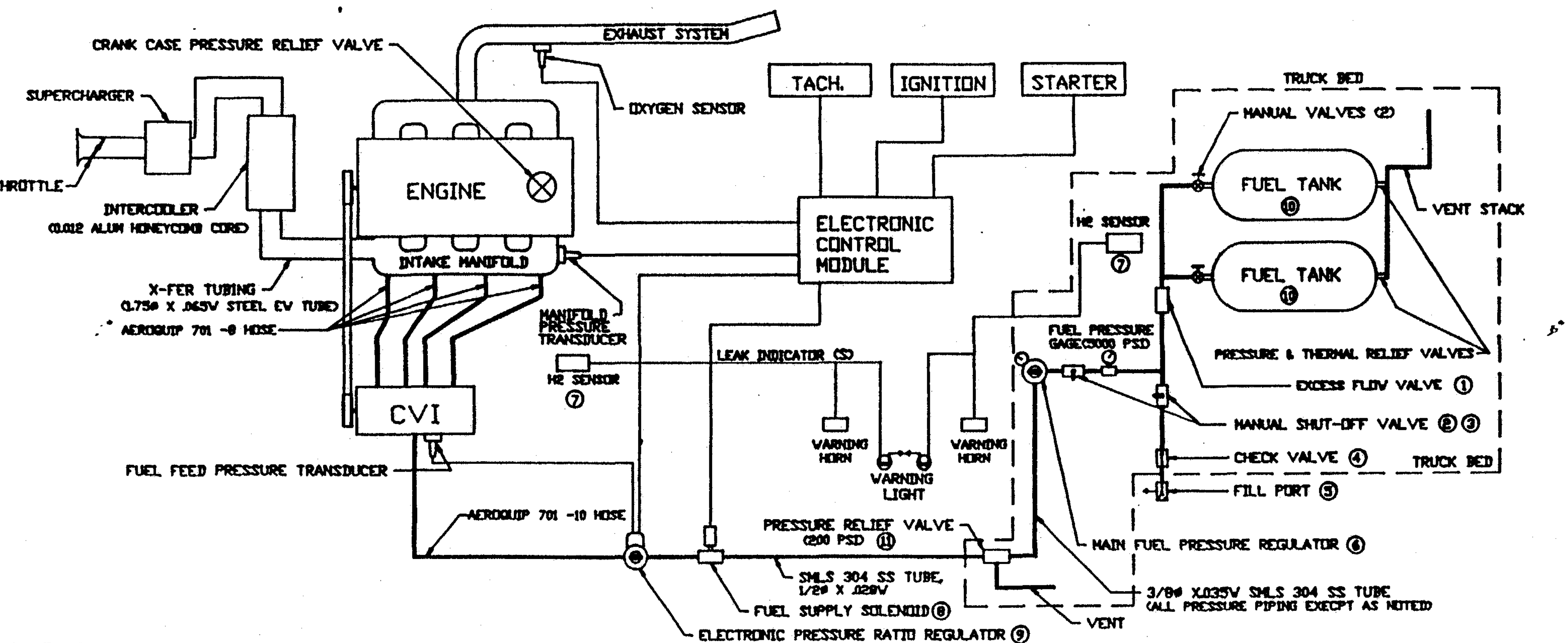
Prior to delivery, each vehicle was sent to CE-CERT for extensive chassis dynamometer testing. The primary emphasis of this testing was to quantify exhaust emissions, but engine power output and fuel consumption were also measured. The results are to be published by CE-CERT and furnished to Clean Air Now as part of the project final report.



CHASSIS DYNAMOMETER LOAD TESTS

ENGINE HORSEPOWER COMPARISON

FIGURE 1



NOTES:

E.C.M. SEQUENCING
START-UP:
1. IGN. SV. ---- ON
2. ENGINE CRANKING .5 SEC.9approx)
3. IGN. SYS.---- ON (CRANKING)
4. FUEL ---- ON TILL START

E.C.M. SEQUENCING
SHUT-DOWN
1. IGN. SV. ---- OFF
2. FUEL ---- OFF
3. ENGINE SPEED < 100 RPM
4. IGN. SYSTEM ---- OFF

COMPONENT SPEC.

1 CHEM-TECH EFV-250(B494) (ZERO FLOW IN CLOSED POS.)
2 NUPRO B-4P4T4
3 WHITEY SS83KS6
4 NUPRO SSDCHS6-1 DOUBLE CHECK
5 STANDARD CGA-350 CONNECTOR
6 TESCOM 20-1032-2915 REGULATOR (125PSI MAX.OUT)
7 CCI CONTROLS 7907 H2 DETECTOR
8 ADVANCED FUEL COMPONENTS MODEL 121 SOLENOID VALVE
9 NORGREN 11-008-130 REGULATOR (400 PSI MAX. IN)
BUZMATIC SPC1R-0E5-0A100-S12 DOME LOADER
10 EDO LITERIDER MODEL 165 TANK (5.64 CU. FT. VOL.)
POLYETHYLENE/CARBON FIBER,3600PSI RATED (NGV-2)
11 200 PSI RELIEF VALVE (APPROX.0.25SQ IN FLOW AREA)

FIGURE 2

H2FSYS2

TOLERANCES: .XX ± .010 .XXX ± .005 FRACT. ± 1/64 ANGLE ± .5 EXCEPT AS NOTED	ADVANCED MACHINING DYNAMICS	
	TITLE FUEL SYSTEM SCHEMATIC	
REV.	DRAWN W.J.K.	DATE 4-29-95
FIN:	APPROVED:	DATE
HEAT TREAT:	MATERIAL SPEC:	
DWG. NUMBER H2FSYS	APPLICATION: XEROX-CANI H2 FUELED FORD RANGER	

VOLUME PRODUCTION COST ESTIMATES

Current costs for production of <u>converted</u> 4 cylinder pickup trucks on a 1 to 10 unit basis is in the $50,000 range. This is due to the number of custom made components required and the limited volume of commercial components to be purchased. As the number of vehicles per order is increased, costs can be decreased due to wholesale purchasing of materials and components. Production jigging and fixturing for what are now hand made components will also reduce costs drastically. Labor costs can be reduced as well,since highly skilled fabricators can be largely replaced by specialized operators.

The size of such cost reductions are dependent on the actual numbers of vehicles of a given type produced in a given period of time. Each new type of vehicle will require a period of development, with attendent higher costs, before low cost production is achieved. It should be noted that, at best, Converted vehicles will always have a net cost higher than vehicles originally produced for hydrogen fuel. However, conversions are the most economical way to develope the market and the infrastructure for hydrogen fueled vehicles.

Based on the best current experience, the following table shows the cost per unit as production numbers of hydrogen fueled vehicles increase. Predictions become less and less precise as the production numbers increase; however, the data are based on historically typical trends.

NUMBER OF VEHICLES	UNIT COST (DOLLARS)
LESS THAN 25	$50,000
25 TO 100	$35,000 TO $42,000
LESS THAN 1000	$21,000 TO $27,000
LESS THAN 10,000	$ 9,000 TO $16,000
MORE THAN 10,000	$ 4,000 TO $ 7,000

A reasonable estimate of production costs indicate that hydrogen fueled vehicles could be produced at least as cheaply as gasoline fueled vehicles in similar quantitys. Savings in emission control systems should completely offset the higher cost of fuel storage equipment, and basic engine costs should be roughly the same.

SUB CONTRACT # C94094

XEROX-CAN! HYDROGEN FUELED
LEAN BURN - SUPERCHARGED
FORD RANGER PICKUP TRUCKS

FEBRUARY 21, 1996

OPERATING AND MAINTENANCE PROCEDURES

SUBMITTED TO

CLEAN AIR NOW!

PREPARED BY

KAISER ENGINEERING

____

WILLIAM J. KAISER
OWNER

KAISER ENGINEERING

7935 LANKERSHIM AVE.
HIGHLAND, CA. 92346

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XEROX-CAN! AND WEST HOLLYWOOD

JANUARY 30, 1996

HYDROGEN FUELED FORD RANGER OPERATING PROCEDURES

REFUELING PROCEDURE

1. Position vehicle at fueling station so that fueling hose will reach vehicle fill valve easily.
2. Open green handled fuel fill valve to the FILL position, and close the black handled system feed valve to the FILL position.
3. Connect fueling hose grounding cable at vehicle grounding point
   and rotate clockwise 1/4 turn to release fuel door.
4. With fuel door open, remove dust shield from fueling fitting and connect fueling hose securely.
5. Be sure that BOTH FUEL TANK VALVES are fully open.(Max. counter-clockwise position)
6. Following fueling station procedures, fill tanks to desired pressure. DO NOT EXCEED 3600PSI FOR ANY REASON!!
7. When refueling is complete, slowly remove fueling hose and re-place fuel fitting dust shield.
8. While holding fuel door closed, rotate ground cable counter-clockwise 1/4 turn and remove from vehicle.
9. Return both the green handled fuel fill valve and the black handled system feed valve to the run position. (black "on", green "off")

PRE-START INSPECTION

1. Check fuel pressure gauge, at tanks, for adequate fuel.(Empty fuel pressure is 200 psi, full is 3600 psi)
2. Be sure that all fuel tank valves are fully open.(max counter-clockwise position)
3. Check tanks for obvious mechanical damage, loose or damaged lines and fittings, and secure mounting.
4. Check leak detectors for operating condition (green lights "on").
5. Check under hood for loose or damaged fuel system components,belts and hoses.
6. Check oil and coolant for proper levels.
7. Generally check vehicle for damage or unsafe conditions.

STARTING PROCEDURE

1. Set parking brake and shift transmission to neutral.
2. Depress clutch pedal, open throttle slightly, and turn ignition switch to START position until engine fires.
3. When engine starts, adjust throttle to obtain a fast idle for at least 15 seconds. This will avoid fouling of spark plugs due to water condensation in the cold engine. This step is un-necessary if the engine is fully warmed up.
4. Drive vehicle normally, as required.

SHUTDOWN PROCEDURE

1. With the engine idling, turn ignition switch to OFF position.
2. At the end of the day, turn the fuel tank valves located in the bed of the truck to the OFF (fully clockwise) position and close the fuel system feed valve.

CAUTIONS AND WARNINGS

1. Fuel tank valves should be closed whenever the truck will be unused for longer than 4 hours.
2. Always check the fuel leak detectors when the truck is put into service.
3. Never start a trip with less than 1000psi in the tanks.
4. If the fuel leak detector warning horn sounds: STOP the truck, switch off the ignition, and close the fuel tank shut-off valves. Have the fuel system checked and repaired before re-starting.
5. When starting the engine from cold,if the engine dies and will not restart;the spark plugs may be water fouled. If this occurs, it may be necessary to remove the plugs and dry them.
6. If the engine fails to start after a reasonable period of cranking, WAIT 25 TO 30 SECONDS before re-trying. This will insure against a buildup of hydrogen in the exhaust system, resulting in a large backfire upon engine start.
7. NEVER attempt to fuel the vehicle without proper grounding to the fueling station system.
8. If while driving, a loss of power accompanied by a pinging sound is encountered, lift the throttle for a few seconds then reapply power slowly. this will usually restore normal operation.

NORMAL DRIVING TECHNIQUES

1. General operating characteristics of these vehicles are quite similar to standard gasoline fueled vehicles. The following are a tips to make driving these vehicles more enjoyable.
2. Try to use the throttle as smoothly as possible.
3. Shift the transmission in a leisurely manner. (NO SPEED SHIFTING)
4. Co-ordinate throttle, clutch, and transmission to give smooth shifts.
5. Do NOT lug the engine. Keep engine speed comfortably high by downshifting whenever necessary.

GENERAL MAINTENANCE INFORMATION

1. Lubrication and basic vehicle maintenance requirements are the same as with a standard Ford Ranger.
2. The electronic ignition system needs no maintenance other than occasional timing checks.
3. spark plugs should be replaced at 25,000 mile intervals.
4. Due to the constant power demand of the hydrogen leak detectors,the battery should be disconnected if the vehicle is to be inoperative for more than 36 hours. A larger capacity battery can extend this time.
5. The constant volume injector drive belt tension must be checked regularly. Every 6 weeks check that no more than 5/8" belt deflection exists at the drive belt midpoint. adjust as required.
6. In the event of a broken CVI drive belt it is necessary to re-establish proper timing with the following procedure:

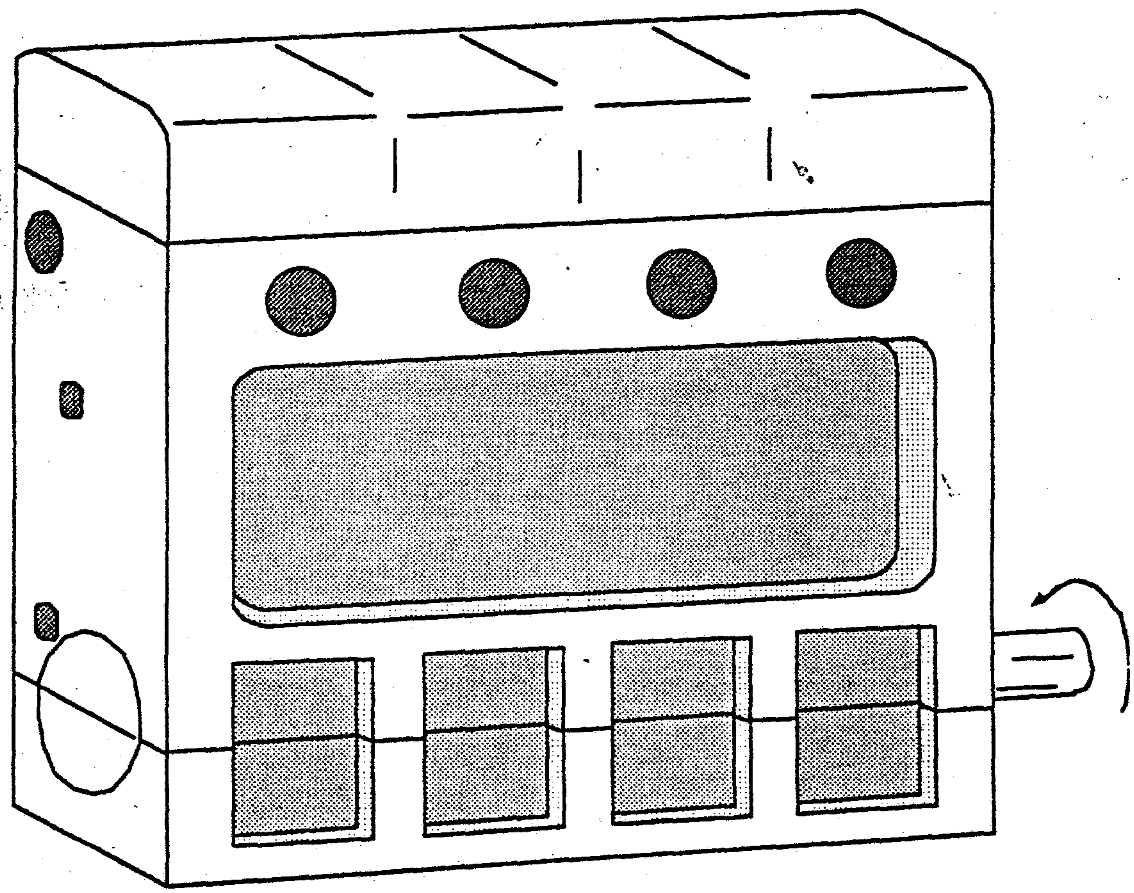
    1. Rotate the engine to 90 degrees past top dead center, #1 cylinder, on the <u>INTAKE STROKE.</u>
    2. Rotate the CVI shaft until the keyway is pointing toward the top of the CVI, (vertical relative to the CVI unit)
    3. Install and tension the drive belt as as above.

7. If fuel system components or lines require removal,re-installation must follow Swageloc specifications for all fittings. A leak detector should be used to verify integrity of all joints before returning the vehicle to service.
8. For more information on maintenance of the CVI system, please see Appendix A, "CONSTANT VOLUME GASEOUS FUEL INJECTION SYSTEM INSTALLATION & MAINTENANCE MANUAL".
9. <u>CHANGE NOTICE:</u> The lubrication instructions on page 13 of Appendix A should be changed to read "add ATF to the level of the split line of the crankcase." <u>not</u> to the bottom of the oil check hole.
10. The Roots type supercharger used on these vehicles needs no special servicing. Lubrication is provided from the engine oil system.

APPENDIX A

C V I-4

CONSTANT VOLUME GASEOUS FUEL INJECTION SYSTEM



INSTALLATION & MAINTENANCE MANUAL V1/95

HYDROGEN CONSULTANTS, INC., 12420 N. DUMONT WAY, LITTLETON, CO 80125 (303) 791-7972

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LIST OF FIGURES

INTRODUCTION

This manual describes the theory of operation, installation and maintenance of a CVI (Constant Volume Injection) gaseous fuel control system. To use this manual, you must be thoroughly familiar with the engine on which CVI will be installed. You must have the knowledge, skills and equipment needed to accomplish the following tasks;

A) fabricate a sturdy mounting plate (for timing belt drive) or flange (for gear drive)

B) fabricate/adapt a timing belt or gear drive linkage to the engine

C) modify the engine's intake manifold or cylinder head to accommodate CVI's injection tubes

D) safely install and leak check high pressure tubing and gaseous fuel components per National Fire Protection Association Code 52

E) install the wiring harness supplied with CVI, according to professional automotive wiring standards

F) properly install a wide range oxygen sensor in the exhaust system

G) alter the spark timing of the engine's ignition system.

If you lack the knowledge, skills or equipment needed to carry out these tasks in a safe, neat, workmanlike manner, contact HCI for a list of qualified installers.

CONSTANT VOLUME INJECTION (U.S. Patent No.

The fundamental principle of operation of a constant volume fuel injection system is the ideal gas pressure-volume-temperature relationship:

$$PV = nRT,$$

where;

P is the absolute pressure
V is the volume
n is the number of moles of gas
R is the universal gas constant
T is the absolute temperature.

A constant volume injection (CVI) system consists of chambers that are charged and discharged by poppet valves in phase with the operating cycle of an internal combustion engine. CVI is a form of sequential multi-port fuel injection. Figures 1A, B and C illustrate the CVI process for a 1-cylinder gaseous fueled engine. Multi-cylinder CVI systems have a chamber and a set of valves to serve each engine cylinder.

Figure 1A.
CVI Charging Process

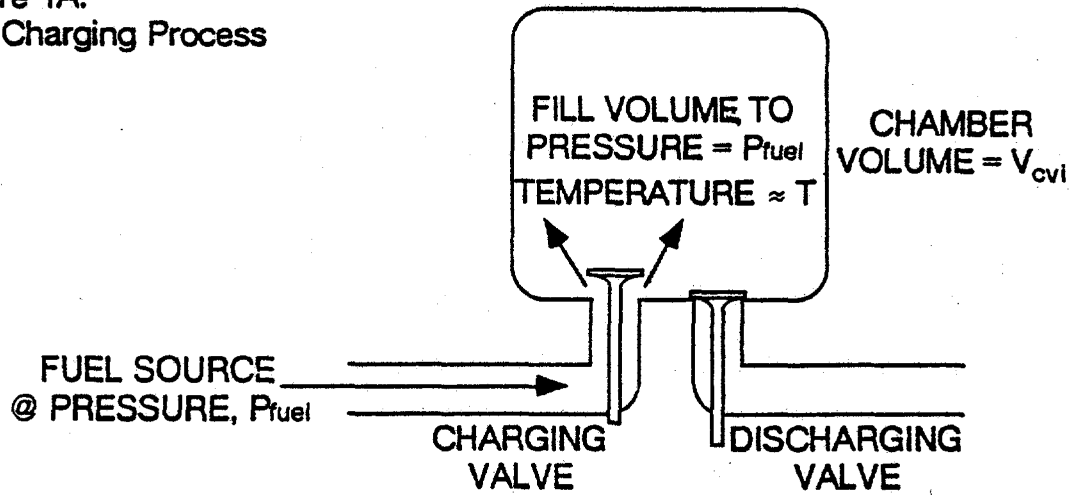


Figure 1B.
CVI Storage Process

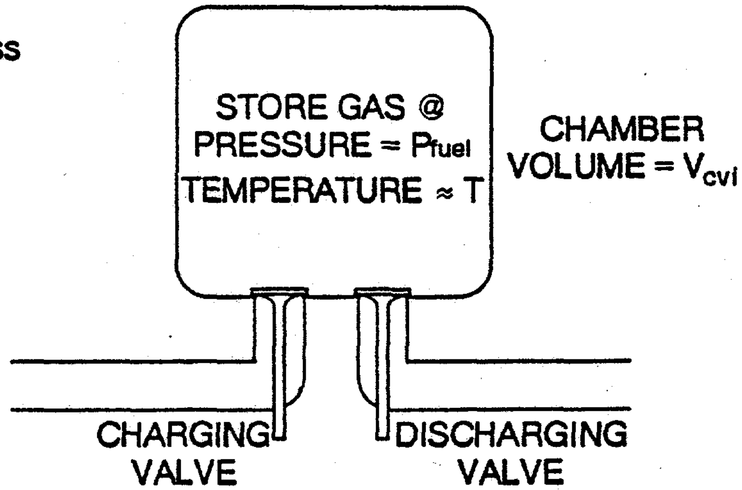
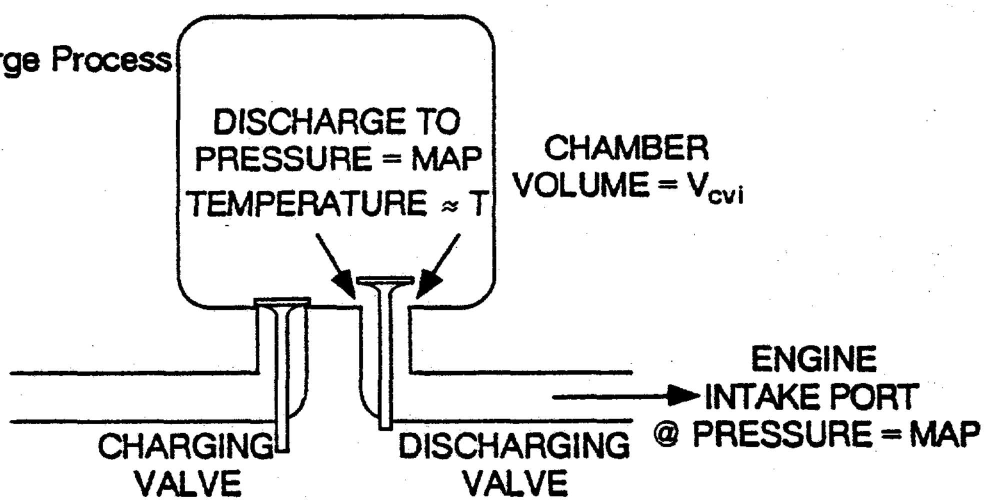


Figure 1C.
CVI Discharge Process



In Figure 1A, a chamber with fixed volume, V_{cvi}, is pressurized to P_{fuel} at approximately constant temperature, T[1]. In Figure 1B, the charging valve is closed and the chamber stores a measured charge of fuel gas quantified by the pressure and temperature of the gas, and by the volume of the chamber;

$$n_i = (V_{cvi}/RT)\, P_{fuel}.$$

In Figure 1C, the discharge valve opens and releases the stored fuel gas through a tube and into the intake port of an engine. The discharge valve opens in phase with the intake stroke so that fuel and air flow into the engine cylinder together. At the end of an injection event, the pressure in the CVI chamber is equal to the manifold air pressure (MAP). The quantity of residual fuel gas in the chamber is,

$$n_f = (V_{cvi}/RT)\, MAP.$$

The difference between the fuel gas inventory in the chamber before and after the injection event is the amount that is delivered to the intake port[2],

(I) $$\Delta n_{fuel} = n_i - n_f = (V_{cvi}/RT)\,(P_{fuel} - MAP).$$

By maintaining a fixed ratio between P_{fuel} and MAP, i.e.,

$$P_{fuel} = k\, MAP,$$

equation (I) may be rewritten as,

$$\Delta n_{fuel} = (V/RT)\,(k\, MAP - MAP)$$

and rearranged as,

(II) $$\Delta n_{fuel} = (V/RT)\,(k - 1)\, MAP.$$

The air/fuel charge in an engine cylinder may also be characterized, to a first order approximation, by pressure, temperature and volume, as illustrated in Figure 2.

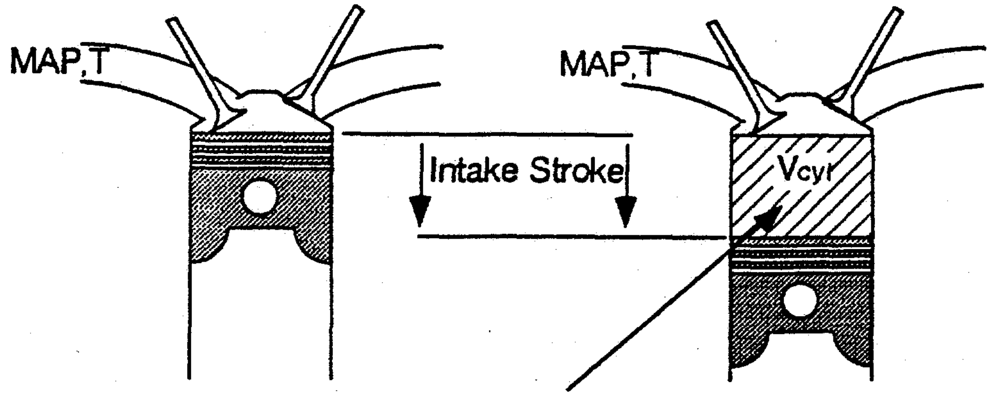
(III)

$$\Delta n_{charge} \approx \frac{MAP \cdot V_{cyl}}{RT}$$

---

[1] Temperature variations will be discussed subsequently.

[2] The amount of gas in the injection line between the CVI and each engine cylinder is constant at any fixed operating condition. Small changes during transients are second order effects, discussed below.



$$\Delta n_{charge} \approx \frac{MAP \cdot V_{cyl}}{RT}$$

Figure 2. The number of moles air/fuel charge drawn into an engine cylinder is approximately proportional to swept cylinder volume and manifold pressure, and inversely proportional to manifold air temperature.

The mole fraction of fuel in the mixture is, to a first order approximation, (II) ÷ (III):

(IV)

$$\frac{\Delta n_{fuel}}{\Delta n_{charge}} = \frac{(V_{cvi}/\cancel{RT})\,(k-1)\,\cancel{MAP}}{(V_{cyl}/\cancel{RT})\,\cancel{MAP}} = (k-1)\,\frac{V_{cvi}}{V_{cyl}}\,.$$

The first order operating principles of CVI show that a constant air/fuel ratio may be maintained by holding k (the ratio of fuel pressure to manifold air pressure) constant. This requires a pressure ratio regulator. A typical value of k in CVI systems is 2.5. Naturally aspirated engines operated near sea level have maximum MAP near 100 kPa (14 psia). This corresponds to a maximum CVI fuel supply pressure of 250 kPa (36 psia). In turbocharged engines, CVI fuel supply pressure ranges up to 700 kPa (100 psia).

The volume of the CVI chamber varies directly with engine cylinder volume and with the desired mole fraction of fuel gas in the intake mixture.

The simplified, first order considerations discussed above show that fuel and air flow in a CVI-equipped engine are directly related to pressures and volumes. Variations in air and fuel temperatures also affect flow. So do variations in the volumetric efficiencies of the engine and CVI. These effects are small, relative to the first order operating principles, yet significant.

To handle these real world variations, CVI's electronics adjust the value of k (equation IV) applied by an electronic fuel pressure regulator. Figure 3 is a sketch of a complete CVI control system. If k is 2.5, based on idealized calculations, the feedback electronics may revise it to, say, 2.4 or 2.6, as necessary to account for small errors in the first order assumptions. The full range of CVI's controller is $2 \le k \le 3$.

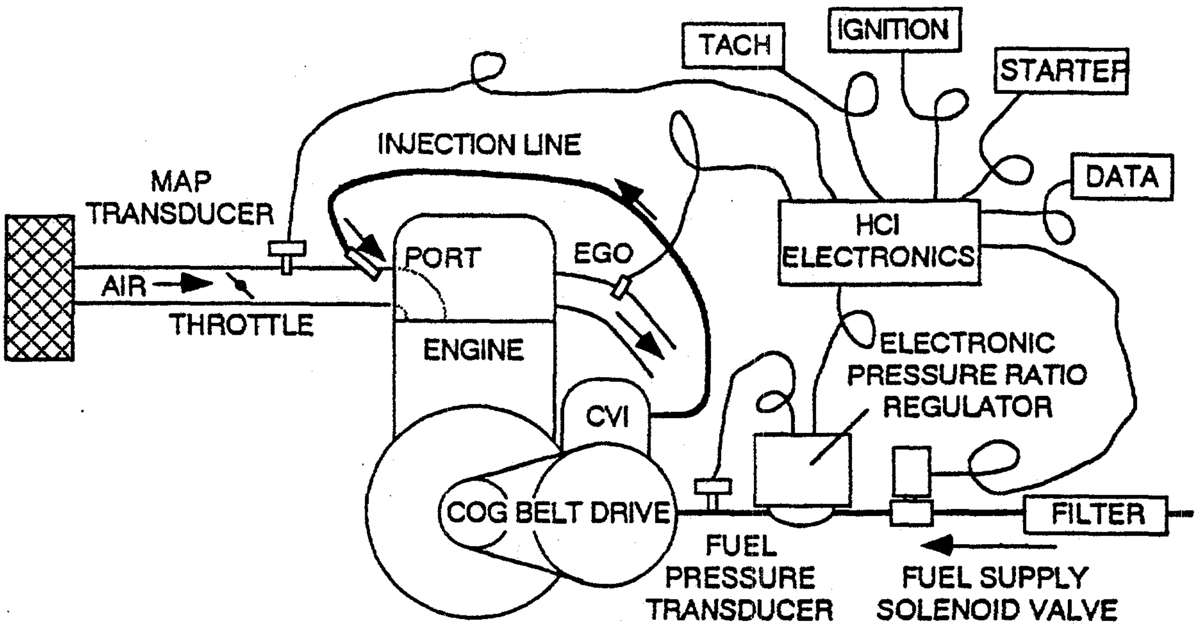


Figure 3. The CVI control system employs feedforward control, based on a "learned" value of fuel/air pressure ratio, k. k is continually revised by exhaust oxygen feedback. The electronics also switch the ignition and fuel solenoid valve during engine starting and stopping.

Revising k in this way is the analog equivalent to adaptive learning in digital controls. During a sudden transient to a new operating condition, the old value of k is CVI's first "guess" at feedforward control for the new condition. Since the old condition k was adjusted for ambient temperature, volumetric efficiency, etc., this "learned" information is carried forward. CVI-equipped engines do not stumble during transients because k is always close enough to assure a burnable air/fuel mixture. Further fine tuning of k occurs as quickly as the oxygen sensor and electronic pressure regulator can react to the small but inevitable feedforward errors.

MOUNTING

CVI must be mounted firmly to the engine block or front gear case to avoid vibration. Figure 4 is a generic mounting diagram. Mount the CVI so that its camshaft is parallel to the engine's crankshaft. The CVI must be within 30° of vertical. A flat mounting surface is necessary to avoid distortion of the CVI. CVI's bottom mounting flanges are aluminum. The support of hardened washers is necessary to prevent recession of the mounting bolts into the aluminum surface. The recommended mounting hardware is shown in Figure 4. Alternative bolt locations are permissible but at least two bolts are needed on each side (total of four). Mounting for timing belt driven CVIs must also include a stiff belt tensioning mechanism.

CVI must be mounted in a location that is shielded against direct heat radiation from the exhaust system. Use the shortest possible timing belt. The selected location should also be conducive to neat plumbing with a minimum of fittings and bends. Access to the oil fill, drain and level check holes is also required.

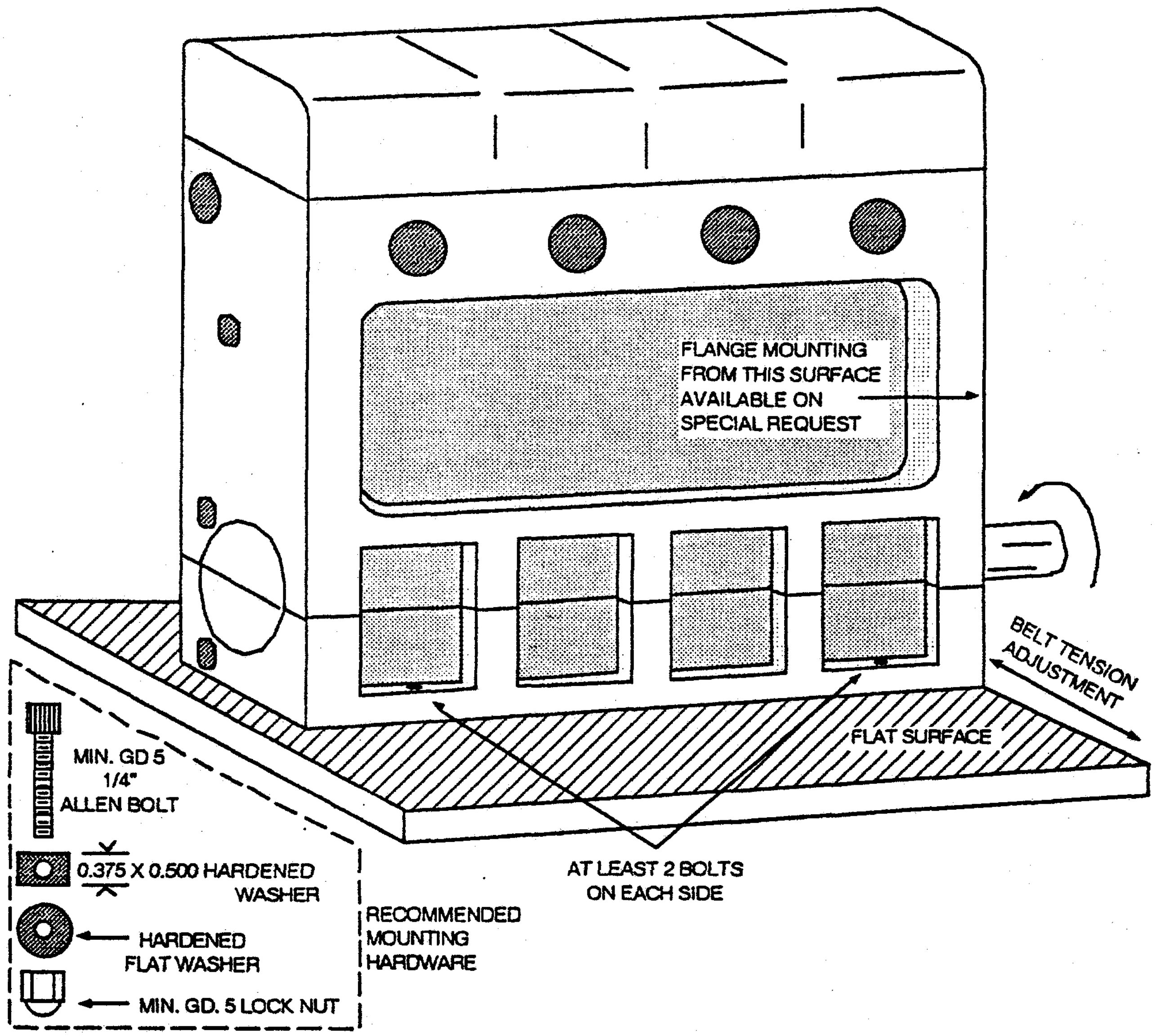


Figure 4. Generic mounting arrangement for a timing belt driven CVI. The brackets and tensioning mechanism (not shown) must be stiff enough to prevent vibration.

CVI may also be flange-mounted from the front in gear driven applications (e.g., diesel-derivative gas engines). HCI will provide front flanges to customer specifications.

TIMING BELT DRIVE

The installation and alignment of the belt must be according to manufacturer's guidlines (e.g., Gates Rubber Co.). HCI recommends the use of 2 flanged pulleys. It is good practice to keep pulley rim speeds below 6500 feet per minute. Use a straight-edge across the pulleys to align them. Any misalignment will reduce the life of the belt.

CVI's standard drive is a 3/8" pitch, 1/2" wide timing belt with a minimum of 24 cogs on the CVI pulley. Install the belt with a tension of 13 to 15 lbs of force. Excessive tension will shorten the life of the belt. CVI may be driven directly from an engine's camshaft or at 1/2 speed from the crankshaft. A cover is recommended to keep foreign objects (e.g., fingers) out of the drive. HCI will be happy to quote on drive covers built to customer specifications.

The CVI shaft protrudes 1.5 inches from the front of the valve body, as illustrated in Figure 5. The preferred method of attaching a pulley or gear to the CVI shaft is with a tapered bushing, such as Martin type SH. Align the keyway with the vertical axis of the CVI, pointing upward toward the chambers. Rotate the engine to 90° after top center on the intake stroke and install the timing belt, maintaining the alignment as nearly as the cogs permit.

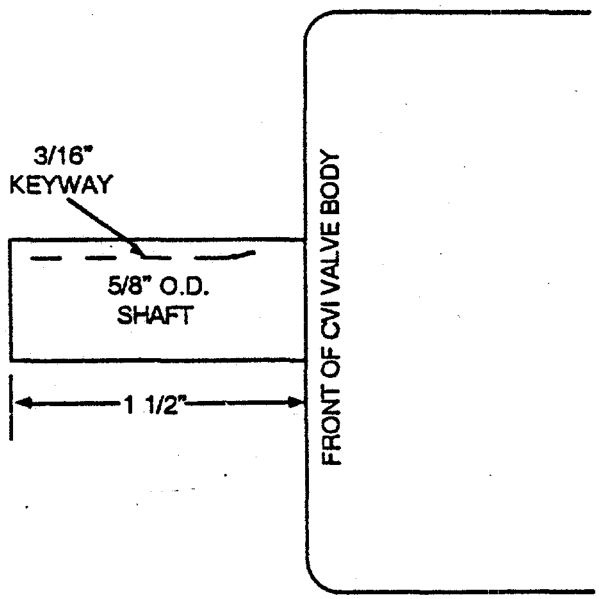


Figure 5. The CVI cam is driven by a 5/8" O.D. shaft with a 3/16" keyway, protruding 1.5" from the front of the valve body.

LOW PRESSURE PLUMBING

The plumbing connections necessary to install a CVI are illustrated in Figure 6. Safety and proper operation of CVI require careful installation and thorough leak check of the plumbing. All fuel plumbing and components must be mounted in locations that are protected from impact due to minor traffic accidents. Mounting brackets must be fabricated and installed to provide support and prevent stresses from being applied to the plumbing. All plumbing and fuel control components must be protected from direct heat radiation from the exhaust system.

Filtered fuel is supplied to the solenoid valve at 100-120 psi. The plumbing between the solenoid and the electronically controlled final pressure regulator must be have the largest I.D. consistent with 120 psi service pressure. It is also important to

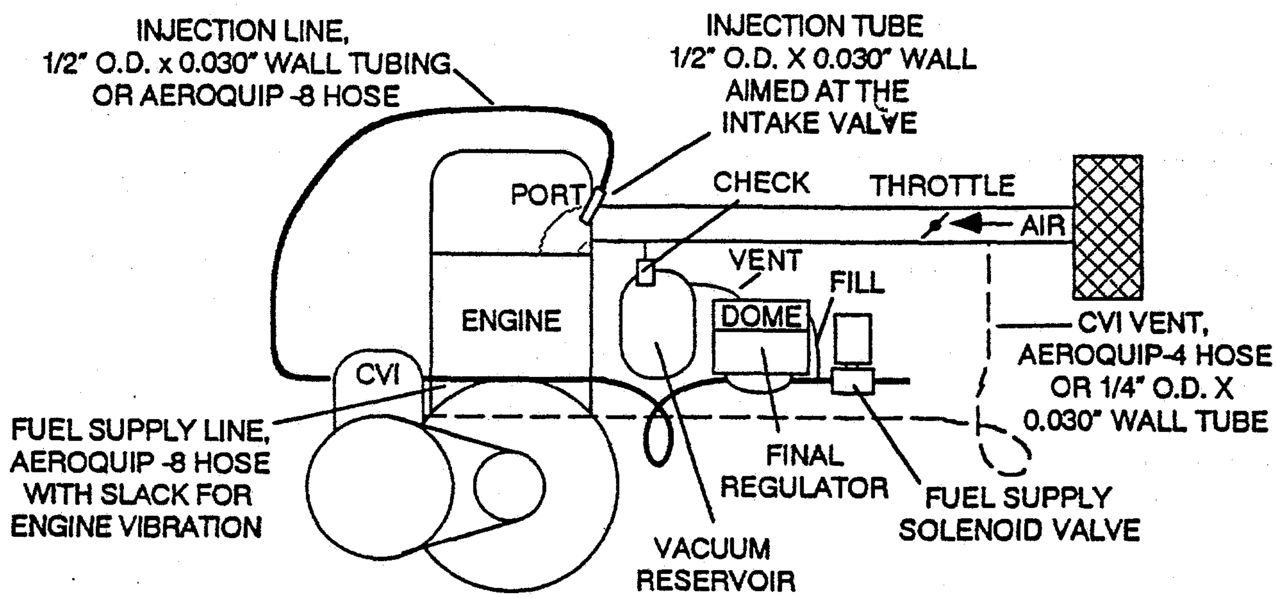


Figure 6. Fuel and vacuum plumbing required during installation of CVI.

use the sizes of tubing or hose indicated in Figure 6. If the I.D.s of the fuel plumbing are too small, the engine may go out of closed loop control (lean) under maximum power conditions. There is a "T" between the solenoid and the final regulator that supplies pressure to an internal control valve to load the dome. The connection should be made with 1/4" O.D. x 0.030" wall SS tubing.

The dome is unloaded through an internal control valve to the vacuum reservoir. The reservoir is evacuated during periods of low manifold air pressure through a check valve with a built-in restriction that limits the maximum rate of fuel bleed into the intake manifold. The connection should be made with 1/4" O.D. x 0.030" wall stainless steel tubing or Aeroquip -4 hose.

The front of the CVI valve body has a 1/4 NPT female fitting that must be vented to the intake system upstream from the throttle, as shown in Figure 6. This releases any fuel that slips past the CVI valve seals into the intake air flow.

Figure 6 shows only one injection line. CVI has one injection line for each engine cylinder. The injection order is 1-3-4-2. The injection lines should be of the size indicated in the figure with the least number of bends and fittings possible. Use the largest I.D. fittings that are consistent with the maximum injection pressure of the CVI. If the injection lines are too restrictive, the injection duration may be excessive. This will cause fuel to fill the intake port after the closure of the intake valve. This may result in intake manifold backfiring, especially with hydrogen-rich fuel gases. The engine may also go out of closed loop control (lean) under maximum power conditions if the injection lines are too restrictive.

WIRING & ELECTRONIC CONTROLS

Small errors in matching the breathing characteristics of CVI to a particular engine are inevitable. Electronic feedback adjustment of fuel flow compensates for these errors, as discussed above. A sensor in the exhaust manifold produces a voltage that varies with oxygen content. A setpoint voltage corresponding to the desired air/fuel ratio is used as a reference for an electronic feedback controller. If the air/fuel ratio is off the setpoint, the controller revises the pressure ratio, k, and commands the electronic pressure ratio regulator to eliminate the error.

CVI's electronic control module (ECM) performs several other control functions that are essential to the safe and clean operation of a gaseous fueled motor vehicle. These functions are as follows;

- ignition and fuel on/off sequencing during engine cranking and shutdown
- fuel off if engine stops for any reason
- open loop control of air/fuel ratio immediately after engine start-up
- closed loop control of air/fuel ratio after exhaust oxygen sensor heats up
- output of oxygen sensor voltage to data acquisition system

IGNITION AND FUEL ON/OFF

The following ignition and fuel solenoid sequencing functions of the ECM are designed to minimize the accumulation of unburned air/fuel mixture in the intake or exhaust systems.

When cranking is sensed by the ECM, a delay period is allowed for the engine to clear itself of any residual air/fuel mixture. The ignition is then switched "on" in preparation for the arrival of combustible mixture. Finally the fuel solenoid is opened allowing the engine to start. All of this takes place in about one second so the vehicle operator is not aware of significant delay on start-up.

When the vehicle's ignition key is switched off, the fuel solenoid closes immediately. The ignition remains on to ignite the small amount of combustible mixture supplied as the final regulator and plumbing are depleted of fuel. The engine stops due to fuel starvation with the ignition still on. About 1 second later, the ECM switches off the ignition.

FUEL OFF IF ENGINE STALLS

A Hall-effect tachometer pick-up must be installed in the bell housing. It senses the passage of the teeth on the starter gear of the torque converter. If the engine stalls for any reason, the ECM reacts to the loss of tach signal by closing the fuel solenoid.

OPEN-LOOP CONTROL OF AIR/FUEL RATIO

Immediately after the engine starts there is no signal from the oxygen sensor. The electronics send a good "guess" signal to the electronic pressure regulator until the oxygen sensor warms up.

Another open-loop control feature of the ECM is to store "learned" information about changes in ambient conditions, etc. that affect the fuel pressure ratio applied to the manifold air pressure signal. Upon a sudden transient, the old pressure ratio is the first "guess" for the new operating condition. Since the old ratio accounted for ambient variables, etc., this information was, in effect, "learned".

CLOSED-LOOP CONTROL OF AIR/FUEL RATIO

The ECM trims air/fuel ratio by adjusting the fuel pressure ratio applied to the manifold air pressure signal on its way to the electronically controlled pressure regulator. As explained above, the primary control of air/fuel ratio is assured from basic fluidic principles and feedforward control. The electronics compensate for small "real" deviations from ideal principles.

OXYGEN SENSOR SIGNAL TO DATA ACQUISITION SYSTEM

A good way to check on the performance of a modern engine control system is to monitor the oxygen sensor voltage trace. After filtering out "noise", the ripple on the oxygen sensor voltage is indicative of the accuracy of the control system.

The ECM has a Weather Pack connector for observing the oxygen sensor voltage trace during dynamometer testing. The cable should be disconnected at the Weather Pack during normal operation of the vehicle to avoid possible pick-up of electronic "noise" from the environment.

CONTROL SYSTEM BLOCK DIAGRAM

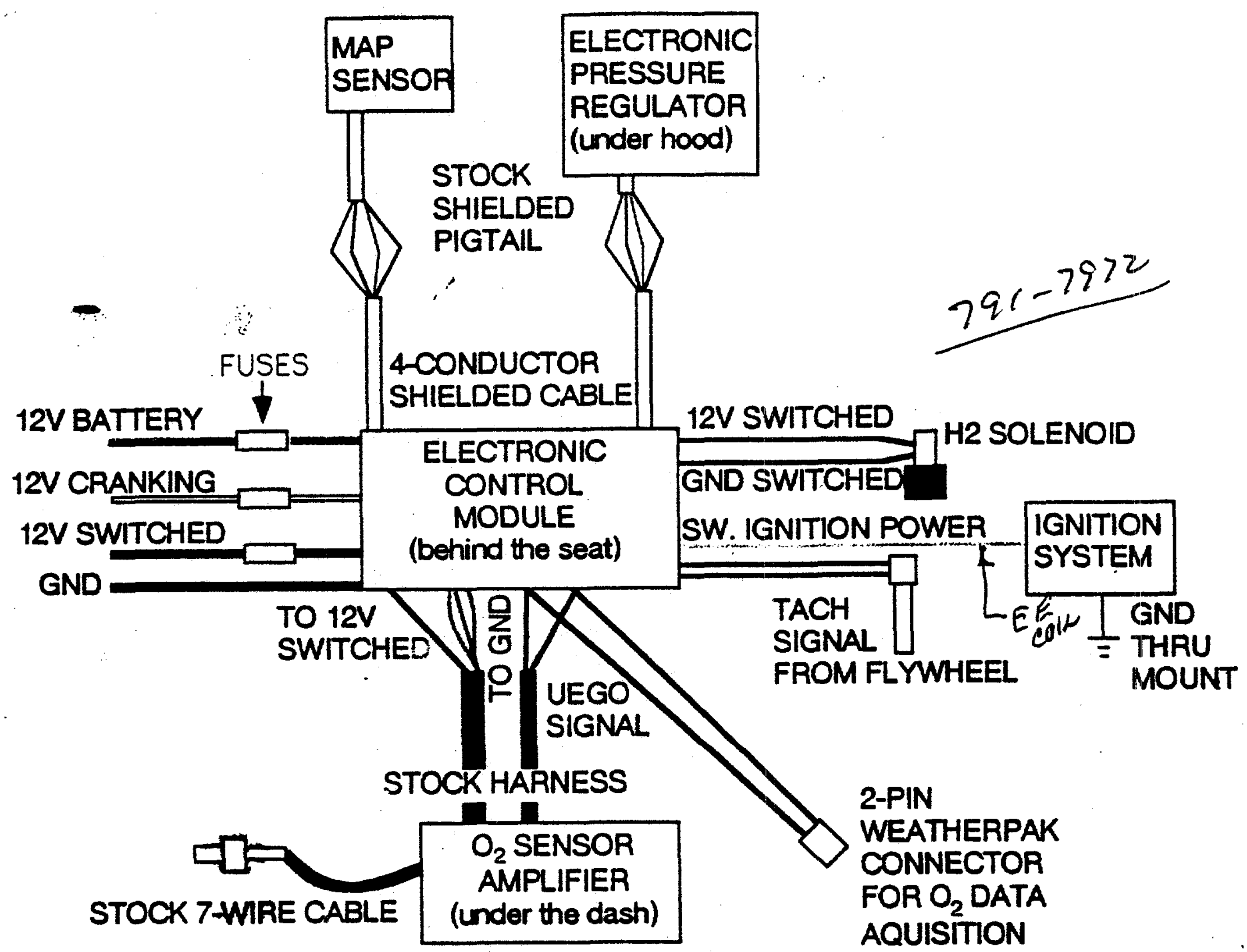
Figure 7 is a color-coded block diagram showing the components of the control system and how they are connected to one another. There are no user serviceable components in the electronic control module, the electronic pressure regulator or the exhaust oxygen sensor amplifier. The latter component has an "on-off" switch on its side that must be in the "on" position for the control system to operate properly.

Working around Figure 7 clockwise from the top, the connections of peripheral components to the electronic control module (ECM) and their functions is described below;

Functional Description of Wiring Schematic:

Electronic Pressure Regulator (EPR)

FIGURE 7. ELECTRONIC CONTROL SYSTEM BLOCK DIAGRAM AND COLOR CODE.



The EPR accepts a "setpoint" command signal from the ECM. The electronics onboard the EPR then adjust the output pressure of the regulator until its internal pressure transducer reads the same as the setpoint.

Fuel Solenoid Valve
The fuel solenoid valve is supplied with 12V through the vehicle ignition key. The ground side of the solenoid floats until the safety circuit "enables" operation by grounding it .

Ignition System
The ignition system is powered when the vehicle ignition key is in the "on" position and the safety circuits in the ECM call for ignition. The ignition system is grounded directly to the engine block.

Tachometer
The tachometer signal is an AC wave produced by a Hall sensor that detects the passage of flywheel teeth.

Universal Exhaust Gas Oxygen (UEGO) Output Signal
The ECM has a signal (green) and ground (black) wire. Observing the signal shows how well the ECM and EPR maintain the desired mixture.

UEGO Amplifier
The UEGO amplifier converts an oxygen pumping current from inside the sensor to a voltage for use by the ECM. It receives switched 12V from the vehicle ignition key and sends back an exhaust oxygen concentration signal (0-5VDC). The three yellow wires are power ground. The black wire is signal ground.

Ground
The ECM must be well grounded to the chassis.

12V Switched
The ECM requires 12V power supplied through the vehicle ignition switch.

12V Cranking
The ECM requires 12V power from the starter circuit.

12V Battery
The ECM requires 12V power straight from the battery to continue sparking after the ignition is turned off, clearing all fuel from the engine before it stops.

Manifold Air Pressure Sensor (MAP)
The manifold air pressure sensor sends a 0-5V signal to the ECM indicating 0-50 psia of manifold air pressure. The ECM performs analog math operations on the MAP signal and issues a command "setpoint" to the EPR.

All wiring and electronic components must be installed using good automotive wiring practice. The wiring must be properly supported, protected from exhaust heat radiation and from chafing by vehicle vibration.

LUBRICATION

CVI's camshaft is partially submerged in Dextron III automatic transmission fluid (ATF). The ATF is transferred directly onto the roller tappets by contact and up into the tappet bores by splashing and centrifugal spray from the cam.

To check the ATF level in the CVI, put the vehicle on level ground and remove the 1/4 NPT oil-check plug at the lower rear of the valve body. Remove the 1/4 NPT fill plug at the upper rear of the valve body and add ATF until it spills out the oil check hole (see Figure 8). Over filling the oil reservoir will cause venting of oi land may damage the CVI.

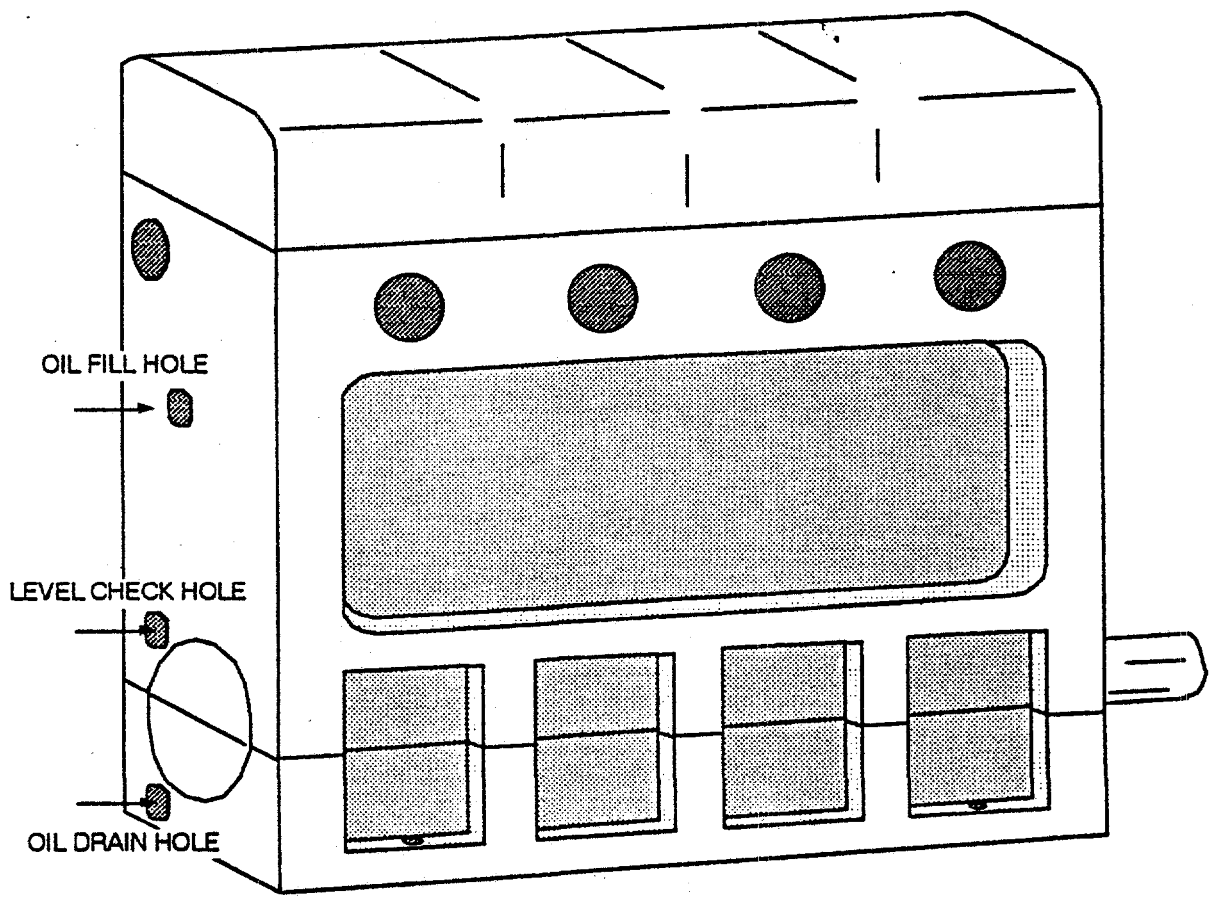


Figure 8. The bottom of a CVI has an oil reservoir. Fill it with Dextron III automatic transmission fluid until it begins to leak from the level check hole.

At the first engine oil change after CVI is installed, remove the 1/4 NPT oil drain plug at the bottom rear of the CVI oil sump. Replace the plug and fill with ATF as described above.

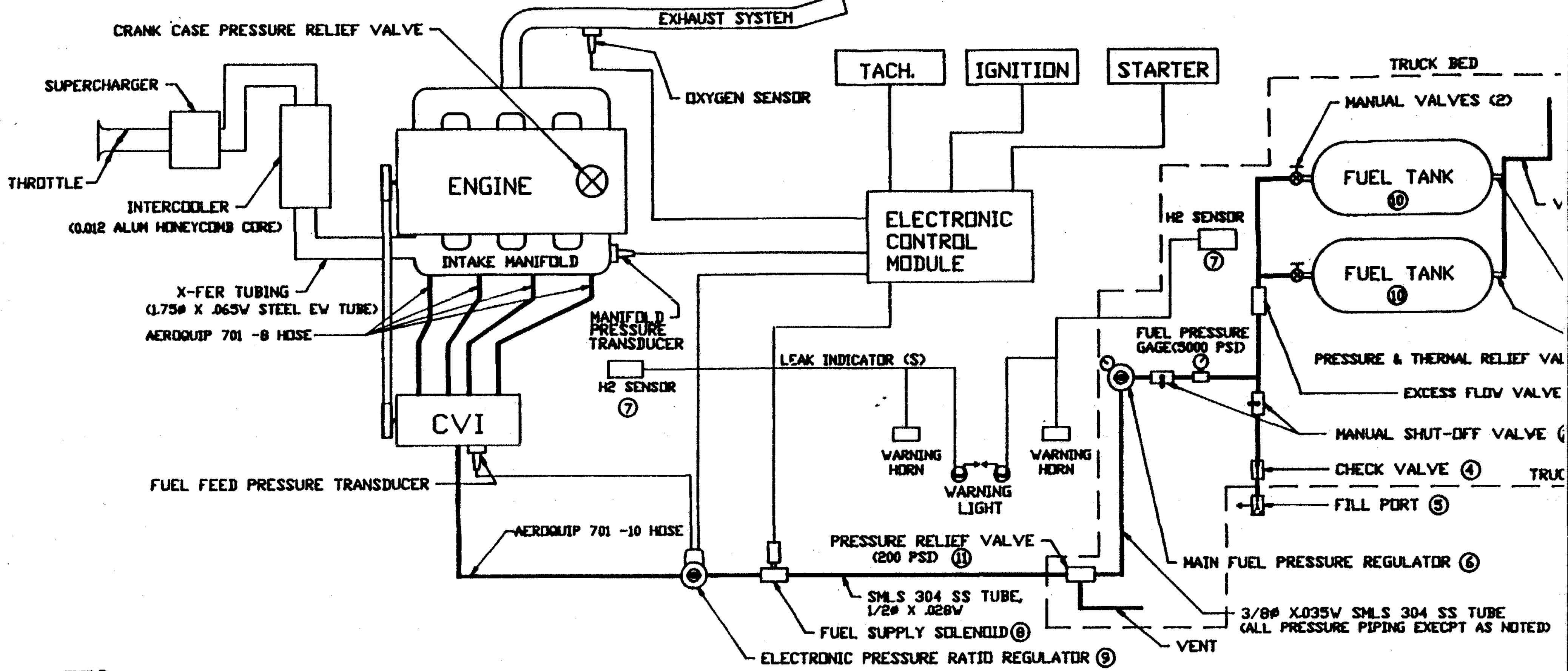
PROBLEMS?

If you have any problem with the operation of a CVI, please call HCI. We will be happy to work with you to diagnose the cause and correct the problem. There are no user servicable parts inside the electronic control module (ECM) or electronic (EPR) pressure regulator. If a problem is traced to the ECM or EPR, please call HCI for a return authorization number.

The CVI valve body may be disassembled, diagnosed and repaired by anyone skilled in automotive repair (e.g. grind the valves, replace ball bearings or shaft seal). Some replacement parts may be purchased from automotive and industrial parts stores. Other standard auto parts are modified by HCI during fabrication of CVI. If you find a damaged part in the valve body, please call HCI to determine the most expedient way to get a replacement part. Of course you may simply return the CVI to HCI after calling for a return authorization number.

If you repair your own CVI, clean the mating surfaces thoroughly and lightly coat them with RTV silicone rubber sealant. Allow the sealant to cure for 24 hours and leak check the CVI before reinstalling it on the engine. To leak check a CVI, make sure all bolts are in place and properly tensioned.

APPENDIX B



NOTES:

E.C.M. SEQUENCING
START-UP:

1. IGN. SW. --- ON
2. ENGINE CRANKING. .5 SEC.9approx)
3. IGN. SYS.--- ON (CRANKING)
4. FUEL --- ON TILL START

E.C.M. SEQUENCING
SHUT-DOWN

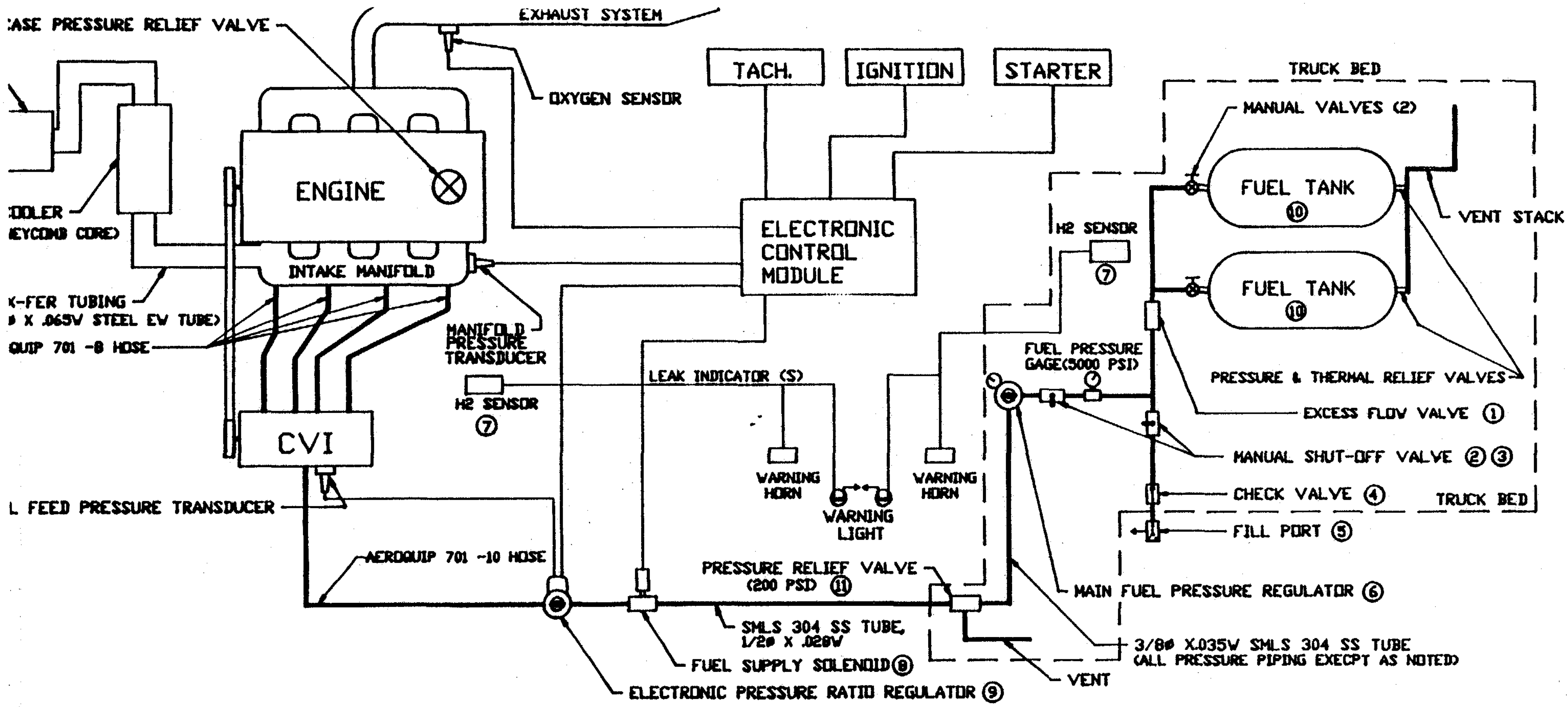
1. IGN. SW. --- OFF
2. FUEL --- OFF
3. ENGINE SPEED < 100 RPM
4. IGN. SYSTEM --- OFF

COMPONENT SPEC.

1 CHEM-TECH EFV-250(B494) (ZERO FLOW IN CLOSED POS.)
2 NUPRO B-4P4T4
3 WHITEY SS83KS6
4 NUPRO SSDCHS6-1 DOUBLE CHECK
5 STANDARD CGA-350 CONNECTOR
6 TESCOM 20-1032-2915 REGULATOR (125PSI MAX.OUT)
7 CCI CONTROLS 7907 H2 DETECTOR
8 ADVANCED FUEL COMPONENTS MODEL 121 SOLENOID VALVE
9 NORGREN 11-008-130 REGULATOR (400 PSI MAX. IN)
BUZMATIC SPC1R-0E5-0A100-S12 DOME LOADER
10 EDO LITERIDER MODEL 165 TANK (5.64 CU. FT. VOL.)
POLYETHYLENE/CARBON FIBER,3600PSI RATED (NGV-2)
11 200 PSI RELIEF VALVE (APPROX.0.25SQ IN FLOW AREA)

H2FSY

TOLERANCES: .XX ± .010 .XXX ± .005 FRACT. ± 1/64 ANGLE ± .5 EXCEPT AS NOTED	ADVANCED M DYNAM
	TITLE FUEL SYSTE
REV.	DRAWN W.J.K.
FIN.:	APPROVED:
HEAT TREAT:	MATERIAL SPEC.:



CING

G. .5 SEC.9approx)
(CRANKING)
ILL START

CING

F

100 RPM
- OFF

COMPONENT SPEC.

1 CHEM-TECH EFV-250(B494) (ZERO FLOW IN CLOSED POS.)
2 NUPRO B-4P4T4
3 WHITEY SS83KS6
4 NUPRO SSDCHS6-1 DOUBLE CHECK
5 STANDARD CGA-350 CONNECTOR
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POLYETHYLENE/CARBON FIBER,3600PSI RATED (NGV-2)
11 200 PSI RELIEF VALVE (APPROX.0.25SQ IN FLOW AREA)

H2FSYS2

TOLERANCES: .XX ± .010 .XXX ± .005 FRACT. ± 1/64 ANGLE ± .5 EXCEPT AS NOTED	ADVANCED MACHINING DYNAMICS	
	TITLE FUEL SYSTEM SCHEMATIC	
REV.	DRAWN W.J.K.	DATE 4-29-95
FIN.:	APPROVED	DATE
HEAT TREAT:	MATERIAL SPEC.:	
DWG. NUMBER H2FSYS	APPLICATION: XEROX-CANL H2 FUELED FORD RANGER	

PM10 POLLUTION//SOLAR HYDROGEN SOLUTION

ROBERT M. ZWEIG, M.D.
CLEAN AIR NOW

WORLD CAR CONFERENCE,
CE CERT
JANUARY 19 - 22, 1997

ABSTRACT:

The Industrial Revolution of the twentieth century has been a great for mankind. International society benefitted greatly, participating in this labor - saving milieu, made possible by the "Fossil Fuel Economy" (FFE). Today in 1997, inhabitants of Planet Earth are beginning to experience unpleasant complications brought on by increasing Fossil Fuel (FF) combustion. Increasing world population and urban concentration are exerting greater demands on energy supplies. As we progress from the "Industrial Society" to an "Information Society", so must we elevate our standard of living with a new "Non-Polluting Society". Transition to a Hydrogen Fuel Based Economy(HE) from the traditional (FFE) is critical, timely, and socially desirable. Replacement of FF with hydrogen would eliminate Particulate Matter [less than 10 micra in diameter](PM10) and other harmful urban pollutants which cause Public Health problems resulting from human exposure to these ambient toxic pathogenic substances. Scientists assure us that no major technological breakthrough is required for an orderly transition to this HE, only strong socio-political leadership and dedication to a healthier environment.

INTRODUCTION:

Global dependence on the Fossil Fuel Economy(FFE) has severe public health ramifications. The Crude Oil Life Cycle(COLC) chain,[from protection of fuel supply to human morbidity and mortality complications], requires national expenditures which otherwise could be used to finance a total Hydrogen Economy(HE). This paper will deal with only those signifigant medical links in this unhealthy "Chain"(i.e. Military Protection of Persian Gulf Crude Oil Supply and Universal Medical Problems). Economics will dictate rapid action if health costs which subsidize the FFE are included in formulating the <u>true</u> cost of a fuel.

PROBLEMS:

Medical and economic considerations regarding sequelae generated by the Crude Oil Life Cycle(COLC) must be addressed in a timely manner. Identification of the following "hidden" costs of fossil fuel supplies will lend a perspective rarely considered in total energy costs:

- o U.S Department of Defense - maintenance of standby troops to "protect our interests".
- o U.S. Veterans Administration Medical Department - "Desert Storm Syndrome".
- o Petroleum/Trucking Industry - "Clean-Up" for tanker/trailer oil spills and mishaps.
- o Municipal Fire Departments - Road Vehicular conflagrations.
- o Emergency Services - Carbon Monoxide Inhalation.
- o World Health Organization - health problems from CO2 Greenhouse Effect.
- o Taj Mahal - "Cleanup and Pollution Protection".
- o Oil Industry - Subsidies.
- o Municipal Water Utility Departments - acid rain complications.
- o Medical Profession - myriad public health pollution-related diseases.

Even though air pollution related diseases are caused by chemical components of fossil fuel combustion (stationary and vehicular), we will concentrate only on medically pertinent segments of the chain. It is stated that death is considered the "end-point" of adverse pollution reaction. Other respiratory diseases, including chronic obstructive lung disease(COPD), cardiovascular disease(CD), and asthma are caused by or aggravated by pollution. We will address asthmatic trends, localized demographic epidemiology, diesel emission health effects, and a limited discussion of medical aspects of Persian Gulf involvement. "Desert Storm Syndrome" ramifications will be mentioned only as they pertain to general civilian health.

Annual expenditures for treating urban smog related diseases were accurately well identified by Veziroglu(1) at WHEC. Present FFE produces 23 million tons of toxic emissions annually. Worldwide environmental damage costs to taxpayers amounted to $2,700 billion in 1996 (representing about 14% of the Gross World Product).

The following references to authors and their contributions to a timely data base will serve as background arguments for expediting transition to a clean alternative fuel such as hydrogen:

o Sherwin	(USC)	Premature aging of lung tissue
o Shprentz	(NRDC)	Riverside worst in USA, with 122 annual cardiopulmonary deaths
o Hall	(Fullerton)	Health cost@ $9 - $14 billion/year in SCAB
o Peters	(USC)	Pulmonary Function changes in elementary school children
o Abbey	(LLUMC)	Increased cancer incidence related to long-term PM10,O3 exposure
o Prasad	(AQMD)	Linear relationship of morbidity, mortality and PM10 levels

Asthma:

The National Research Defense Council(NRDC)(2) reports that asthma in children is increasing in incidence, morbidity, and mortality. Joseph(3) states that the number of deaths from asthma in New York City was 26 times the national average In 1995. Philadelphia experienced a 44% increase in asthmatic office visits from 1993 to 1995. There is a growing body of evidence that acid aerosol particulates are especially responsible for serious health risks in children. In Southern California over 100,000 children have been identified with asthma. One third of these children are under 17 years of age. The younger the child, the greater the risk of asthma.

Several pathophysiological mechanisms are responsible for this process:

Inhaled irritating pollutants *damage* and *constrict* bronchial airways.
Resulting irritation *triggers immunological defense* responses.
Particulates *impair immune response.*
Particulate entrapment aggravates *lung impairment and inflammation.*
Children breathe faster, thus are *exposed to higher total dosages* of smog.

Diaz-Sanchez(4) has reported new findings which implicate diesel exhaust as aggravating immune response in asthmatic patients. Takenaka(5) has shown that certain components of diesel exhaust(DEP) actually destroy the protective effects of the immune mechanism. The U.S. Environmental Protection Agency(EPA) regulations for diesel emissions require alterations of fuel and engine configurations which may alter physical and chemical emission characteristics. These changes in design may have adverse effects upon human health. These new data should mandate immediate mitigation measures to alter the trend of this ominous impending medical catastrophe.

Geographic Demographics:

Public Health studies confirm that high levels of Total Particulate Matter(TPM), (especially PM2.5, PM1.0), found in urban ambient air, are the *most hazardous* to human health. Here, (the Riverside/San Bernardino portion) of the South Coast Air Basin(SCAQMD), has been identified as the most severely PM10 impacted area in the United States. Thus, this unique, involuntary sub-population suffers the highest PM10-related morbidity and mortality rates in the country. Clinical studies from various independent research centers confirm that acute and chronic health changes are scientifically identifiable. These medical conditions (pollution-related morbidity and mortality) could be eliminated from this group of involuntary experimental patients by cleaner fuel substitution.

.California Health Department(6) reports that increased incidence of deaths from heart disease and strokes found in California cities with populations over 20,000. Many of these sites correlate closely with areas identified with high levels of PM10, Ozone, and Carbon Monoxide.

Since all fossil fuels contain precursors of TPM, elimination of carbon, sulfur and other impurities from coal, crude oil [and its by-products], and natural gas, will eliminate a high percentage of tailpipe emissions contributing to the "smog problem". Diesel fuel utilization is increasing. It is estimated that diesel truck traffic will escalate substantially, especially in the Los Angeles Port area with the advent of Pacific Rim supply shipments. Therefore, special efforts to correct the smog problem should concentrate on eliminating these health-hazardous toxins from such highly impacted sites.

Cass and Gray analyzed regional emissions and atmospheric concentrations of diesel particulate matter in the Los Angeles Basin. They discovered that the highest levels(127 ug/m3) is found in Riverside. Diesel exhaust accounts for only 3% of total particulates but 7% of fine particles! Diesel engines use 6% of total fuel supplies, but produce 67% of elemental carbon particles. Because diesel exhaust is one component of urban air pollution, we must be aware that carcinogenic effects are not confined only to occupational exposure.

Diesel Exhaust Health Effects :

Many human health problems are identified with diesel exhaust emissions. Two main reactions of human response to diesel exhaust components will be analyzed: (Long Term Exposure and Acute Immunological Response.)

Diesel exhaust contains many compounds, (mostly unhealthy) such as Carbon Monoxide(CO), Oxides of Nitrogen(NOX), Hydrocarbons, [Volatile Organic Gases] (VOG), Particulates(TPM)[including PM10, PM2.5, and PM1.0]. Other compounds include ammonia, cyanides, phenols, organic amines and lesser concentrations of aldehydes, ketones and sulfur dioxide. Recent published data confirm that continued use of present fossil fuels will have other micro and macro health/economic sequelae.

K.H. Lies(7) analyzed diesel exhaust components specifically and concluded that there are many unknowns regarding health effects. Essential components of diesel exhaust fall into one of two categories :"Regulated"and "Unregulated", which actually overlap. Regulated components consist of Monoxide(CO), Oxides of Nitrogen(NOX), Hydrocarbons (VOG), and Particulates(TPM). Unregulated components consist of ammonia, cyanides, phenols,and organic amines with lesser concentrations of aldehydes, ketones, hydrogen, and sulfur dioxide. Each of these components have been implicated at one level or another with adverse health effects. We will concentrate on the PM effects on laboratory animals, and human exposure.

Bagley(8) concludes that particles, vapors, and gaseous emissions from diesel engines continue to have adverse effects on human health and environment. Long term exposure to diesel exhaust causes a small increase in relative risk for lung cancer. Cox(9) states that the risk of developing lung cancer in men exposed to diesel exhaust have 1.2 to 1.5 times the risk of unexposed individuals. The Health Effects Institute recognizes that diesel particulate air pollution is also associated with other *noncarcinogen* effects. Watson(8) concludes that exposure of laboratory animals to diesel exhaust will result in chronic inflammation, cell hyperplasia, metaplasia, alteration of connective tissue, pulmonary fibrosis, and compromised pulmonary function.

Crude Oil Supply Protection:

Abou-Donia(10) concludes that troops exposed to poison gas in the Persian Gulf shall incur extensive and expensive health costs associated with long term treatment. The Presidential Advisory Committee Gulf War Veterans' Illness is studying 80,000 veterans who suffer from 23 separate ailments related to service in the Persian Gulf. Causes of the "Desert Storm Syndrome range from *smoke inhalation produced from the burning oil rigs*, to prophylactic vaccine reactions. These medical costs are included in the total $50 billion annual budget.

When "Crude Oil Life Cycle"(COLC) expenses involved in the operation of the chain are included in the total " real fuel cost", we deduce that society can afford other more desirable energy systems. The new alternative system could eliminate the need for:

A. active military protection of the crude oil supply, and

B. medical expenditures for pollution related human disease treatment.

We therefore conclude that continued use of fossil fuels is anti-social, and a totally unconscionable act. To repeat: "This Crude Oil Life Cycle" of the FFE chain requires national expenditures that would be eliminated entirely by the shift to a total Hydrogen Economy(HE)..

Timing for transition to this "Hydrogen Economy" is urgent, appropriate and critical. The EPA, California Air Resources Board(CARB) and the Southern California Air Quality Management District(AQMD) are presently promulgating new air quality standards for all pollutants, (including ozone, PM10, and PM2.5). Without rapid substitution of hydrogen fuelled vehicles, these more stringent target levels will be very difficult or impossible to obtain Hydrogen powered I.C.E's or Fuel Cell electric vehicles(FCEV)presently operating in the SCAB can be utilized as prototypes for gasoline and diesel vehicles and fleets now operating in this basin.

Once more: "Health costs charged to the Fossil Fuel Economy(FFE) are more than sufficient to subsidize a complete Hydrogen Fuel Economy(HE) replacement program."

Solar Hydrogen for Urban Trucks

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Abstract

The Clean Air Now (CAN) Solar Hydrogen Project, located at Xerox Corp., El Segundo, California, includes solar photovoltaic powered hydrogen generation, compression, storage and end use. Three modified Ford Ranger trucks use the hydrogen fuel.

The "stand-alone" electrolyzer and hydrogen dispensing system are solely powered by a photovoltaic array. A variable frequency DC-AC converter steps up the voltage to drive the 15 horsepower compressor motor. On site storage is available for up to 14,000 standard cubic feet (SCF) of solar hydrogen, and up to 80,000 SCF of commercial hydrogen. The project site is 3 miles from Los Angeles International airport.

The engine conversions are bored to 2.9 liter displacement and are supercharged. Performance is similar to that of the Ranger gasoline powered truck. Fuel is stored in carbon composite tanks (just behind the driver's cab) at pressures up to 3600 psi. Truck range is 144 miles, given 3600 psi of hydrogen. The engine operates in lean burn mode, with nil CO and HC emissions. NOx emissions vary with load and rpm in the range from 10 to 100 ppm, yielding total emissions at a small fraction of the ULEV standard. Two trucks have been converted for the Xerox fleet, and one for the City of West Hollywood.

A public outreach program, done in conjunction with the local public schools and the Department of Energy, introduces the local public to the advantages of hydrogen fuel technologies.

The Clean Air Now program demonstrates that hydrogen powered fleet development is an appropriate, safe, and effective strategy for improvement of urban air quality, energy security and avoidance of global warming impact. Continued technology development and cost reduction promises to make such implementation market competitive.

I - INTRODUCTION

Urban air pollution reduction, energy security and global warming concerns motivate us to use hydrogen as a vehicle fleet fuel. Clean Air Now (CAN), a California non-profit educational Corporation, has teamed with the South Coast Air Quality Management District (AQMD) and the White House Technology Reinvestment Project to fund and install renewable hydrogen generation and a fleet of hydrogen fueled trucks at a Xerox Corporation facility near Los Angeles International Airport.[a]

A primary goal is to demonstrate technical feasibility of hydrogen as a clean fuel, leading to corporate and public acceptance of hydrogen technologies.

Herein we first describe the hydrogen generation and storage, then the truck conversions to use the hydrogen as a fuel. Public health benefits are analyzed, in comparison to present experience in Los Angeles. The role of Xerox Corporation, safety and economic acceptance will also be discussed.

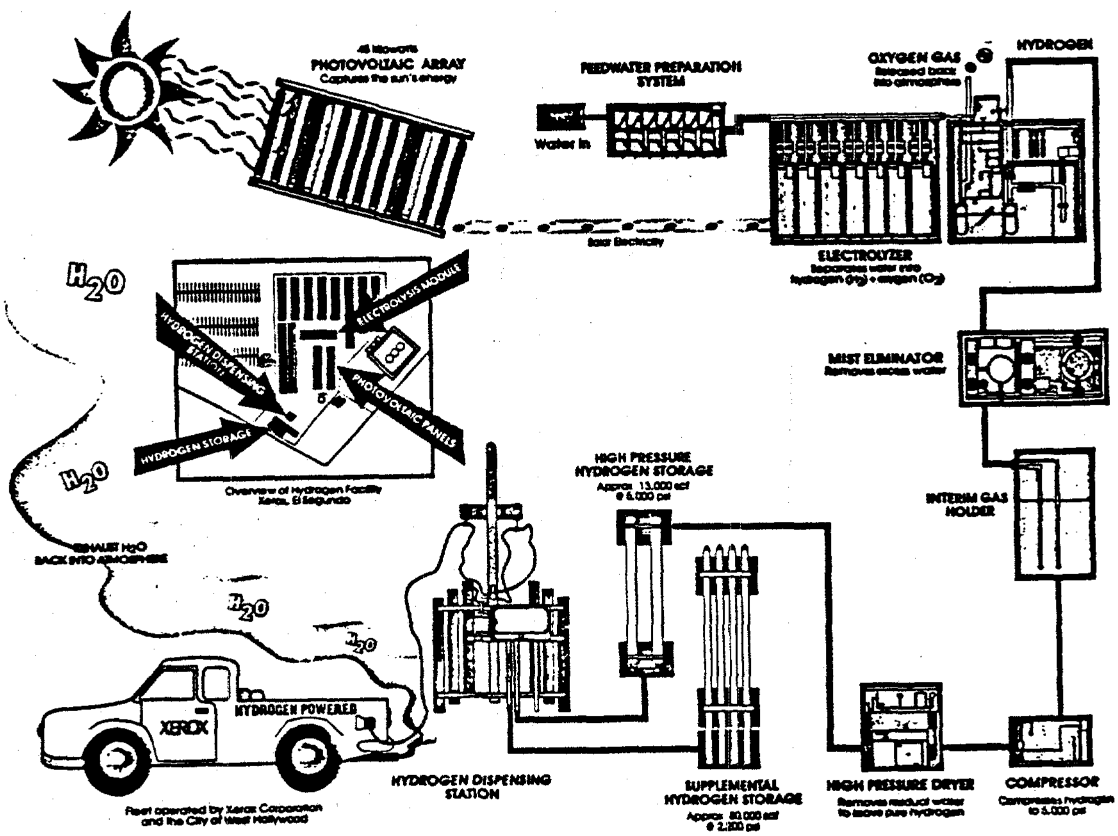

Figure 1. Solar hydrogen generator, fueling station and truck.

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[a] The project is supported, in part, by the South Coast Air Quality Management District and by DOE contract DEFC36-94GO10039. Such support does not constitute an endorsement by DOE of the views expressed herein. Substantial cost sharing investment was also made by all members of the project team.

II - THE STAND-ALONE HYDROGEN GENERATOR

Hydrogen fuel is unique in that it yields heat without carbon monoxide or dioxide, hence poisoning neither life nor earth. The CAN Solar Hydrogen Generator is designed to "stand-alone", i.e. have no connection to the commercial power grid, such that all hydrogen produced results from solar energy. The CAN trucks run on a truly renewable fuel. It is produced by using electricity from the sun's energy to split water to hydrogen, which recombines with oxygen to water by combustion in the engine of the truck.

Xerox Corporation considers social and environmental responsibility essential to a healthy long-term bottom line. This philosophy, the source of its strong Corporate Environmental Policy, paved the way for this hydrogen fuel fleet demonstration project.

Figure 1 schematically shows sunlight converted to electricity powering the electrolyzer. The system is designed for operation at 16 volts, with currents to 2700 amperes. Water purification is by ion exchange membrane. The compressor is also powered from the solar array, with a variable frequency DC to AC inverter which provides a "slow start" for the compressor. The compressor will not run at low insolation; hydrogen generated during these periods is stored in the gasholder.

Batteries, recharged only from the PV array, are used for control functions to ensure that the electrolyzer runs optimally even with nil or low insolation.

The compressor can fill only the high pressure solar hydrogen storage. The supplemental hydrogen storage was installed for commercial hydrogen, which is trucked to the site by tube trailers. Due to trucking regulations the supplemental hydrogen is limited to 2200 psi pressure. The solar hydrogen is contained in dual steel cylinders rated for pressures to 5000 psi.[b] The solar hydrogen supply has been adequate for the truck fleet. The commercial hydrogen is provided to assure that we can meet the needs of visitors (such as when CAN hosted the Ballard bus for demonstrations at LAX).

The hydrogen dispensing station is used to make the connection from the fixed storage tanks to the tankage on the trucks. Both the commercial and the solar hydrogen storage are kept separate in two (higher and lower pressure) reservoirs. Fill valves allow the operator to select from first the lower pressure, then topping off from the higher pressure storage (of either solar or commercial hydrogen).

Meticulous attention to grounding is essential to safety when using hydrogen, as a consequence of the low ignition energy. Multiple ground rods are located near the fueling

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[b] Presently the system is programmed to shutdown at a maximum pressure of 4200 psi, as the tankage on the trucks is rated for a working pressure of 3600 psi.

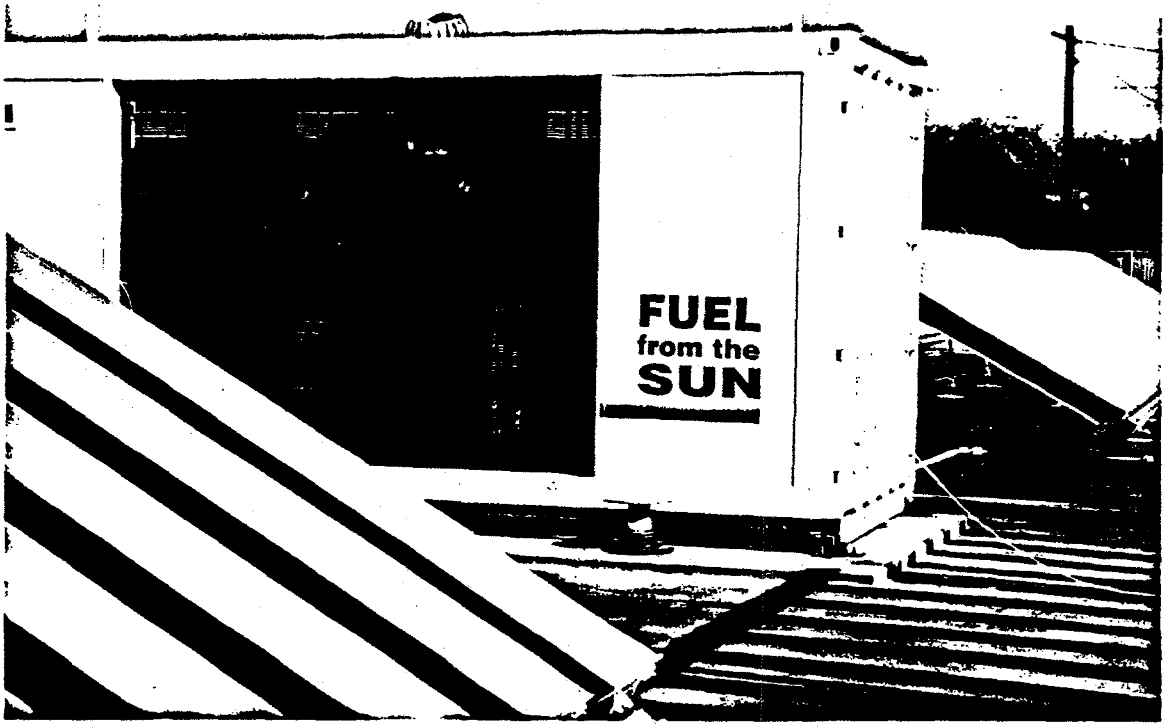

Figure 2. The photovoltaic array and electrolyzer module.

station and near the electrolyzer, with massive copper cable and brazed connections assuring all locales are at the same potential.

Figure 2 shows the photovoltaic array and electrolyzer installation. Approximately 60% of the photovoltaic power is provided by tracking Fresnel lens concentrators, with a fixed array of flat plate modules supplementing the tracker power.

The operation of the facility is illustrated in Figures 3 and 4. Figure 3 illustrates operation on a cloudless day. The insolation is measured by a Licor semiconductor sensor mounted on one of the trackers, so that it is a measure of the insolation incident on the Fresnel lens. The current is the total amperage from the tracking and the fixed arrays. It is *almost* a cloudless day - note that some wisps of high cirrus must have come before the sun about noon, and again just before 5 p.m.[c] there is some obscuration - probably coastal haze brought over by the on-shore breeze.

Iinv represents the inverter current. The inverter first came on at about 8:30, shortly after it finished compression the system was shut down for maintenance - thus there is a gap in the compression activity until after 9 a.m. The compressor runs intermittently, coming on for some 10 minutes followed by a like period of refilling the gasholder. The system is interlocked to shutdown at a nominal 4200 psi, this day it attained 4187 psi just after 1 p.m.,

[c] On these figures the time is expressed in 24 hour clock units, so 5 p.m.=17:00.

Feb. 18, 1997

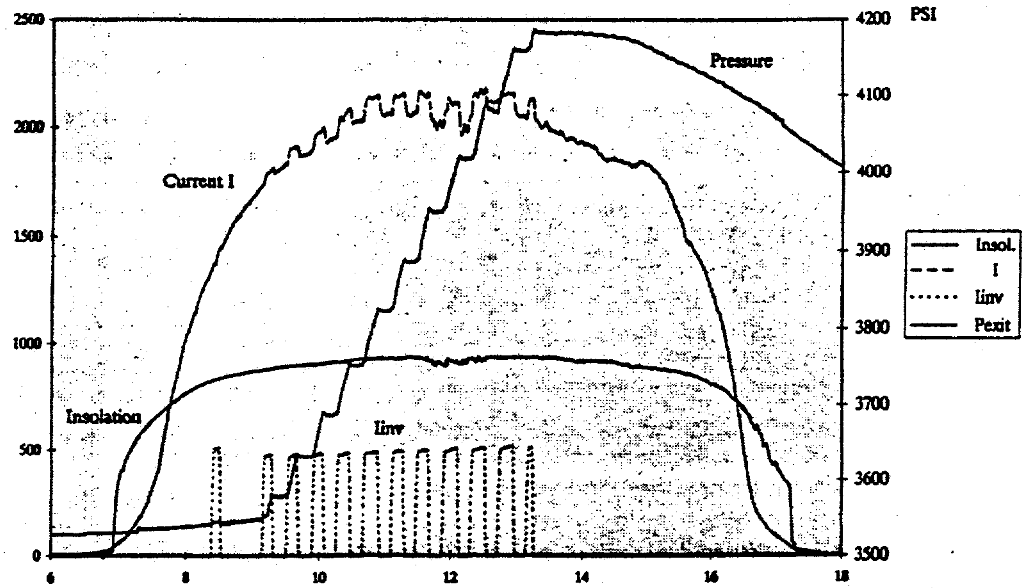

Figure 3. Illustrating insolation, total current I, inverter current Iinv, and the resulting hydrogen pressure.

Jan. 27, 1997

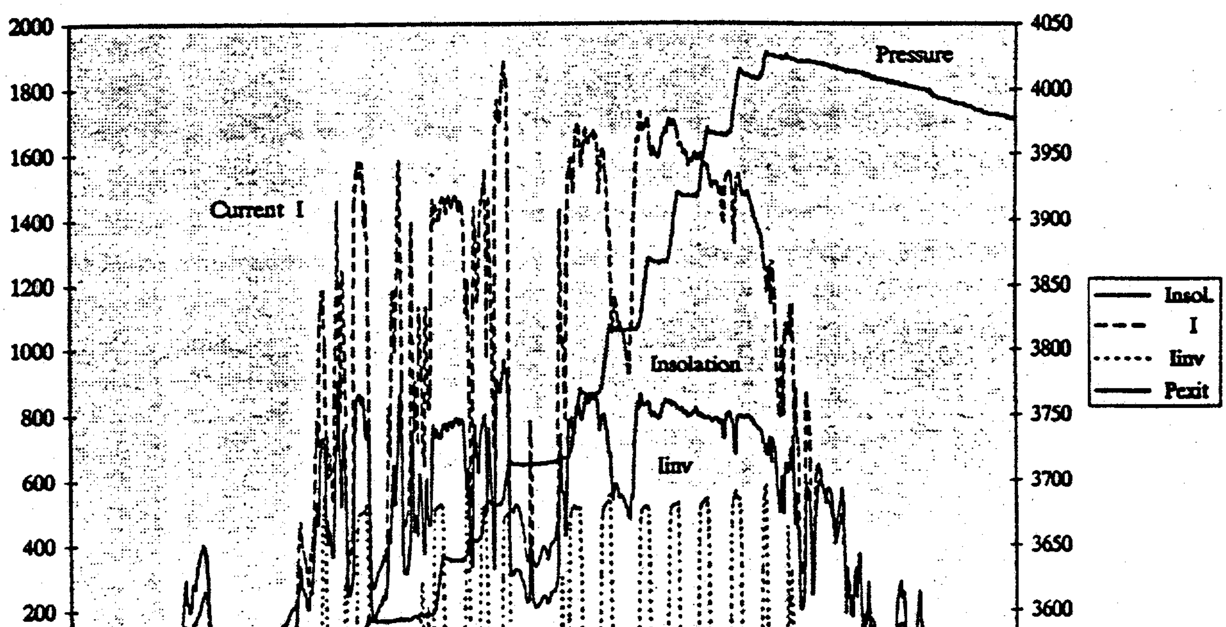

Figure 4. As in Fig. 3, but for a partly cloudy day.

and thus did not compress for the rest of the day. Note that there are morning and evening periods during which the voltage-current conditions will not support compressor operation. During these periods the generated hydrogen is used to fill the gasholder, following which overage is released to the atmosphere.

Note that as the compressor is on, the total current increases. Due to the lowered circuit impedance with the compressor on line, the voltage is dropped and hence the current from the PV (photovoltaic) supply is increased.

The pressure increases sharply with each compression cycle, more notably on these days because only the high pressure cylinder was connected to the system. The pressure rise of 660 psi corresponds to approximately 1340 SCF (and would have been some 2000 but for the maximum pressure cutoff). On the day with sporadic cloudiness approximately 900 SCF of hydrogen was generated.

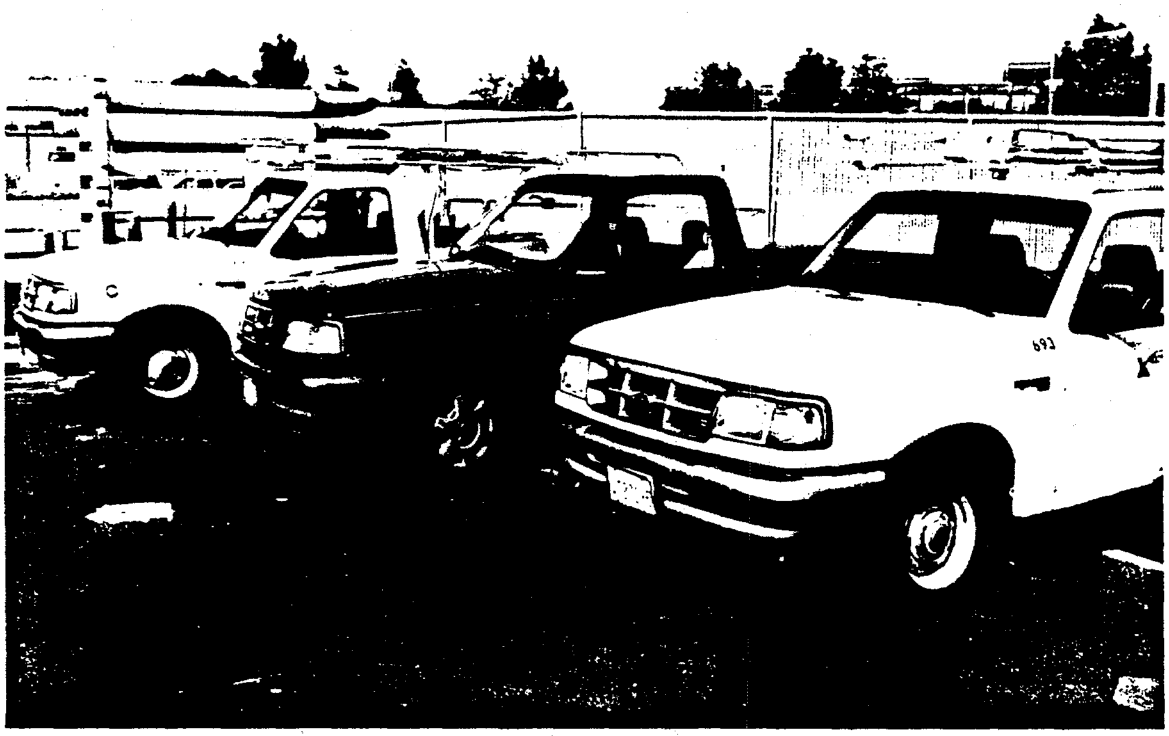

Figure 5. The Xerox (white) and West Hollywood hydrogen fueled trucks.

III - THE HYDROGEN FUELED TRUCKS

Three Ford Ranger trucks were converted to store and use compressed gaseous hydrogen as fuel. Figure 5 shows a "family photo" of the trucks.

Vehicle safety is of paramount concern. The use of hydrogen as the fuel is itself a key safety feature, as it avoids fires following liquid fuel spills.[d] Were the flammable gas to escape, it most likely would burn harmlessly while rising above the vehicle. To prevent such escape, additional structure has been added to protect the tankage and fuel lines from a side impact collision. Dual check valves and an excess flow limiting valve protect from a regulator or line failure. Hydrogen detectors are located under the hood and near the fuel lines.

A large crankcase relief valve is provided to open in case of a pressure rise in the crankcase/valve cover space.

Transferring hydrogen to the trucks is a critical step. Grounding is an essential safety precaution. A ground cable (#4 copper) is first connected to the ground receptacle on the truck body. Mating *Tweco* welding connectors (they require insertion and then a twist) are used, with the fueling door interlocked until the grounding connector closed. The twist motion retracts a pin from the fuel port door, allowing the door to pop open yielding access to the fuel connector.

The truck bed mounts dual carbon fiber wound tanks, storing 2418 SCF hydrogen at 3600 psia. Range, using 3500 psi of fuel, is 140 highway miles.

The truck engines are converted from the stock 4 cylinder, 2.3 liter Ford engine. Bore and stroke are increased to 2.9 liters and a supercharger further increases mass airflow. The hydrogen injection system is of the Constant Volume Injection (CVI) design from Frank Lynch of Hydrogen Components, Inc. Engine compression ratio is increased to 11:1 to enhance efficiency. Air heating caused by the supercharger boost, as high as 7 psi, is removed by a large cross-flow intercooler.

The engine controller delays fuel flow for 1/2 second after cranking starts. As the key is turned off, cranking and spark continue briefly following fuel flow cutoff.

The equivalence ratio (hydrogen-air mixture ratio) is run ultralean - at less than 0.5 of stoichiometric - to reduce the flame propagation speed, promote "cool" combustion and

[d] Cannon (Ref. 1) reports that 600 lives are lost each year - in the USA alone - in automotive vehicle accident fires. One of the health benefits of conversion to gaseous fuels will be the virtual elimination of these tragic deaths.

minimize NOx production. An exhaust gas oxygen (EGO) sensor is used in the CVI control loop to continually monitor the degree of combustion and maintain a set mixture.

Misfires, and even backfires, are reported as a problem with earlier hydrogen fueled engines. These engines, when properly set up, are relatively benign. Misfires do occur sporadically but only under extreme operating conditions.

Each of the three trucks was evaluated using the chassis dynamometer and associated instrumentation at the University of California at Riverside, College of Engineering, Center for Environmental Research and Technology (CE-CERT) under contract to CAN. Proper adjustment of the CVI controller was found to be critical for proper operation. For example, CAN1 initially was subject to surging and excessive NOx, with highly irregular combustion pressures. CAN3 originally was set up to run very lean, at equivalence ratio of approximately 0.32, with the result of reduced low end performance and extremely low NOx - below 35 ppm.

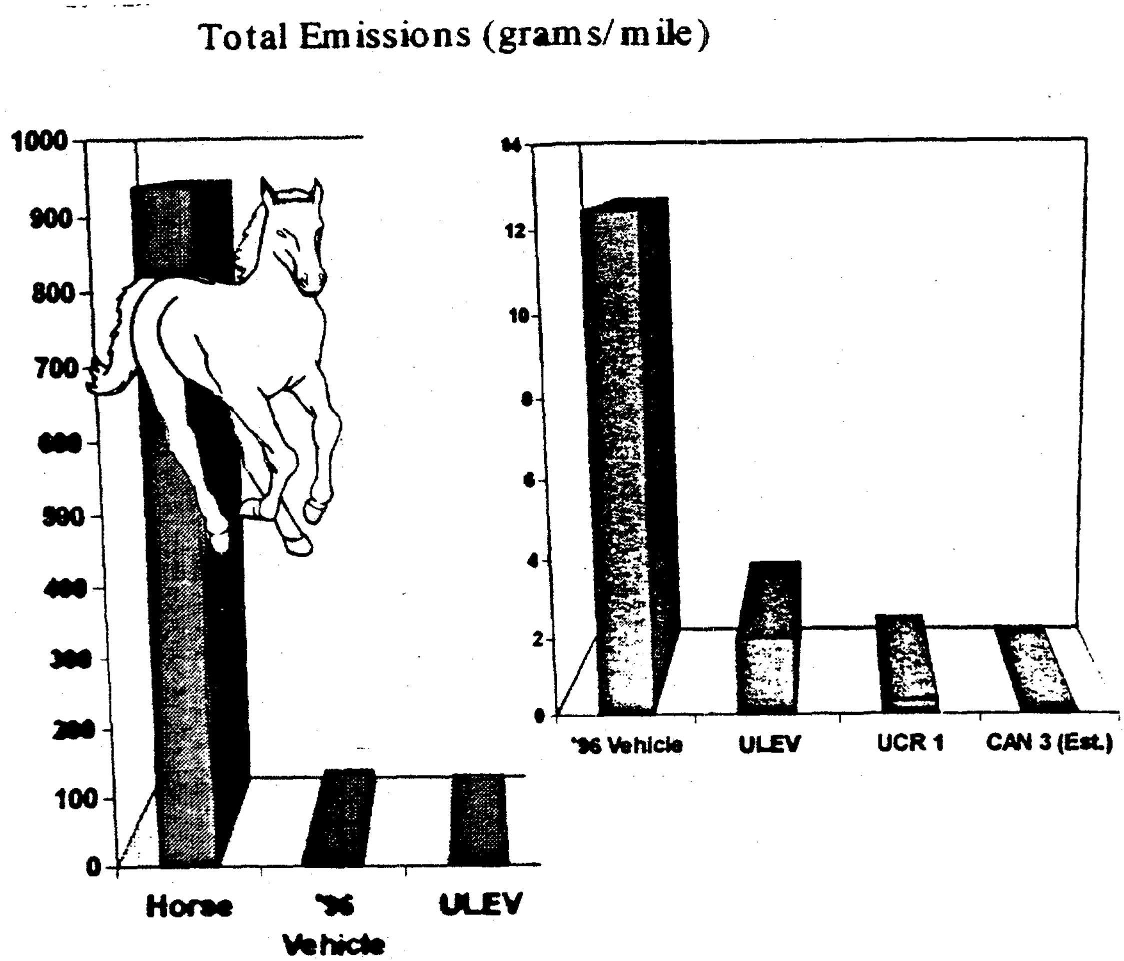

Figure 6. Showing emissions reductions over the last century.

Chassis dynamometer tests show the hydrogen fueled engine is more powerful than the stock gasoline powered engine at all but the highest engine speeds. Peak power occurs at about 4000 rpm. Even at this highest power level, measurement shows less than 100 ppm NOx.

Dramatic public health progress is shown in Figure 6. Before 1900 the horse, with some 940 grams/mi "emissions"[1], was the preferred means of personal transport. Barely a hundred years from the introduction of the horseless carriage the total emissions are down to 12.5 gm/mi (for the average car on Los Angeles freeways), or down to 2 grams/mi for a modern car meeting the ULEV standard. UCR1, the first of the Ford Ranger trucks converted to hydrogen fuel two years ago at the UCR CE-CERT facility, tested at a total emissions (CO, HC and NOx) of 0.37 grams per mile. The CAN trucks are cleaner than UCR1. By further improvement in the control system, we believe below 0.1 gm/mi is achievable. Van Blarigan et.al. have shown hydrogen, or hydrogen/natural gas mixed fuel engines can achieve the proposed EZEV (Equivalent Zero Emission Vehicle) California standards.[2] As an additional benefit, the greenhouse gas yield is also cut by factors of hundreds (using renewable hydrogen).

IV - HEALTH BENEFITS - A KEY MOTIVATION FOR USE OF HYDROGEN FUEL

The CAN Solar Hydrogen Project was motivated by the health effects of the air of Los Angeles and other metropolises. The epidemiological data showing the effects of fossil fuel combustion byproducts has been extensively documented.[3] In the last 3 years particular attention has been focused on the health effects of small particulate matter and ozone[4], resulting in proposed new EPA standards.

Of particular concern are the small (submicron to 2.5 micron size) particles, which are small enough to be inhaled deeply into the lungs where they may persist. Diesel engine exhaust is the dominant source of elemental carbon particle emissions in the Los Angeles area.[5] These products of diesel combustion include known mutagens, carcinogens, and lung irritants. The bulk of particulate emissions (by mass) are in this small size range. They are not accounted for by present PM10 standards.

Ironically, as we ask that engine manufacturers get rid of diesel smoke, the result is a substantial reduction by weight of total particulate matter, and an increase by 15 to 35 times in the total number of particles due to increase in the small, primary particles.[6]

Hall et.al.[7] have presented a cost benefit assessment of the health effects of ozone and particulate matter in the Los Angeles region. They estimated **annual benefits of $10 Billion** would accrue by avoidance of these effects. Nationwide health cost estimates range to ten times this.[8]

Worldwide, air pollution is severe in many cities - particularly in evolving economies such as Mexico and China. Many would benefit from a cost effective means of using hydrogen for motive power.[e]

V - IMPLICATIONS AND CONCLUSION

Some cite the cost of renewable hydrogen as excessive, particularly as compared to USA gasoline prices. Cannon, noting that the consumer's fuel cost is composed of the sum of the wholesale cost, the distribution and the tax costs, cites the gasoline distribution costs at 25 cents per gallon.[1] He suggests that, "Refueling station costs are

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[e] Let us pause to speculate on the implications of a program which would devote 10% of the health cost of air pollution towards a long term - non-carbon - solution. This national program would grow to invest up to 3 billion dollars per year into research and development of a hydrogen economy. We now spend 70 billion per year to import oil, this would add some 4%, or about one dollar, to the cost of an imported barrel of oil. The cost to the motorist or trucker - at the peak of the program - would be about 2 cents per gallon.

Benefits of the program would include improvement in urban population health, improved national economic security - as we are weaned from imported oil - and new employment and exports as new and attractive technologies move into production.

Appropriate goals of such a program would include:

* Providing increasing support for promising investigations regarding improved hydrogen production, storage, and utilization.
* Providing tax credit incentives for conversion of van, bus and trucking fleets to EZEV vehicles, and for fueling stations open to the public.
* Development of a national capability, including NASA, aircraft manufacturers and suppliers, for building a fleet of hydrogen fueled transport aircraft.

Politically impossible? Without leadership, yes. George Bush, in a moment of watery vision in 1990, proposed a NASA mission to Mars with cost ten times this. He didn't sell it - but it is hard to argue it hurt his Presidency. A legacy of taking the world to a hydrogen economy could be even larger than that John Kennedy won with going to the moon.

projected to range from 30 cents per equivalent gallon[f]... to 70 cents for a liquid hydrogen refueling station."[9] Further, he claims a hydrogen manufacturing cost range from 80 cents/equivalent gallon (from natural gas) to $4/equivalent gallon.[g] Including some transportation fees, the cost at the pump - given the cost reductions available with a large, assured market - could be as low as $1.45/eq. gallon for non-renewable hydrogen (from natural gas). Hydrogen from renewable resources will be more expensive, perhaps $3 in some locales.

We emphasize that the CAN fleet of three trucks is but a quick and crude conversion of an engine designed for gasoline use. Trucks designed specifically for hydrogen fuel will be more drivable and more efficient. In fact, much more efficient if hybrid design is used[10]. Given these improvements, the range of a state of the art hydrogen truck can be over 300 miles, and the **cost of renewable hydrogen fuel becomes less than 5 cents per mile.** Considering the national economic security, job creation and export potential in combination with health benefits, a national opportunity exists.

The CAN demonstration features on-site PV generation of the hydrogen fuel. It is important at this time to implement site specific generation using different methods. An important next step will be hydrogen production at a wind generation site. Biomass and waste pyrolysis are also of interest for some sites.

Large scale implementation of hydrogen for fleet use is now appropriate in urban areas. The immediate public health benefit will be the substitution of water vapor for the present toxic carbon monoxide and hydrocarbons from car engines or the toxic particulates and fumes from diesel engines. Potentially of great importance are increased operator safety and assured fuel supply. These trucks will not be idled by turmoil in the mideast - a factor that will be of key importance to companies that need assured transportation!

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[f] The "equivalent gallon" used by Cannon, and herein, is that amount of gas which contains the energy of a gallon of gasoline. However, the "equivalent gallon" quantity of hydrogen may be <u>much</u> more effective, with the range of a 21st Century hydrogen vehicle likely approaching 80 miles per equivalent gallon. Hence when Cannon refers to hydrogen at $3 per equivalent gallon, we are speaking of $12 to $15 to fill the tank.

[g] Our analysis shows wind generated electricity driven electrolysis to be a most attractive renewable source. Using **today's cost** (5 cents per kilowatt hour) for wind electricity, the hydrogen cost at generation site would be $2.60/equivalent gallon. This would likely be halved in the next decade.

Solar Hydrogen Project Mission Statement

The Solar Hydrogen Project promotes the development and awareness of clean renewable technologies and the use of hydrogen as a means of energy storage, making available domestically produced and environmentally benign technologies essential to our national security and public health.

It is the intent of the Solar Hydrogen Project to develop clean technologies using solar fuel, and to demonstrate these technologies to the community. We invite innovative projects for collaboration. The site is open to visitors including - in particular - school children from surrounding communities. Hundreds of children have made Solar Hydrogen the subject of a field trip and class projects in recent months, providing for them a glimpse of the possibility of a pollution free energy economy.

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7. J. V. Hall et.al., "Valuing the Health Benefits of Clean Air", *Science* 255, (14 Feb. 1992)

8. L. Lave, M.D., in a Carnegie-Mellon University publication, estimates the nationwide cost at $30 Billion.

9. J.S. Cannon, Harnessing Hydrogen, op.cit., p. 207

10. Our analysis shows wind generated electricity driven electrolysis to be a most attractive renewable source. Using **today's cost** (5 cents per kilowatt hour) for wind electricity, the hydrogen cost at generation site would be $2.60/equivalent gallon. This would likely be halved in the next decade.

11. J. Ray Smith, The Hydrogen Hybrid Option, UCRL-JC-115425, Lawrence Livermore National Laboratory, 1993

BOEING

HYDROGEN GENERATION, STORAGE, AND DISPENSING SYSTEM SAFETY ASSESSMENT - A CASE STUDY

Kevin T. Knudsen

Member of the Technical Staff

Advanced Programs and Business Development

March 11-13, 1997

Boeing North American, Inc.
Rocketdyne Division

Introduction

- A brief description of ETEC
- Clean Air Now! - Background
- ETEC safety assessment
  - Approach
  - Findings
  - Results
  - Lessons Learned
- Summary

A Brief Description of ETEC

- Formerly a Department of Energy laboratory operated by the Rocketdyne Division of Rockwell International
- Presently a commercial testing facility for the Rocketdyne Division of Boeing North American, Inc.
  - Gas turbines
  - Hydrogen systems
  - Liquid metal systems
  - Seismic testing
  - Energy auditing

P.5

Past and Current Hydrogen Activities

- Safety analysis and testing for:
  - Clean Air Now photovoltaic, water electrolysis, hydrogen fueling station and hydrogen fueled pick-up trucks
  - DOE phosphoric acid fuel cell bus
  - Hydrogen generation by partial oxidation
  - Hydrogen purification by high temperature metal membranes
  - PEM fuel cells for stationary and vehicular application
- Design, construction, and safet...

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ETEC's Approach To Safety

- Adherence to:
  - DOE safety orders
  - Rocketdyne safety orders and procedures
  - Local/State/Federal regulations
  - Appropriate codes and standards
- Systems approach to safety
  - Safety analyses performed up front as part of the design process
    - Operational analysis
    - Casualty study (HAZOP)
    - Safety analysis

ETEC's Approach To Safety (continued)

- Rocketdyne "Won't Fail Analysis"
- Design and safety documents design reviewed
- System construction oversight required
- System readiness review required
- Health, safety, fire, and environmental oversight required during operations

Clean Air Now Project
Background

- Hydrogen generation, storage, and dispensing system using “off-of-the-shelf” hardware
    - 42kWe PV Array: Solar Engineering Applications Corporation
    - 424 SCFH Electrolytic Skid: Electrolyser Corporation
    - 5,000 psig Storage and Dispensing System: Praxair
- Located at the Xerox facilities in El Segundo, California
- System used to fuel Xerox utility vehicles converted to operate on hydrogen
- City of El Segundo was “uncomfortable” with this “new” technology

Clean Air Now Project
Background
(continued)

- City of El Segundo therefore required that:
  - A safety assessment be performed on the system
  - The safety assessment be performed by an independent agency, qualified in such analyses
- The safety assessment became a requirement to close the building permit and to obtain an operating permit
- ETEC hired to perform safety assessment
  - ETEC already under contract to perform performance and safety testing on the Xerox utility vehicles

ETEC Safety Assessment Approach

- Review and understand system operation
- Apply DOE safety orders and ETEC/Rocketdyne safety procedures
- Review system design against existing codes and standards
  - ASME/ANSI B31.1 Piping Code
  - ASME Boiler and Pressure Vessel Code
  - NFPA 50A, Standard For Gaseous Hydrogen Systems
  - NFPA 52, Standard For Compressed Natural Gas Vehicular Fuel Systems
  - NFPA 70, National Electric Code

ETEC Safety Assessment Findings

- Determined that all hazards were equivalent to other commonly accepted public and industrial hazards
  - High pressure gases
  - Flammable gases
  - Electrical
  - Noise
  - Chemical
  - Tripping
- Determined that adequate hazard controls were installed, precluding or mitigating identified casualty events
- Identified deficiencies in construction oversight

ETEC Safety Assessment Findings (continued)

- Mechanical and electrical deviations from applicable codes and standards found:
  - System valves not suitable for planned design conditions
    - Required the de-rating of the system from operation at 5,000 psig to 4,200 psig (relief valves reset)
  - Hydrogen storage separation distances per NFPA 50A not completely met
  - Some electrical components installed not rated for Class I, Division 2, Group B locations

ETEC Safety Assessment Results

- All identified construction and code problems and deviations were corrected
- Safety assessment was completed and released
  - Assessment reviewed by the City of El Segundo building department
  - Best management practices suggested for existing system
  - Recommendations made for future systems
- Building and operating permit signed off by the City of El Segundo building and fire departments

ETEC Safety Assessment
Lessons Learned

- Perform safety assessments before construction begins
  - Preferably during the project design phase
- Identify and brief appropriate permit, regulatory, and safety people early in the project
  - Appropriate people are site/location specific
- Construction oversight is critical
- Post-construction safety/readiness review is critical
- Safety must be approached and assessed with a systems viewpoint
- For public fueling stations, utilize NFPA 52 (CNG fueling systems) where applicable until a hydrogen standard is developed

Summary and Conclusions

- No "new" hazards were identified during this review
  - Identified hazards were equivalent to other commonly accepted public and industrial hazards
- Sufficient codes, standards, and safety practices exist such that hydrogen demonstration systems can be designed, built, permitted, and safely operated
- The performance of independent safety assessments on all hydrogen program demonstrations is critical
- Post-construction safety/readiness reviews on all hydrogen program demonstrations are critical
- Specific codes, standards, and safety practices for hydrogen systems would simplify the permit process

Clean Air Now

Clean Air Now's Solar Hydrogen Vehicle Project

A Hydrogen Fuel Technologies Deployment Project

at

Xerox Corporation

in

El Segundo, California

USA

DR. Paul Scott, Principal, Touchstone Technology; Project Engineer

James J. Provenzano, Executive Director

Presented at the 11th World Hydrogen Energy Conference, June 1996, Stuttgart, Germany

Where Is The $ Coming From?

- The White House Technology Reinvestment Project
- California AB2766 funding
- Clean Air Now's cost share
- Project Partners' cost share

Project Partners

- Clean Air Now (CA non-profit corporation - funded entity)
- United States Department of Energy
- South Coast Air Quality Management District
- Xerox Corporation, Corporate Strategic Services
- The Electrolyser Corporation, Buffalo, NY
- Praxair, Inc., Tarrytown, NY
- Energy Technology Engineering Center, Canoga Park, CA
- Touchstone Technology, Inc., Northridge, CA
- Kaiser Engineering, Highland, CA
- W. Hoagland & Associates, Inc., Boulder, CO
- City of West Hollywood, CA
- PhotoVoltaics International, Santa Clara, CA
- U. C. Riverside CE-CERT
- Matrix Construction & Engineering, San Marcos, CA

Some Project Outputs

- Safety & Failure Mode Assessments
- Systems emissions testing / data acquisition
- Validation & Certification by CARB
- Systems performance tracking & analysis
- Insurance industry rating (potential)
- Efficiency study (BTUs in Vs. BTUs out)
- Technology test bed/Tie-in to *Hydrogen Corridor*
- Public awareness/education campaign

Some Project Aspects

- Stand-alone “off the grid” system
  - including compression (8-12kW) (280-320SCFHw/cycling)
  - only data collection/monitoring will be on grid
- Round the clock use, “where the rubber meets the road”, by Xerox Maintenance personnel
- Lynch CVI unit technology for ICE retrofits
- Start w / 3 - 2.3L 4 cyl Ford Ranger pickups
- Vehicle improvements
  - Supercharged in lieu of Turbo (low-end torque)
  - Increase stroke/bore to 2.9L
  - Higher rear end ratio (4.10:1 or better)
- Station available to outside interests i.e. Ballard, other fleets, South Bay, LAX, etc.

Xerox & Site Benefits

- Xerox self insured
- "Top down" commitment to the environment
- Xerox site engineers have track record w / El Segundo / Fire Department
- Senior site management are engineers and knowledgeable about technologies
- Xerox familiar w / H2 handling & use onsite
- El Segundo familiar w / H2 - SCE & others
- E, H & S resources and internal review process lent to the project
- Hurdles are internal politics/non-core business issues

The Developing Hydrogen Corridor

Southern California

Presented at the 11th World Hydrogen Energy Conference
June 1996,
Stuttgart, Germany

Robert M. Zweig, MD
Chairman
Clean Air Now

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 fuel combustion with hydrogen would eliminate both of these pollutants along with the majority of all the carbon-based emissions.

Dr. Alan Lloyd, ex-Chief Scientist for the SCAQMD, stated very aptly in 1991: "In order for the District to achieve its air quality goals, all available clean technologies need to be implemented. The future potential for hydrogen is significant. The lack of sufficient technological research and development efforts, coupled with limited funding resources, and an absence of determined, focused national energy agenda, has provided a limited exploration of hydrogen potential to date. For hydrogen to become a viable energy option in the United States, progress in the production, handling, and storage of the fuel are essential."

Hence, Clean Air Now has formulated a master plan to develop and demonstrate the hydrogen energy economy. The integrated "Hydrogen Corridor" will extend from the Pacific ocean at Clean Air Now'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 for the hydrogen economy.

Hydrogen: Energy Carrier for a Sustainable Society

Transportation: It has been estimated that transportation is responsible for more than 65% of Southern California's air pollution and 50% in the San Francisco Bay area. The simple elegance of hydrogen is that it is derived from water and becomes water again when combusted or used in a fuel cell. Promoting hydrogen as a vehicle fuel will create jobs while reducing the automobile's impact on the environment and public health. Hydrogen can be used as a clean burning fuel in internal combustion engines, hydrogen hybrid vehicles, and fuel cells for electric vehicles.

Immediate Markets:

- **Corporate**: Strict new federal and state clean air laws mandate the use of clean fuel fleets for large companies located in the Los Angeles area. These purchases represent a great potential market for purpose built and converted hydrogen vehicles.

- **Government**: Municipal purchases are an enormously important catalyst for the acceptance of emerging technologies. Clean Air Now will actively court municipal fleet purchasers to demonstrate converted and purpose built hydrogen vehicles in their zero and ultralow emissions vehicle fleets.

- **Public Utilities**: California's electric utilities are increasing their use of wind, solar, and geothermal produced electricity. Unfortunately, these forms of electrical generation are subject to natural forces, while consumer demand is not. Hydrogen and fuel cells are effective peak power storage and load leveling mechanisms. Operators of natural gas power plants can also be counted among prospective customers, as Hythane can help them meet air quality requirements without costly emissions controls.

Economics of Hydrogen:

Advancements in fuel cell development, and declining prices for solar, wind and geothermal electricity have made renewably generated hydrogen increasingly attractive. As the manufacture of these technologies improves, the costs will continue to decrease.

Hydrogen can be produced with electricity from advanced wind turbines for as little as $1.16 per gallon of gasoline equivalent. While this is a competitive price, one should consider the absence of any pollutants from production or use, and hydrogen is three times as efficient an energy carrier as gasoline.

Infrastructure Components in Southern California:

- **Clean Air Now Solar Hydrogen Vehicle Project**: Currently, CAN is administering the solar hydrogen refueling facility and fleet vehicle conversion program at Xerox Corporation's facilities in Southern California. This facility is the largest demonstration site of its kind in the United States and, as such, will be of paramount importance with regard to increasing public awareness and acceptance of hydrogen as a transportation fuel and renewable energy storage medium. High-pressure storage with state-of-the-art composite tankage is being used.

- **Large Scale Production:** Ultimately, Clean Air Now proposes a 100 MW solar hydrogen production facility in Southern California, and a 60 MW facility in the San Francisco Bay region. These sites would provide fuel for hydrogen vehicle fleets and serve as clean energy production facilities. The initial phases would consist of a 2-3 MW solar facility at ETEC (see below) and a 1 2 MW solar facility at one of the San Francisco area military bases due to be closed.

- **Energy Technology Engineering Center (ETEC)**: Canoga Park. A national laboratory available through the US. Department of Energy (DOE) to assess the necessary engineering quality control, safety and environmental aspects of new hydrogen demonstrations in the SCAQMD.

- **City of West Hollywood:** The city will be using a hydrogen vehicle in its city fleet. The practical demonstration vehicle approach is an integral part of efforts to increase public awareness and understanding of hydrogen technologies.

- **South Coast Air Quality Management District (SCAQMD):** Diamond Bar. The SCAQMD Technology Assessment Office (TAO), developed under the previous leadership of Chief Scientist Dr. Alan Lloyd and Dr. James Lents, is considered a prime candidate for coordinating the entire regional demonstration project. The SCAQMD has offered financial support for hydrogen programs for years. A basic conceptual hydrogen infrastructure is in development, demonstrating solar electrolysis production, transmission, and end use in internal combustion engine vehicles and fuel cell electric vehicles, including the Ballard Power System's phase 1 bus, and eventually trucks and locomotives. Other programs supported by the SCAQMD that are prime for full integration into the hydrogen corridor include the Palm Desert/Schatz/Humboldt State University/Lawrence Livermore National Laboratories fuel cell program, U.C Davis, Sacramento Municipal Utility District, UCR, CAN and Kaiser Hospital's fuel cell, and their own stationary fuel cell/natural gas and electric vehicle programs.

- **Praxair Hydrogen Production Plant:** Ontario. This plant is able to produce enough hydrogen, using natural gas steam reforming, for the entire corridor during the initial phase of the demonstration project. This will be the only merchant facility using fossil fuel hydrogen. Praxair will continue to supply hydrogen until the basin can be completely converted to solar production. Dr. Joan Ogden of Princeton University has just published her findings concluding there is currently enough excess hydrogen production in the South Coast District to support 100,000 vehicles and 2,000 buses. Local reforming, trucking, rail, and pipelines are all feasible forms of hydrogen transmission.

- **University of California Riverside CE-CERT:** Riverside. This institution has an ongoing hydrogen research, development, and demonstration program. The facility produces solar hydrogen for use in campus fleet vehicles. UCR College of Engineering Center for Environmental Research and Technology (CE-CERT) is available for emissions testing on all hydrogen and alternative fuel vehicles in the SCAQMD. Future plans call for further expansion of the UCR hydrogen vehicle fleet and basic and applied hydrogen research.

- **Kaiser Engineering:** Highland. This small business has been active for over 20 years in converting internal combustion engines from fossil fuels to hydrogen, beginning with the original Zweig Dodge D50 truck. Kaiser, along with Hydrogen Consultants, Inc. performed the ice retrofits for UCR and Clean Air Now.

- **City of Palm Desert:** Several hydrogen programs include electric golf cart conversion from batteries to hydrogen fuel cells and hydrogen production by electrolysis, using photovoltaic systems and wind power available in the San Gorgonio Pass. Palm Desert is positioning themselves as a technology and manufacturing center for hydrogen energy systems.

- **Aero Environmental:** Solar hydrogen aircraft.

- **Los Angeles International Airport:** Energy Partners of West Palm Beach along with Ogden, Inc. is currently retrofitting ground vehicles with fuel cell power plants.

- **NASA:** Edward Air Force Base. NASA in cooperation with the US Navy is constructing a closed-loop PV-Electrolysis-Fuel Cell test bed.

With the development of a hydrogen-related infrastructure, progress of hydrogen demonstrations will be expedited. Coordination with the above mentioned parties and manufactures Daimler-Benz, BMW, Mazda, Toyota, Ballard Power Systems, Energy Partners, etc., the SCAQMD is poised to become a showcase for the entire world regarding the use of hydrogen as a transportation fuel. This will play a critical role in alleviating the health and environmental problems resulting from the combustion of fossil fuels.

Development of an Integrated Hydrogen Infrastructure in Southern California:

California has been a pioneer in the use of hydrogen as a clean burning fuel. The South coast Air Quality Management District (SCAQMD) is a living laboratory for testing benefits of hydrogen utilization as a healthful, environmentally safe fuel. A historical review of hydrogen programs will highlight significant milestones of hydrogen system development:

- 1970 -- Under the direction of Professor Van Vorst and the late Alfred Bush, an American Motors Corporation "Gremlin" was converted at University of California Los Angeles to use high-pressure gaseous hydrogen. Later a United States Post Office jeep was converted to use liquid hydrogen.

- 1972 -- Paul Diegas and Ben Minnick, of Perris, CA, developed a hydrogen vehicle using liquid hydrogen and liquid oxygen on board a small truck. The pilot vehicle was operated by remote control and had a limited life span, but did demonstrate the feasibility of hydrogen vehicle conversions. Diegas and Minnick went on to convert two more vehicles, which were driven on public highways.

- 1973 -- Dr. James Pitts, Director of the California State Air Pollution Research Center at University of California Riverside (UCR) proclaimed that the use of hydrogen as "the universal fuel" would eliminate all of California's air pollution problems.

- 1973 -- California engineering schools clean fuel rally demonstrated various alternative fuel vehicles at the Riverside International Raceway. The committee found hydrogen to be the cleanest of the alternative fuels.

- 1975 -- A Helioscience Conference was held in Palm Springs to investigate the feasibility of using solar energy to produce various energy carriers, such as hydrogen.

- 1976 -- The city of Riverside operated a 19 passenger hydrogen bus, which was evaluated by the California Transportation Authority (CalTrans). Their conclusion: "The hydrogen bus utilized its fuel very efficiently and could reduce air pollution in the South Coast Air Basin (SCAQMD); therefore, hydrogen vehicle technology should be pursued further."

- 1978 -- A United States Department of Energy (DOE) study entitled "Energy Needs in Riverside, California" was performed by Battelle Columbus Laboratory. Their conclusions and recommendations are as follows: "Two synthetic fuels not dependent on petroleum appear to be feasible as substitutes for petroleum-based fuels. These are hydrogen in liquid form and methyl fuel. A satisfactory large scale demonstration of the feasibility and problems associated with the use of these alternative fuels could be conducted with the city of Riverside fleet vehicles."

- 1980 -- A solar hydrogen conference was held at UCR. It was there that a new conversion was presented. This vehicle was a Dodge D50 truck converted by Dr. Robert M. Zweig and Clean Air Now, Denver Research Institute, and Ergenics. It was driven from Denver to Riverside, refueling from a tube trailer supplied by Air Products Corporation.

- 1990 -- A solar hydrogen program was established at Riverside Community College, which was later transferred to the University of California Riverside(UCR). The University plans to have three vehicles running on hydrogen fuel. As the project continues, the staff will implement and test modifications, perform vehicle demonstrations for the AQMD, and conduct ongoing engine analyses.

- 1994 -- During a meeting of the task force committees for the Department of Energy and AQMD regarding hydrogen, both organizations recommended that more demonstration and education programs be pursued to educate the public and elected officials about the beneficial use of hydrogen as an alternative fuel.

- 1994 -- Sandy Thomas, Former Legislative Assistant for U.S. Senator Tom Harkin reported on the need for "Sustainable Energy." His recommendations are as follows: "To speed the development and utilization of hydrogen in the near-term, and to prepare for the eventual widespread use of renewable hydrogen, we propose the creation of regional 'Sustainable Energy Centers.' These centers would provide engineers and technicians with 'hands-on' experience in the safe production, storage, and use of hydrogen. They would also serve as demonstration centers to educate and familiarize the public with the advantages of hydrogen. New hydrogen production, storage and utilization devices could be tested at the centers, and new hydrogen applications developed."

- 1994 -- Eleven California State Legislators recommend to the California Transportation Authority (CalTrans) that all new alternative fuel vehicles developed in the state of California be operated in Riverside and San Bernardino Counties. "Concentrating the vehicles in one region will encourage private business to locate fueling stations and other alternative fuel vehicles there."

- 1994 -- Dr. Alan Lloyd, Chief Scientist with the SCAQMD, testifies before Congress about the benefits of hydrogen and the need for additional research and funding.

- 1994 -- Clean Air Now (CAN) was awarded $1.25 million from the White House Technology Reinvestment Project and $250,000 from the SCAQMD through AB2766, a state fund for pollution abatement programs. The project involved the construction and installation of the largest application in the U.S. of a solar hydrogen generating facility and fueling station. A fleet of Xerox and the City of West Hollywood utility vehicles were converted to run on the solar hydrogen.

The South Coast Air Basin is the site of many developmental hydrogen programs. These programs are designed to share data and encourage proliferation of viable technology for mass production and utilization of hydrogen. In this way we can move to an energy system comprised of non-polluting renewable sources with hydrogen used as a fundamental energy carrier and storage medium. By doing this we would alleviate many health problems, create good jobs, move toward domestic energy independence, and protect our fragile planet from disastrous climate changes.

Demonstration of Fleet Trucks Fueled with PV Hydrogen

J. Provenzano, P. B. Scott, R. Zweig

Clean Air Now
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Riverside, CA 92503

Abstract

The Clean Air Now (CAN) Solar Hydrogen Project has been installed at the Xerox Corporation, El Segundo, California site. Three Ford Ranger trucks have been converted to use hydrogen fuel.

The "stand-alone" electrolyzer and hydrogen dispensing system is solely powered by a photovoltaic array. A variable frequency DC-AC converter steps up the voltage to drive the 15 horsepower motor for the hydrogen compressor. Up to 14,000 standard cubic feet (SCF) of solar hydrogen is stored, and storage of up to 80,000 SCF of commercial hydrogen is co-located. As the hydrogen storage is within 3 miles of Los Angeles International airport, pilot operation of a hydrogen fuel cell bus for airport shuttle service has been demonstrated with fueling at the CAN facility.

The truck engine conversions are bored to 2.9 liter displacement, use a Roots type supercharger and CVI (constant volume injection) fuel induction to allow performance similar to that of the gasoline powered truck. Truck fuel storage is done with carbon composite tanks at pressures up to 3600 psi. Two tanks are located just behind the driver's cab, and take up nearly half of the truck bed space. Truck range is 144 miles, given a 3600 psi fill of hydrogen. The engine operates in lean burn mode, with nil emissions from CO and HC. NOx emissions vary with load and rpm in the range from 10 to 100 ppm, yielding total emissions at a small fraction of the ULEV standard. Two trucks have been converted for the Xerox fleet, and one for the City of West Hollywood. All are in active service for their owners.

The Clean Air Now program demonstrates that hydrogen powered fleet development is an appropriate, safe, and effective strategy for improvement of urban air quality. It further demonstrates that continued technology development and cost reduction will make such implementation competitive.

I - INTRODUCTION

Air pollution reduction, energy security and global warming aversion motivate us to use hydrogen as a vehicle fleet fuel. Clean Air Now (CAN), a California non-profit public interest and advocacy corporation, has teamed with the White House Technology Reinvestment Project to fund and install renewable hydrogen generation and a fleet of hydrogen fueled trucks at a Xerox Corporation facility near Los Angeles International Airport.[a]

The intention is to demonstrate technical feasibility of hydrogen as a clean fuel, leading to corporate and public acceptance of hydrogen technologies.

Herein we first describe the hydrogen generation and storage, then the truck conversions to use the hydrogen as a fuel. The role of Xerox Corporation, safety and economic acceptance will also be discussed.

II - THE STAND-ALONE HYDROGEN GENERATOR

Hydrogen fuel is unique in that it yields heat with neither carbon monoxide or dioxide, hence poisoning neither life nor earth. The CAN Solar Hydrogen Generator is designed to "stand-alone", i.e. have no connection to the commercial power grid, such that all hydrogen produced results from solar energy. The CAN trucks run on a truly renewable fuel, as it is produced by using electricity from the sun's energy to split water to hydrogen, which recombines with oxygen to water by combustion in the engine of the truck.

Xerox Corporation considers social and environmental responsibility essential to a healthy long-term bottom line. This philosophy, the source of its strong Corporate Environmental Policy, paved the way for this hydrogen fuel fleet demonstration project.

Figure 1 schematically shows sunlight converted to electricity powering the electrolyzer. The system is designed for operation at 18 volts, with currents to 2700 amperes. Water purification is by ion exchange membrane. The compressor is also powered from the solar array, with a variable frequency DC to AC inverter which

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[a] CAN acknowledges funding from the South Coast Air Quality Management District and the White House Technology Reinvestment Project. Cost sharing investment was also made by all contractors.

provides for a "slow start" for the compressor. It is accepted that the compressor cannot be run at low insolation, hydrogen generated during these periods is stored in the gasholder.

Batteries, recharged only from the PV array, are used for control functions to ensure that the electrolyzer runs optimally even with nil or low insolation.

Dual steel cylinders store the solar hydrogen at pressures up to 5000 psi. The supplemental hydrogen storage has been installed for commercial hydrogen, which is trucked to the site by tube trailers. Due to trucking regulations the supplemental hydrogen is limited to 2200 psi pressure. We expect that the solar hydrogen supply will be adequate for the truck fleet, the commercial hydrogen is provided to assure that we can meet the needs of visitors (such as for the Ballard bus demonstrations).

The hydrogen dispensing station is used to make the connection from the storage to the tankage on the trucks. Both the commercial and the solar hydrogen storage are kept separate in two (higher and lower pressure) reservoirs. Fill valves allow the operator to select from first the lower pressure, then topping off from the higher pressure storage (of either solar or commercial hydrogen).

Meticulous attention to grounding is essential to safety when using hydrogen, as a consequence of the low ignition energy. Multiple ground rods are located near the fueling station and near the electrolyzer, with a massive copper cable and brazed connections assuring all locales are at the same potential.

Operation of the solar hydrogen generator will follow permitting by the City of El Segundo. At time of writing (January '96) the single-axis tracking Fresnel lens photovoltaic array was undergoing an upgrade to improve performance.

Figure 2 shows the photovoltaic array and electrolyzer installation. The Ballard prototype fuel cell bus is shown during fueling in Figure 3.

III - THE HYDROGEN FUELED TRUCKS

Three Ford Ranger trucks were converted to store and use compressed gaseous hydrogen as fuel. Figure 4 shows a "family photo" of the trucks.

Vehicle safety is of paramount concern. The use of hydrogen as the fuel is itself a key safety feature, as it avoids fires following liquid fuel spills. Were the flammable gas to escape, it most likely would burn harmlessly while rising above the vehicle. To prevent such escape, additional structure has been added to protect the tankage and fuel lines from a side impact collision. Dual check valves and an excess flow limiting valve protect from a regulator or line failure.

Hydrogen leak detectors are located under the hood and in the bed near the fuel lines. A leak detected causes an aural alarm and visual display in the cab.

The engine controller delays fuel injection and spark for 1/2 second after cranking starts, and as the key is turned off continues the spark following fuel flow shutdown.

A large crankcase relief valve is provided to open in case of a pressure rise in the crankcase/valve cover space.

Transferring hydrogen to the trucks is a critical step. Grounding is an essential safety precaution. Figure 5 shows the ground cable (#4 copper) connected to the ground receptacle on the truck body. Mating *Tweco* welding connectors are used, which require insertion and then a twist. The twist motion retracts a pin from the fuel port door, allowing the door to pop open yielding access to the fuel connector.

The truck bed mounts dual carbon fiber wound tanks, storing 2418 SCF hydrogen at 3600 psia. Range, using fuel to approximately 100 psi, is 144 miles.

The truck engines are converted from the stock 4 cylinder, 2.3 liter Ford engine. Bore and stroke are increased to 2.9 liters and a supercharger further increases mass airflow. The hydrogen injection system is of the Constant Volume Injection (CVI) design. Engine compression ratio is increased to 11:1 to enhance efficiency. Air heating caused by the supercharger boost, as high as 7 psi, is removed by a large crossflow intercooler.

The equivalence ratio (hydrogen-air mixture ratio) is run ultralean - at less than 0.5 of stoichiometric - to reduce the flame propagation speed, promote "cool" combustion and minimize NOx production. An exhaust gas oxygen (EGO) sensor is used in the CVI control loop to continually monitor the degree of combustion and maintain a set mixture.

Misfires, and even backfires, have been observed with hydrogen fueled engines. Although these engines have not backfired as such, misfires do occur sporadically. This is most bothersome with the first truck (which we designate CAN1), perhaps because of observed lubricating oil residue in the combustion chamber. Some or all of this oil comes from the CVI system, which requires oil lubrication for its cam which lifts the CVI poppet valves.

Each of the three trucks was evaluated using the chassis dynamometer and associated instrumentation at the University of California at Riverside, College of Engineering, Center for Environmental Research and Technology (CE-CERT) under contract to CAN. Proper adjustment of the CVI controller was found to be critical to proper operation. For example, CAN1 initially was subject to surging and excessive Nox, with highly irregular combustion pressures. CAN3 originally was set up to run very lean, at equivalence ratio of approximately 0.32, with the result of reduced low end performance and extremely low Nox - below 35 ppm.

Chassis dynamometer tests show the hydrogen fueled engine is substantially more powerful than the stock gasoline powered engine at all but the highest engine speeds. Peak power occurs at about 4000 rpm, at which the converted engine power exceeds that of the stock by over 40%. Even at this highest power level, measurement shows less than 100 ppm Nox.

The dramatic progress in cleaning our environment made possible with use of hydrogen is shown in Figure 6. Before 1900 the horse, with some 940 grams/mi "emissions"[1], was for centuries the preferred means of personal transport. Barely a hundred years from the introduction of the horseless carriage the total emissions are down to 12.5 gm/mi (for the average car on Los Angeles freeways), or even down to 2 grams/mi for a modern car meeting the ULEV standard. UCR1, the first of the Ford Ranger trucks converted to hydrogen fuel two years ago at the UCR CE-CERT facility, tested at a total emissions (CO, HC and Nox) of 0.37 grams per mile. The CAN trucks are considerably cleaner than UCR1. Below 0.1 gm/mi is achievable at will. Another benefit - the greenhouse gas yield is also cut by factors of hundreds (using renewable hydrogen).

IV - IMPLICATIONS AND CONCLUSION

Cost appears as the only drawback of renewable hydrogen.

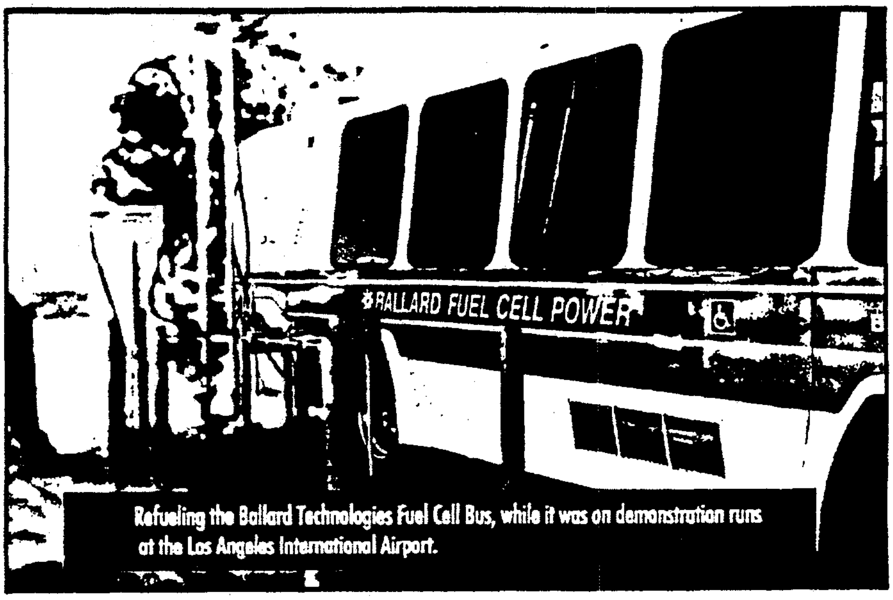


Figure 3. A Ballard fuel cell powered bus refueling at CAN/Xerox.

Figure 4. The Xerox (white) and West Hollywood hydrogen fueled trucks.

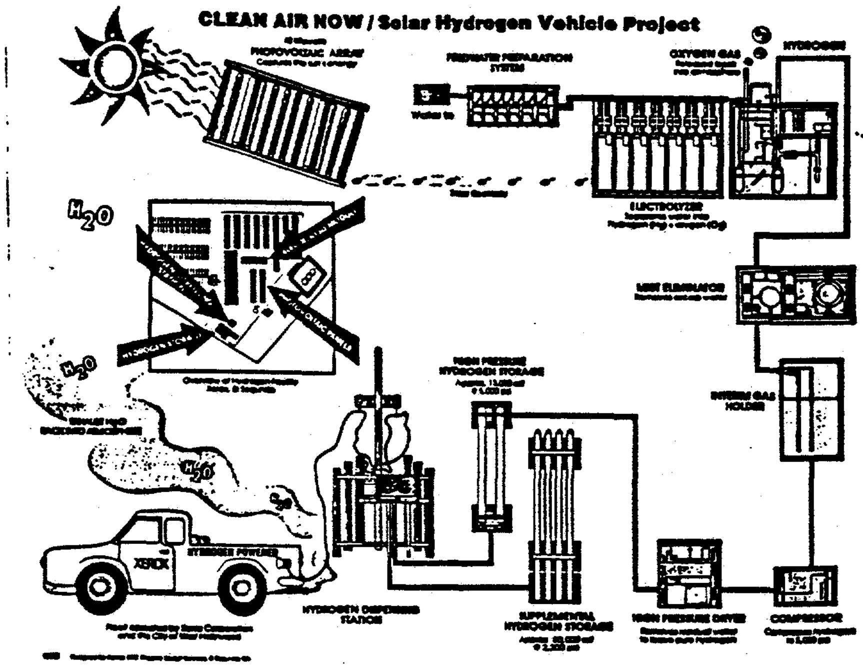


Figure 1. Solar hydrogen generator, fueling station and truck.

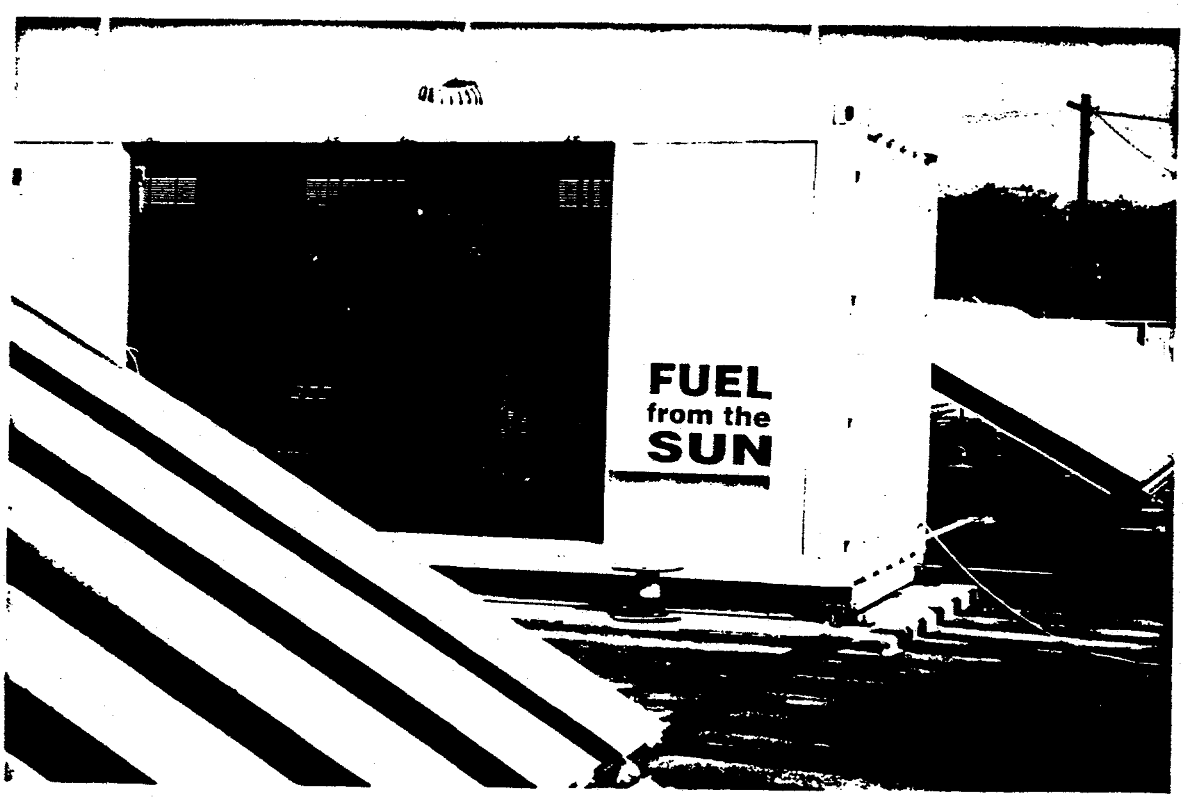


Figure 5. Illustrating use of the "fail-safe" ground, opening the fuel door.

Figure 6. Showing emissions reductions over the last century.

Bill, James
For your critical comment.
P.28

Abstract for the 11th World Hydrogen Energy Conference:

Demonstration of Fleet Trucks Fueled with PV Hydrogen

J. Hansen, W. Hoagland, W. Kaiser, J. Provenzano, P. Staples, P. Scott

Photovoltaic hydrogen generated at a Xerox Corporation maintenance site (El Segundo, California) is used to fuel converted Ford Ranger trucks which do short haul trips for maintenance personnel. Clean Air Now, a non-profit Corporation, has obtained South Coast Air Quality Management District and U.S. Government Technology Reinvestment Project funding, with support from eight participating firms.

Single axis tracking Fresnel lens concentrators, with approximately 10 to 1 concentration ratio and single crystal silicon photovoltaic cells are used on the 48KW PV array. At peak sun the array supplies 2500 amperes at 19 volts to the electrolyzer. The "stand-alone" electrolyzer system is solely powered by the PV array. A variable frequency DC-DC converter steps up the voltage to drive the 15 horsepower motor for the compressor, bringing the hydrogen pressure to a maximum of 5000 psi. Up to 14,000 standard cubic feet (SCF) of PV hydrogen is stored, and storage of up to 80,000 SCF of commercial hydrogen is co-located. As the hydrogen storage is within 3 miles of Los Angeles International airport, pilot operation of a hydrogen fuel cell bus for airport shuttle service has been demonstrated with fueling at the Xerox facility.

The truck engine conversions are bored to 2.9 liter displacement, use a Roots type supercharger and CVI (continuous volume injection) fuel induction to allow performance similar to that of the gasoline powered engine. Truck fuel storage is done with composite tanks at pressures up to 3600 psi. The tankage is located just behind the driver's cab, and takes up nearly have of the truck bed space. Range of the truck is in excess of 70 miles. The engine operates in lean burn mode, with nil emissions from CO and HC. NOx emissions vary with load and rpm in the range from 200 to 1000 ppm. Two trucks have been converted for the Xerox fleet, and one has been converted for the City of West Hollywood.

The Clean Air Now/Xerox program demonstrates that hydrogen powered fleet development is an appropriate, safe, and effective strategy for improvement of urban air quality. It further demonstrates that although this deployment of available technology is adequate to satisfying the basic needs of a maintenance fleet, only further technology development will make such implementation competitive.

Clean Air Now

Benefits of Renewable Hydrogen

- **100%** pollution-free
- **100%** sustainable - feedstock is automatically regenerated
- "Bottling" sunshine
- Safe
- Makes heat and/or electricity
- Frees customer/nations
- Will only get cheaper
- As "green" as it gets

-Pollution free when used in fuel cell

-Renewable/forever fuel/"closes the loop"

-Wind in Alaska can power a bus in Los Angeles, etc. Stores renewable energy

-Relative Vs. absolute. In relation to other fuels: does not pool, smoke, etc.

-Combustion for ICEs/turbines/burners and electrochemical generation of clean electricity

-No longer tied to one supplier, fuel, or infrastructure. Stand-alone, off-the-grid capability. Not subject to price shocks

-Capital costs will come down w/economies of scale. Inexhaustible

-1990 Energy Policy Act recognition

-CEC recognition

-CARB recognition

Clean Air Now

Requirements for Near Term Implementation

- Partnering
- Benefits to the environment is focus
- Operating costs emphasized
- "Trailblazing into future"
- Independence emphasized
- Data acquisition, systems testing & analysis
- Safety & failure mode analysis
- Insurance industry rating
- *Education, education, education*

-Public/private partnerships. Interested parties' subsidies needed for introduction of 'new" technology into civilian markets

-Long term savings. The "right thing to do"

-Operating costs currently competitive with fossil fuels. Capital costs will come down - calculators, computers (IC's)

-Pride in ownership

-Off-the-grid/infrastructure. Can produce fuel at home. Forget OPEC

-Validation & certification by CARB

-Education of local permitting agencies. Separate hydrogen code development

-Data and track record establishment

-Public/policy makers buy-in

-Technology has all ready been proven

Clean Air Now

Hydrogen is Overcoming the Hurdles

- Technologies have proven track record
- Investment and interest is growing
- Bi-partisan support
- Renewable energy continues to become more competitive
- Infrastructure/end use is developing
- Distributed power brings IP's more into the picture
- Public is understanding technology/myths
- Oil price shocks will continue to focus attention
- Environmental & health concerns providing impetus

-NASA's 35 years (hydrogen engines, fuel cells), electrolysis well known, etc.

-Japan, Germany, Canada, US, Partnership for a New Generation of Vehicle, Ballard, Allied Signal, United Technologies, Auto makers. Fuel cells are the integrated circuit of the 21st century

-Bills from both sides. Fuel Cell recognized as ZEV in new 3/96 CARB determination for mandate

-Wind, PV

-Show Hydrogen Corridor map

-Foreign markets, storage requirements (PV, wind), off-the-grid

-Education efforts by CAN, U.S. Department of Energy, UCR

-Current situation

-Global warming fears, European insurance companies, $14B cost in S. California., etc.

CAN/Xerox Solar Hydrogen Fleet

Supercharged Hydrogen Fueled Trucks

W. Kaiser, J. Provenzano, P.B. Scott, P. Staples, R. Zweig

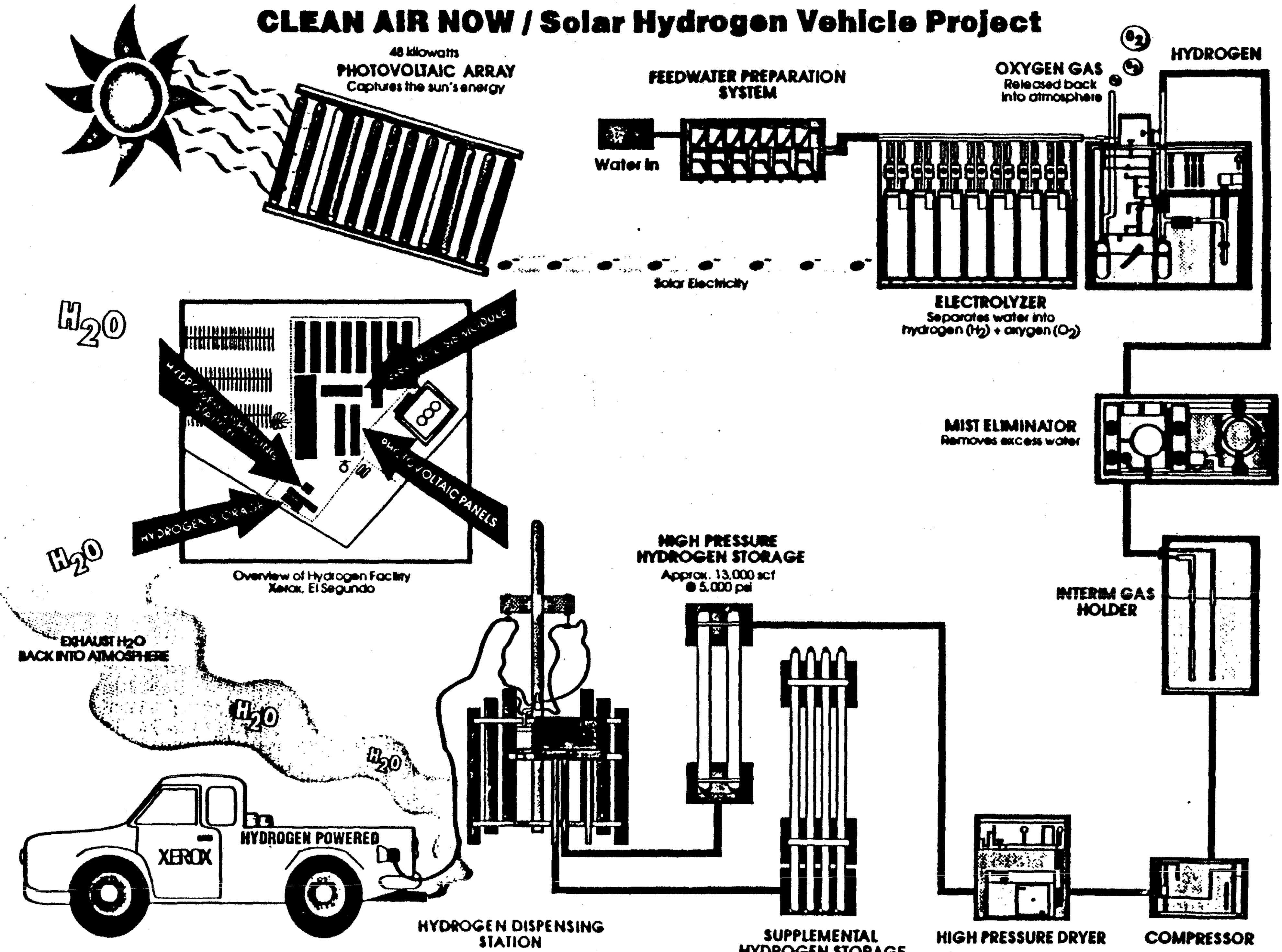
Clean Air Now, Riverside, CA

Michael N McClanahan

UCR CE-CERT, Riverside, CA

Funded by SCAQMD, TRP

CLEAN AIR NOW / Solar Hydrogen Vehicle Project

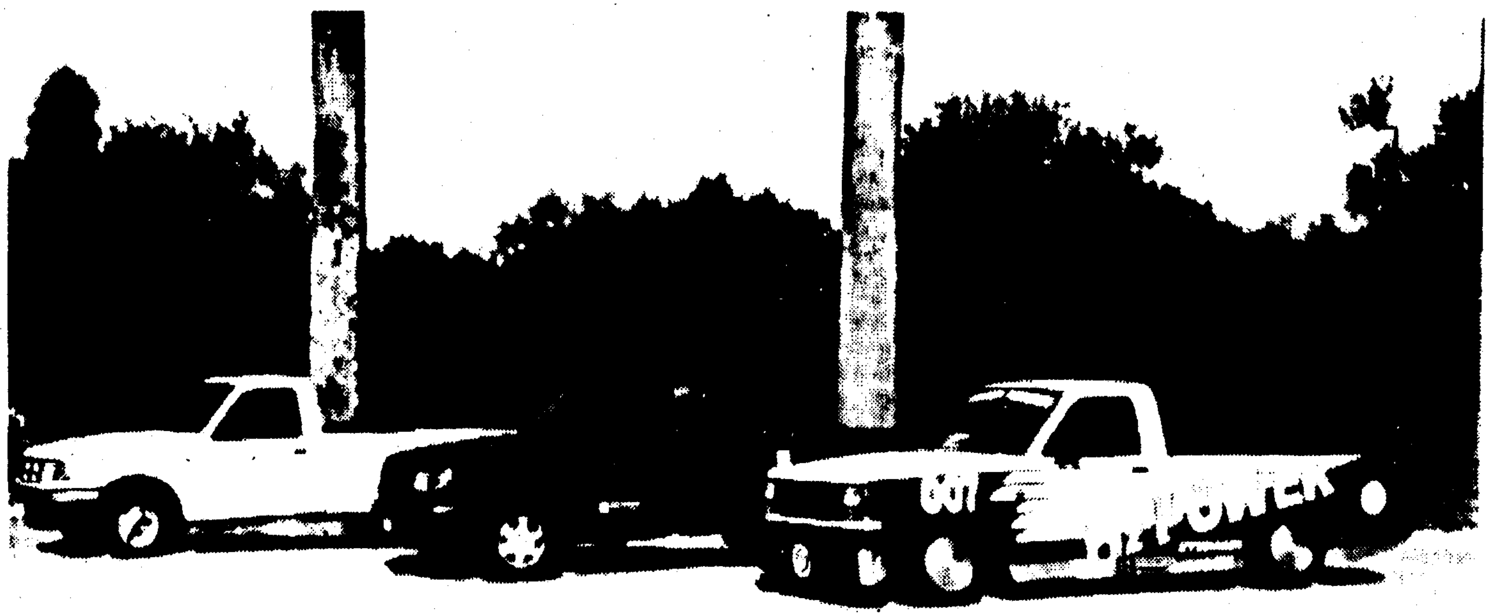


Overview of Hydrogen Facility
Xerox, El Segundo

and the City of West Hollywood

9/98 Designed by Xerox DTC Graphic Design Services, El Segundo, CA

UCR1, CAN2, CAN3



CAN/Xerox Solar Hydrogen Fleet

Vehicle Specifications

Hydrogen Fueled Ford Ranger Trucks

Chassis & Body........................stock Ford Ranger, with added structural cage around fuel line manifold

Engine............................crossflow I4, cast iron heads & block

Valve train..sohc, 2 valve/cyl.

Displacement............................stroked, overbored to 2900 cc

Bore x stroke..9.78 x 9.65 cm

Compression ratio..11.0:1

Fuel...gaseous hydrogen

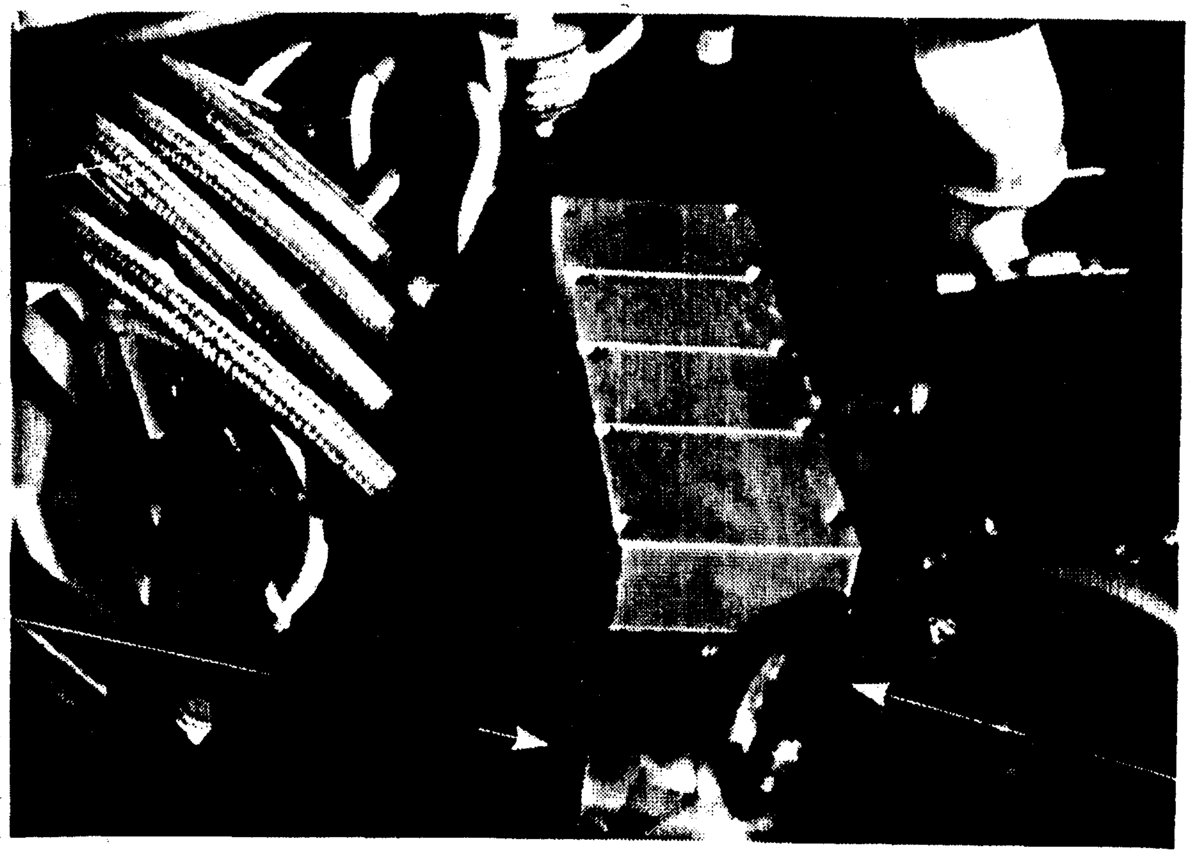
Air induction................spiral Roots supercharger, intercooled

Boost...4-7 psi

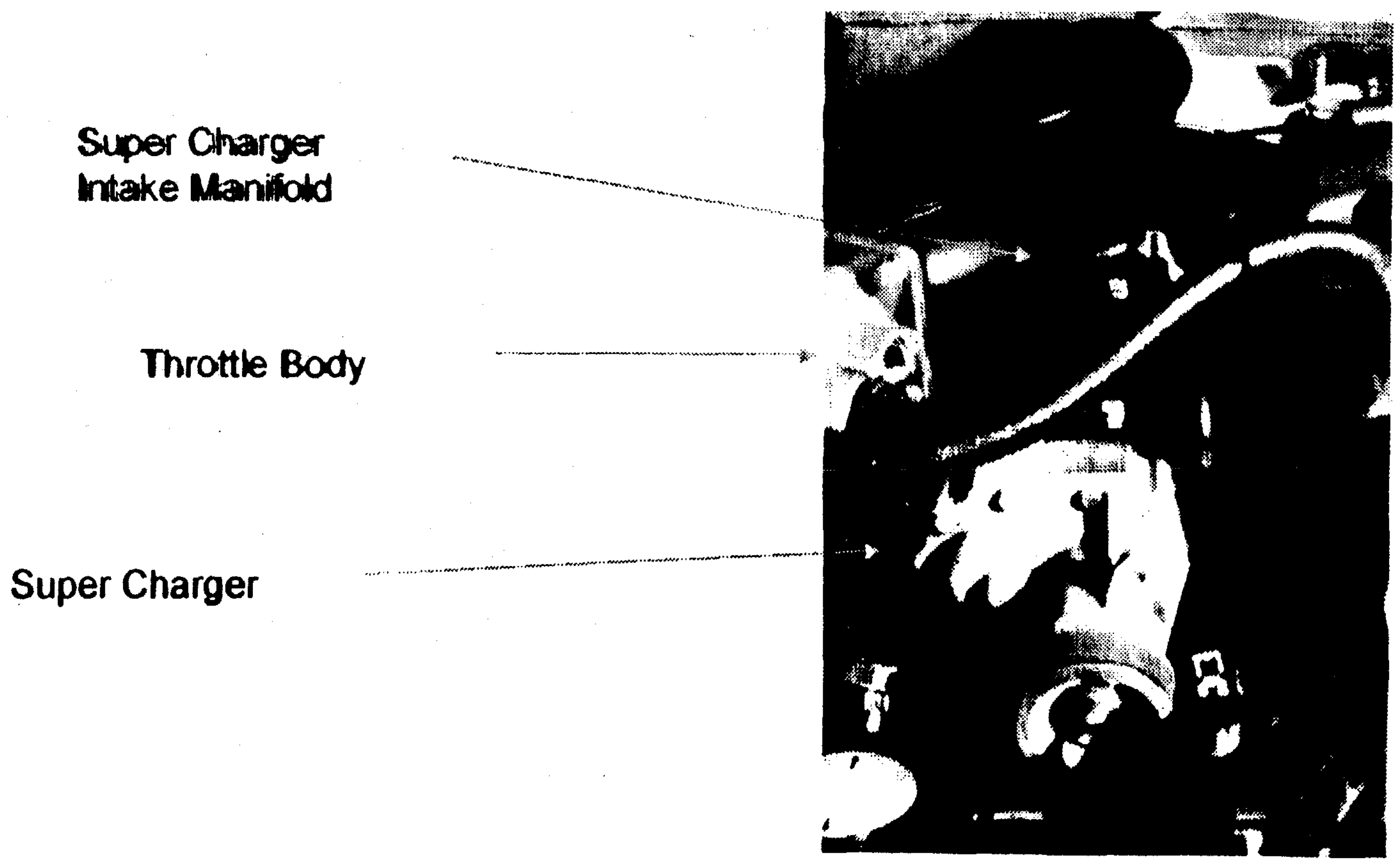
Fuel storage....................................2 carbon wound tanks, approx. 2600 scf @ 3600 psig

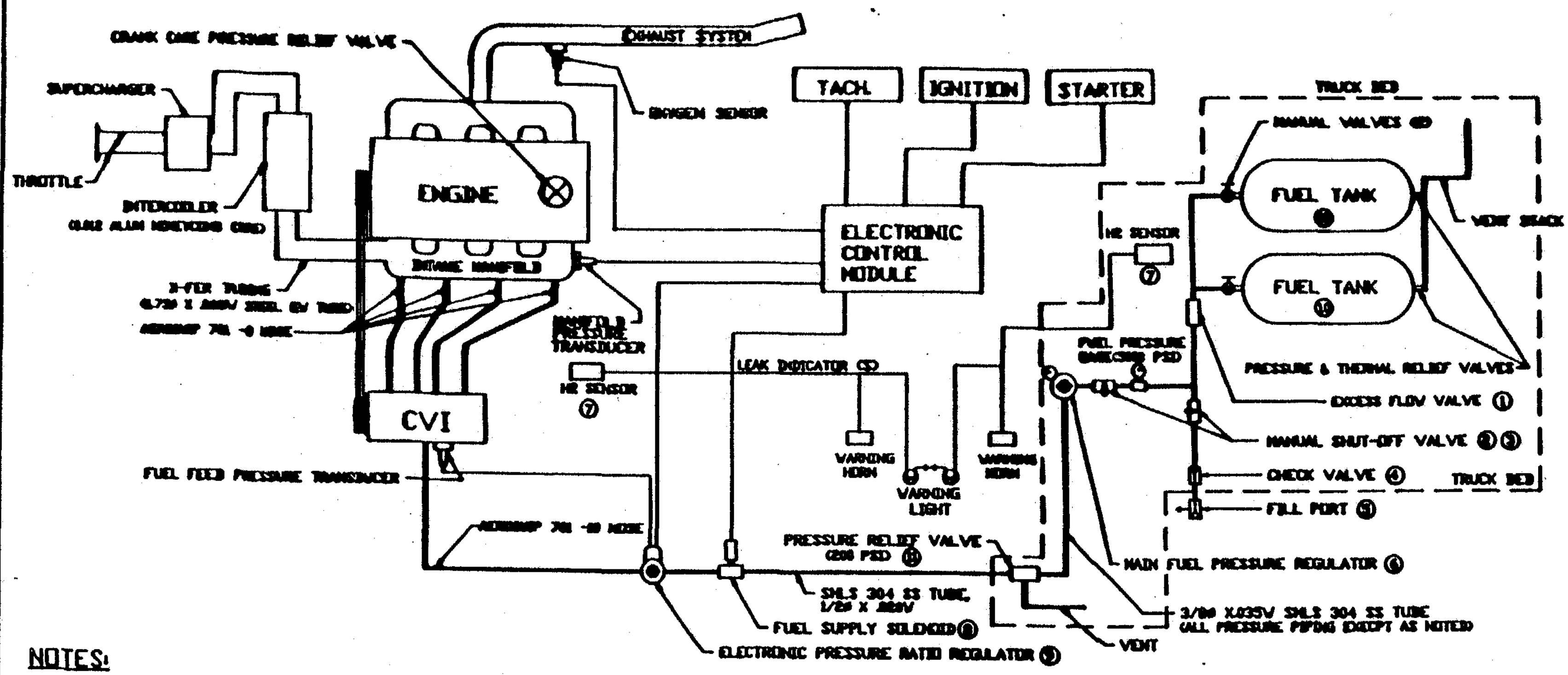
Range..144 miles

CVI FuelInjection System



Typical Super Charger Configuration





NOTES:

E.C.M. SEQUENCING
START-UP:
1. IGN. SV. --- ON
2. ENGINE CRANKING .5 SEC.(approx)
3. IGN. SYS.--- ON (CRANKING)
4. FUEL --- ON TILL START

E.C.M. SEQUENCING
SHUT-DOWN
1. IGN. SV. --- OFF
2. FUEL --- OFF
3. ENGINE SPEED < 100 RPM
4. IGN. SYSTEM --- OFF

COMPONENT SPEC.

1 CHEM-TECH EFV-250(8494) (ZERO FLOW IN CLOSED POS.)
2 NUPRO B-4P4T4
3 WHITEY SS83KS6
4 NUPRO SS8CHS6-1 DOUBLE CHECK
5 STANDARD CGA-350 CONNECTOR
6 TESCOM 20-1032-2915 REGULATOR (125PSI MAX.OUT)
7 CCI CONTROLS 7907 H2 DETECTOR
8 ADVANCED FUEL COMPONENTS MODEL 121 SOLENOID VALVE
9 NORGREN 11-008-130 REGULATOR (400 PSI MAX. IN)
BUZMATIC SPC1R-0E3-0A100-S12 DOME LOADER
10 CNG LITERIDER MODEL 165 TANK (5.64 CU. FT. VOL.)
ALUM./FIBERGLAS.3600 PSI RATED (NGV-2)
11 200 PSI RELIEF VALVE (APPROX.0.25SQ IN FLOW AREA)

TOLERANCES: XX ± .010 XXX ± .005 FRACT. ± 1/64 ANGLE ± .5 EXCEPT AS NOTED	ADVANCED MACHINING DYNAMICS	
	TITLE FUEL SYSTEM SCHEMATIC	
REV.	DRAWN V.J.K.	DATE 4-29-95
FIN.	APPROVED	DATE
HEAT TREAT	MATERIAL SPEC.	

Safety Features

* Hydrogen is used as fuel.

* Grounding connector opens fuel door.
  - No ground, no fuel!

* H_2 leak detectors, located under hood and near tanks, display in cab.

* Stiffened structure protects fuel lines, tanks from side impact.

* Dual check valves, excess flow valve restrict fuel flow in case of line or regulator failure.

* Engine controller: a) starts engine with 1/2 sec. crank before fuel or spark, and
  b) shuts down fuel flow first, then spark.

* Large crankcase pressure relief valve lifts to open in case of burn inside crankcase/valve cover.

* Design reviews, test of first item by Rocketdyne-/ETEC (makers of H_2 fueled rocket engines).

Opportunities for Improvement

* Aluminum head, improved cooling
* Piston design for reduced clearance, improved rings
* Dual ignition
* Variable spark timing advance
* Dry lubricated injection system
* ECU with improved damping, MAF/TPI inputs
* Increased compression ratio (??)

CAN/Xerox Clean Air Fleet

CE-CERT Evaluation of Trucks

Measured Parameters

T-IN	Air temperature between the outlet of the supercharger and the inlet to the intercooler, °F
T-OUT	Air temperature at the outlet of the intercooler, °F
T-EXH	Exhaust gas temperature, °F
T-TANK	Temperature in the hydrogen storage tank, °F
P-TANK	Pressure in the hydrogen storage tank, psi
VREG	Buzzmatic set point, being the signal from the CVI electronic controller which commands the Buzzmatic electronic pressure regulator, presented in psi commanded
P-IN	Hydrogen pressure at the inlet to the CVI volume, psi
MAF	Mass air flow, lb/min
H2F	Hydrogen mass flow, lb/min
MAP	Manifold air pressure, psi
VEGO	Voltage from the exhaust gas oxygen sensor, converted to equivalence ratio phi
TPI	Throttle position indicator
PCYL	Dynamic pressure in cyl. 4

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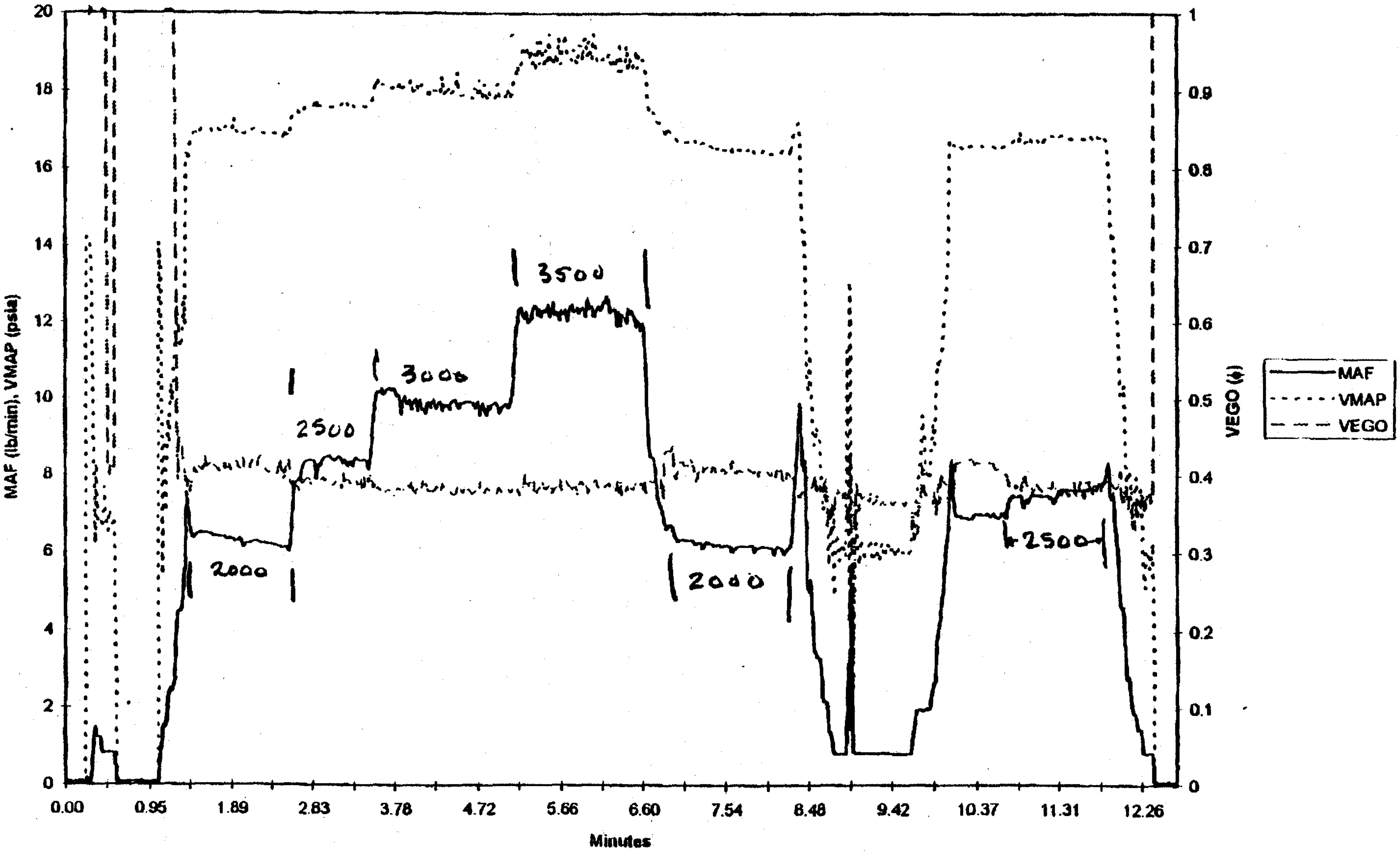
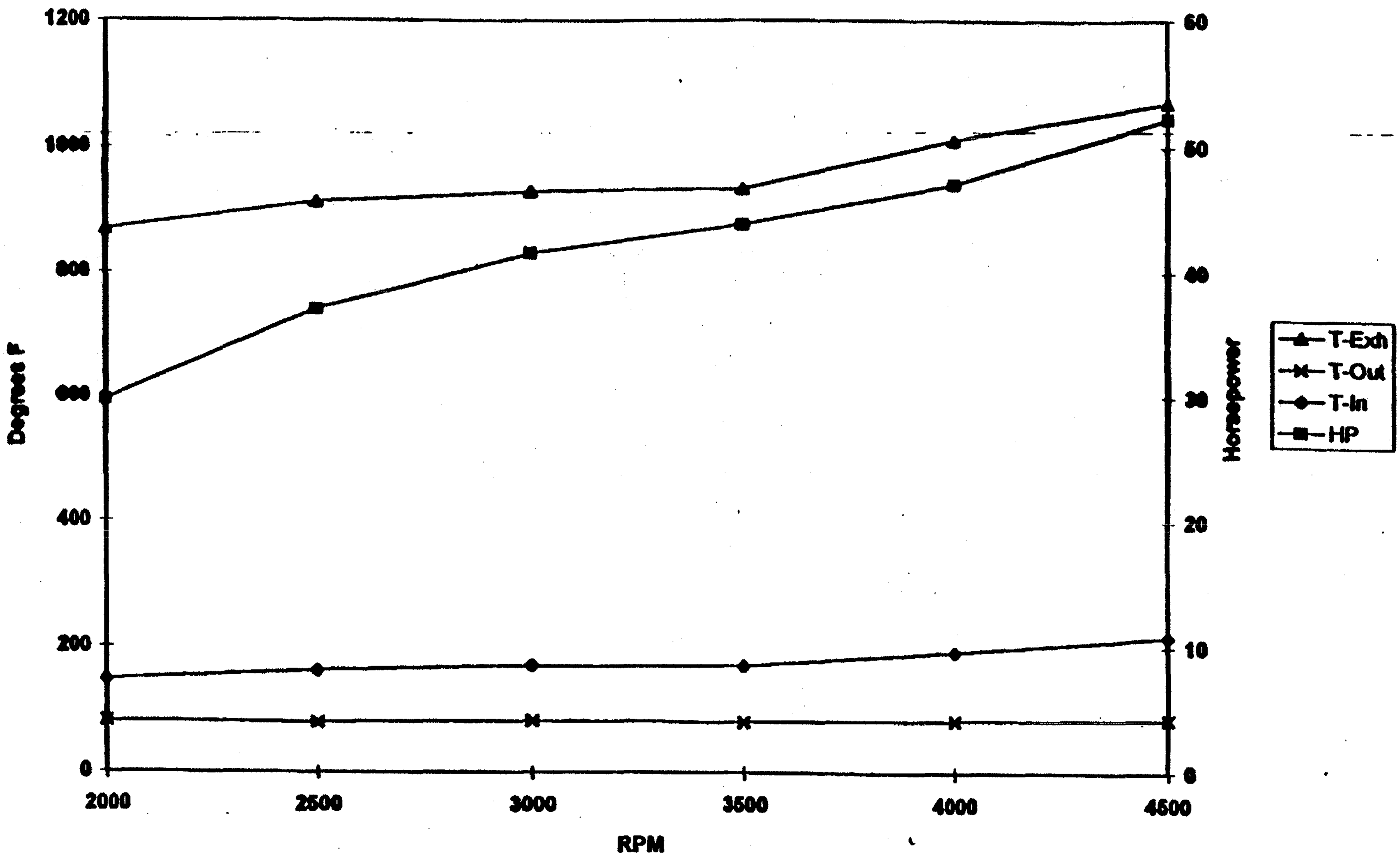
MAF_EGO Chart 1

Xerox 08/03/95 (CAN1)



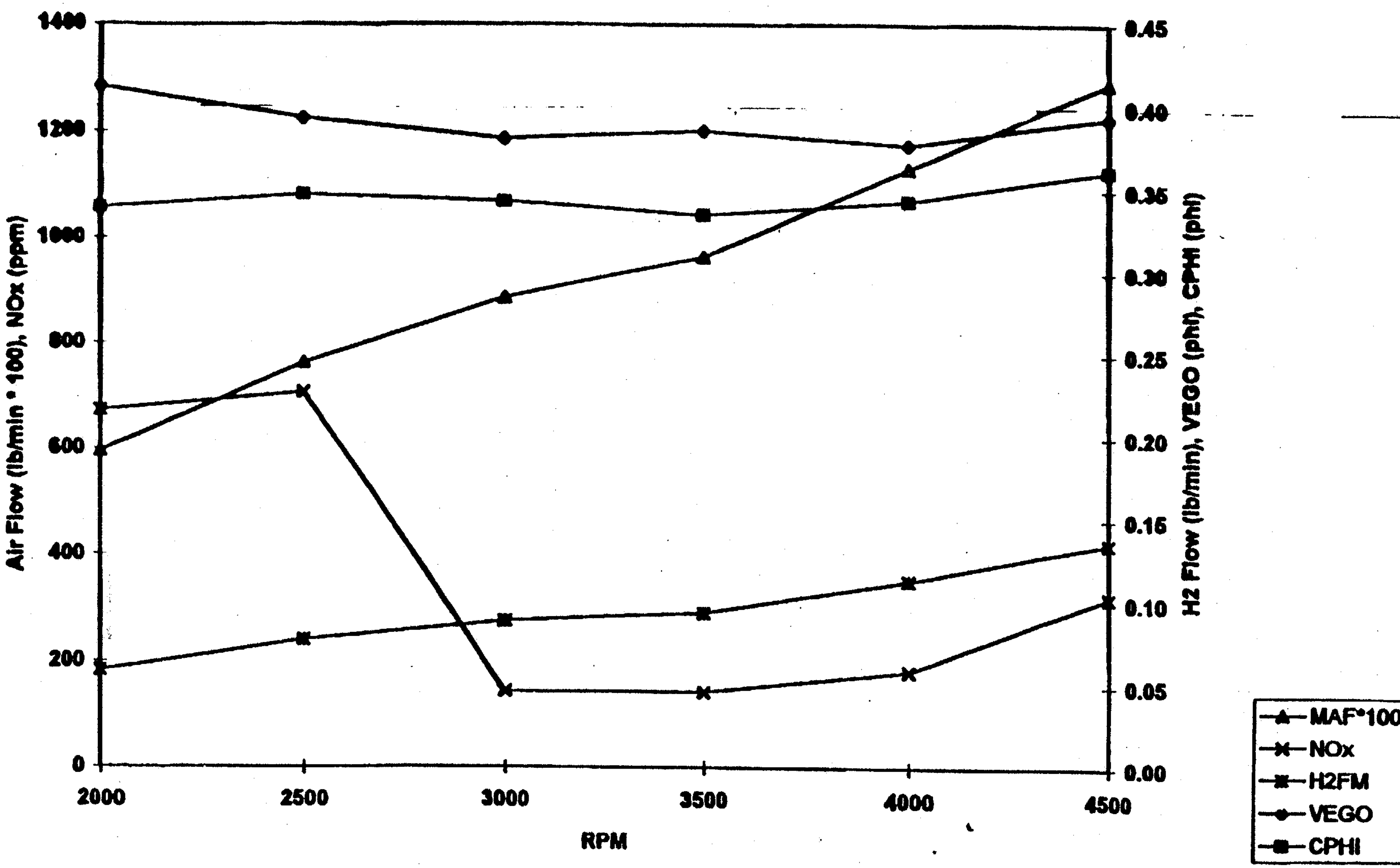
Xerox.xls Summary Chart 9

Xerox 08/95 (CAN1)

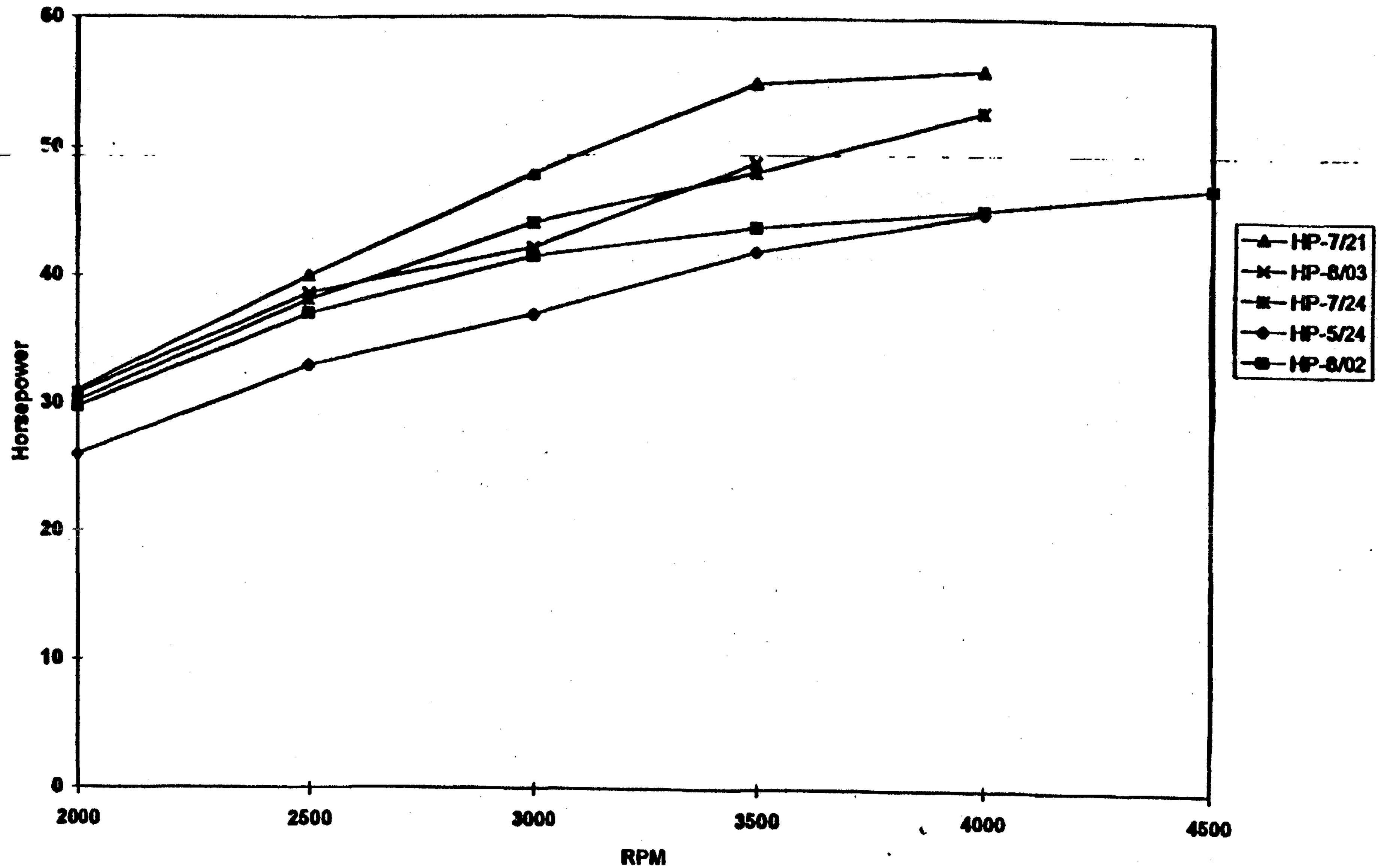


Xerox.xls Summary Chart 8

Xerox 08/95 (CAN1)

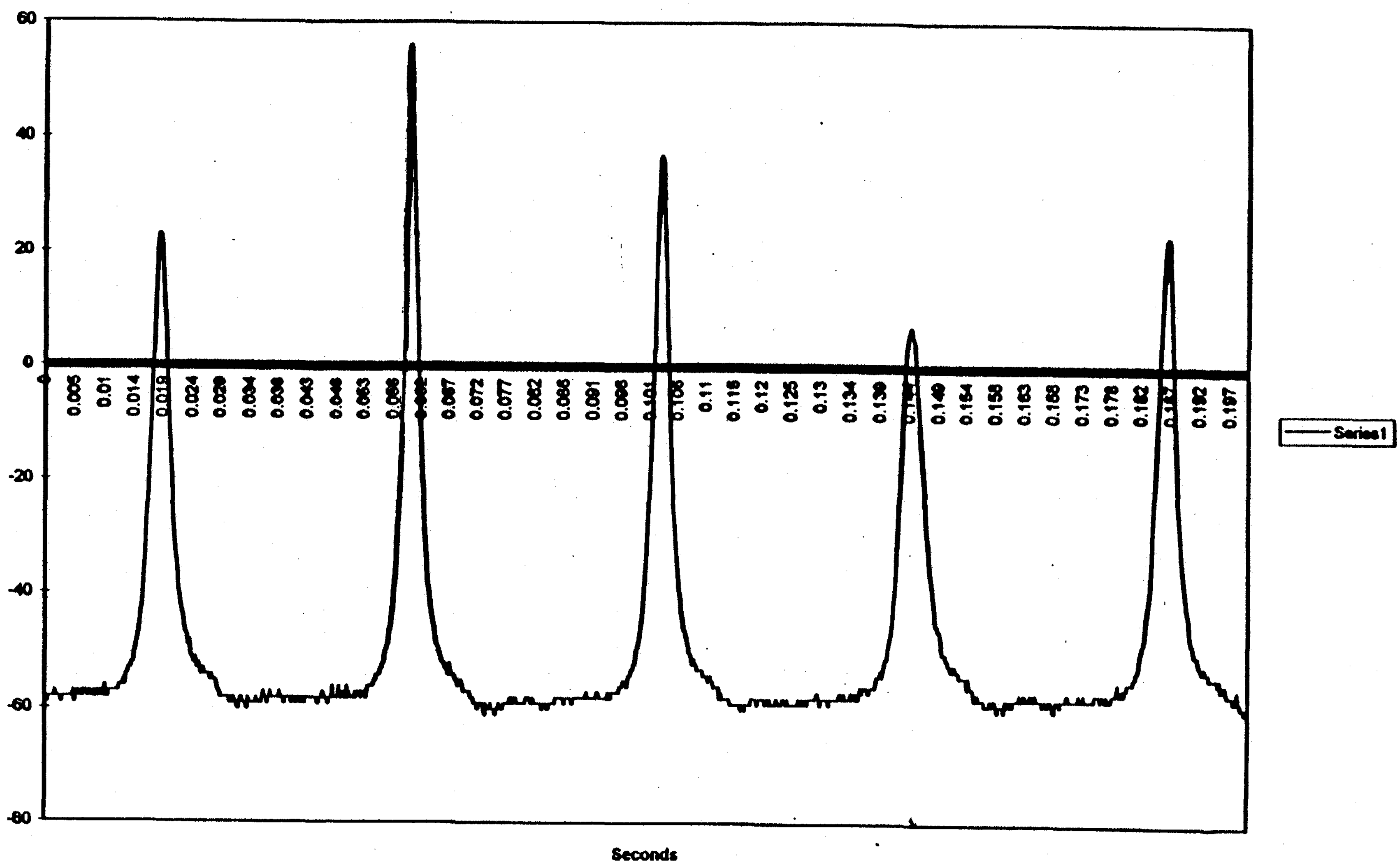


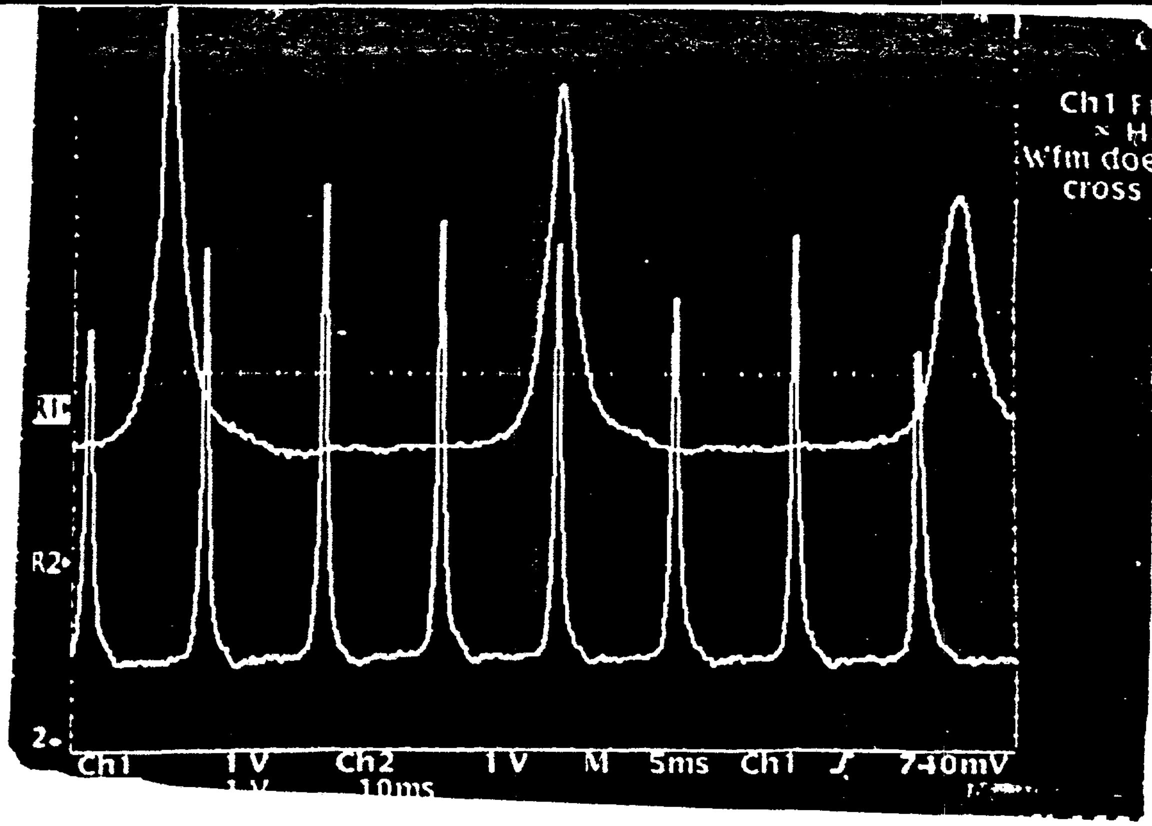
Xerox (CAN1) Horsepower Tests

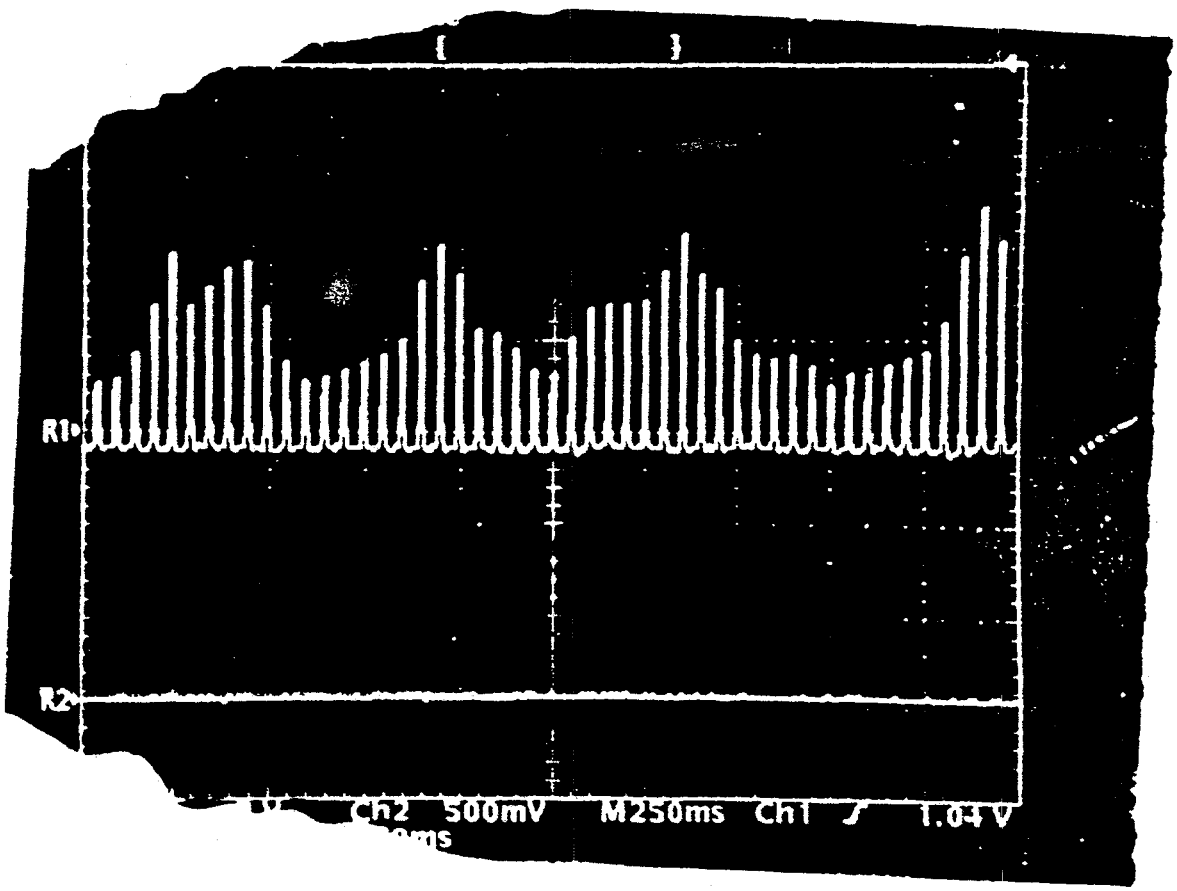


3000

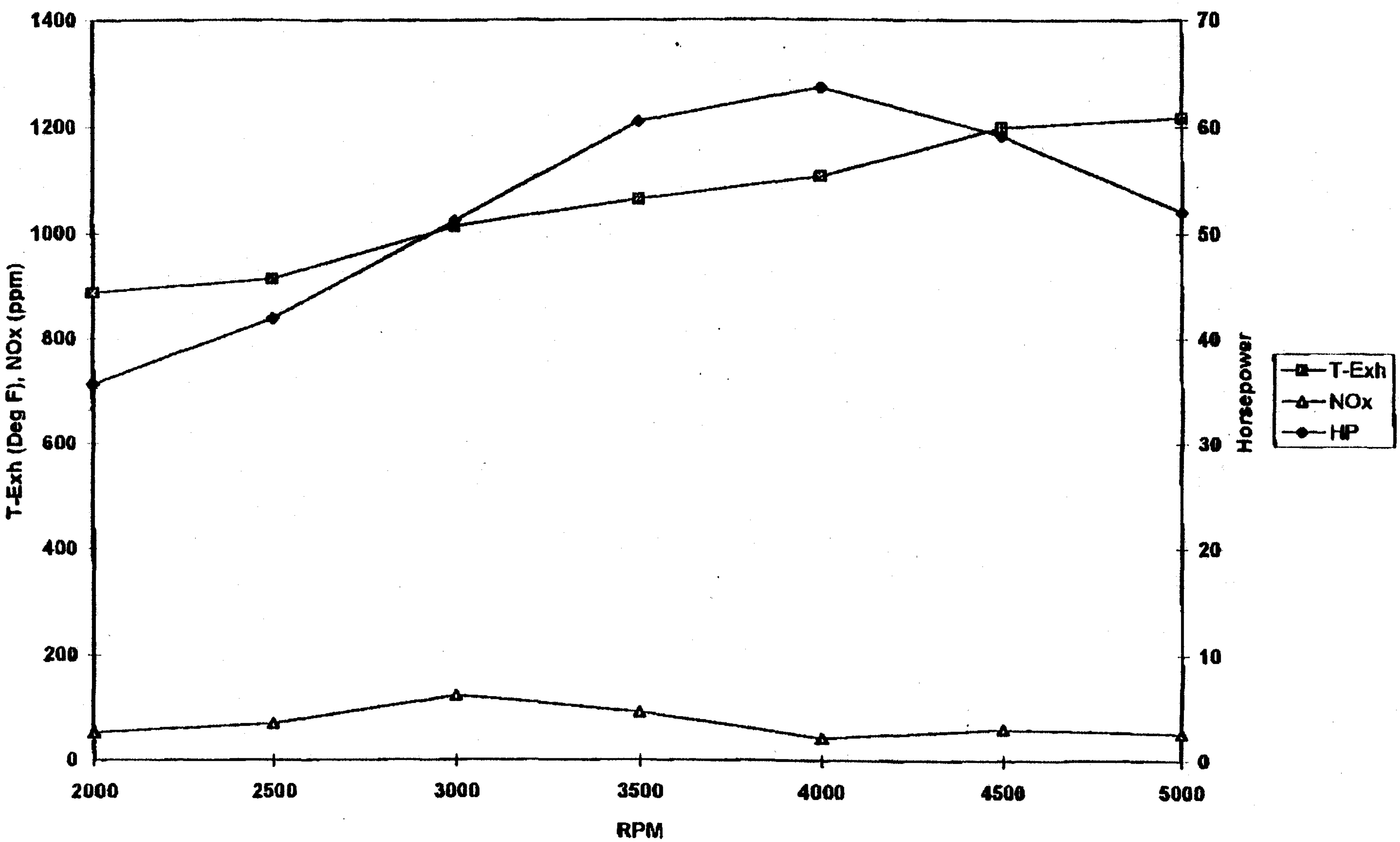
CAN/Xerox H2 Ranger - 8/3/95



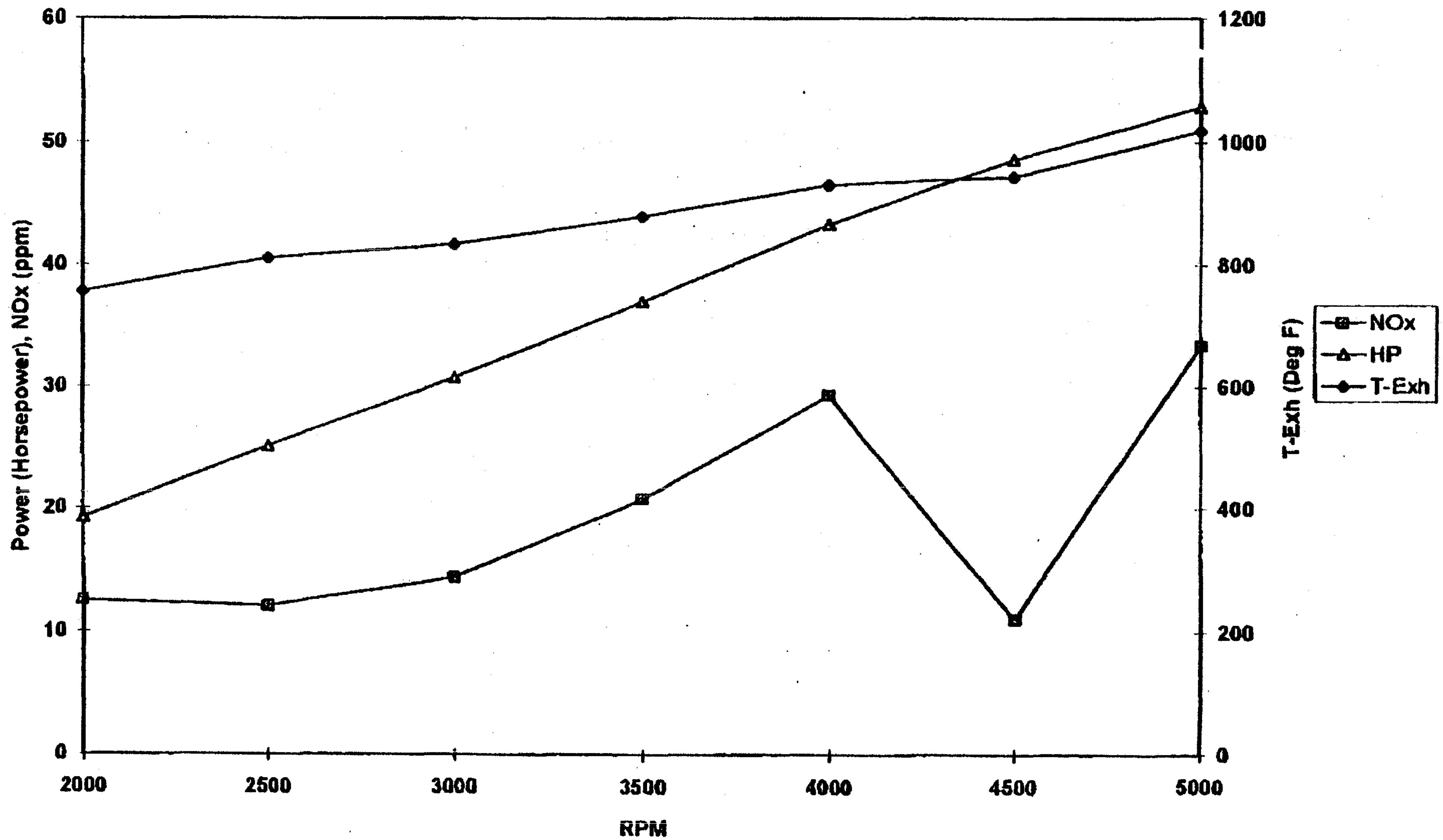

Ch1 F
Wfm doe
cross
R2
Ch1 1 V Ch2 1 V M 5ms Ch1 740mV
1 V 10ms


R1
R2
Ch2 500mV M250ms Ch1 1.04 V

Xerox 11/95 (CAN2)



Xerox 12/95 (CAN3)



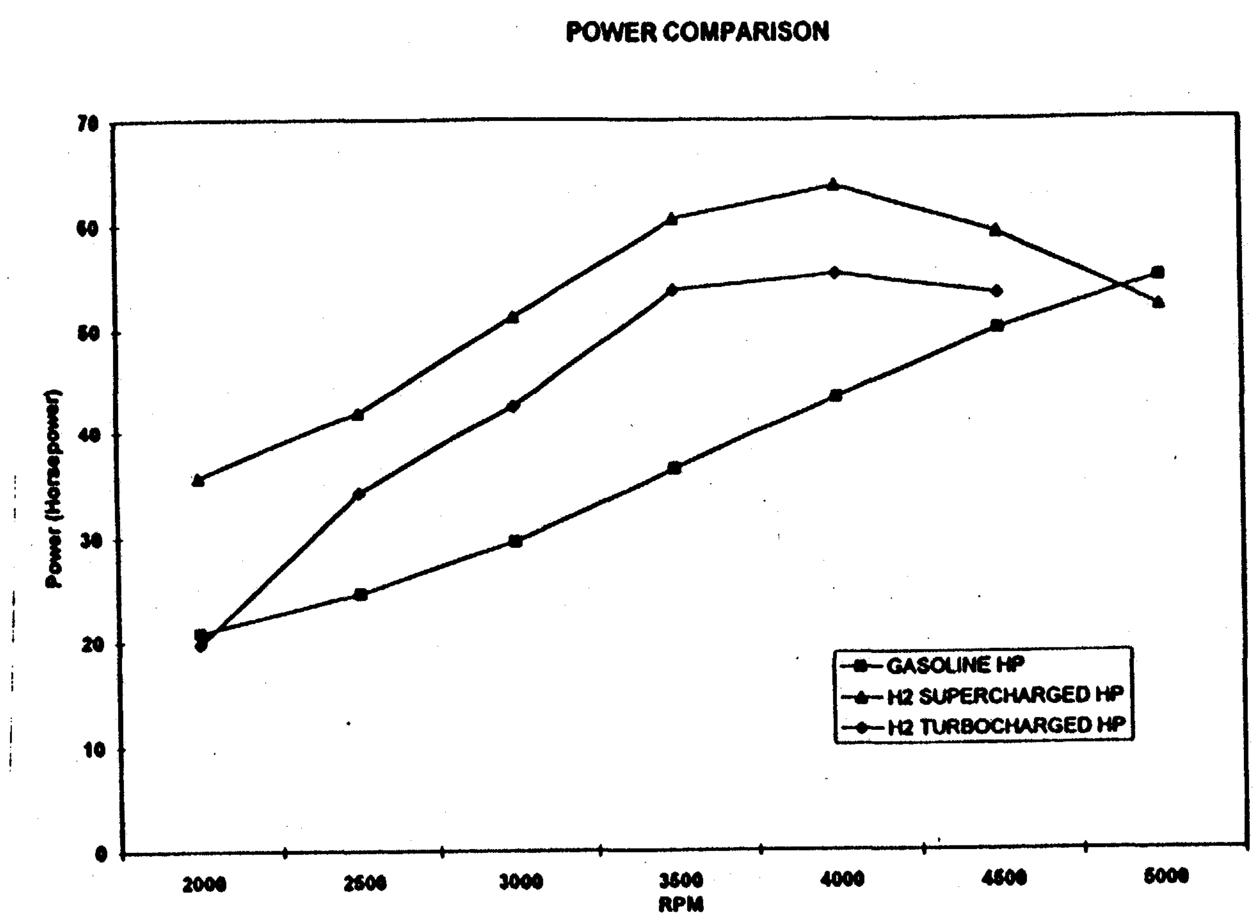
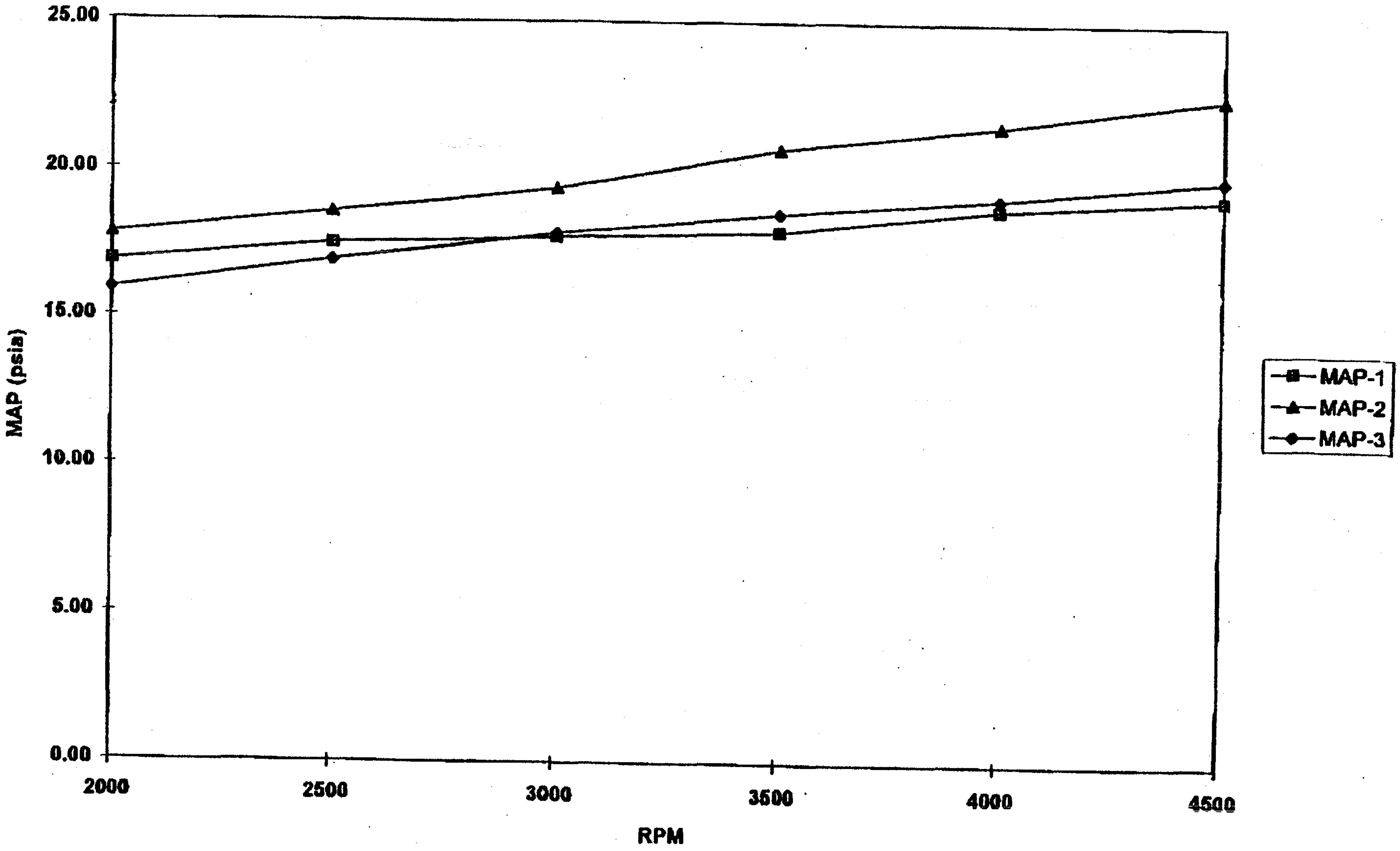
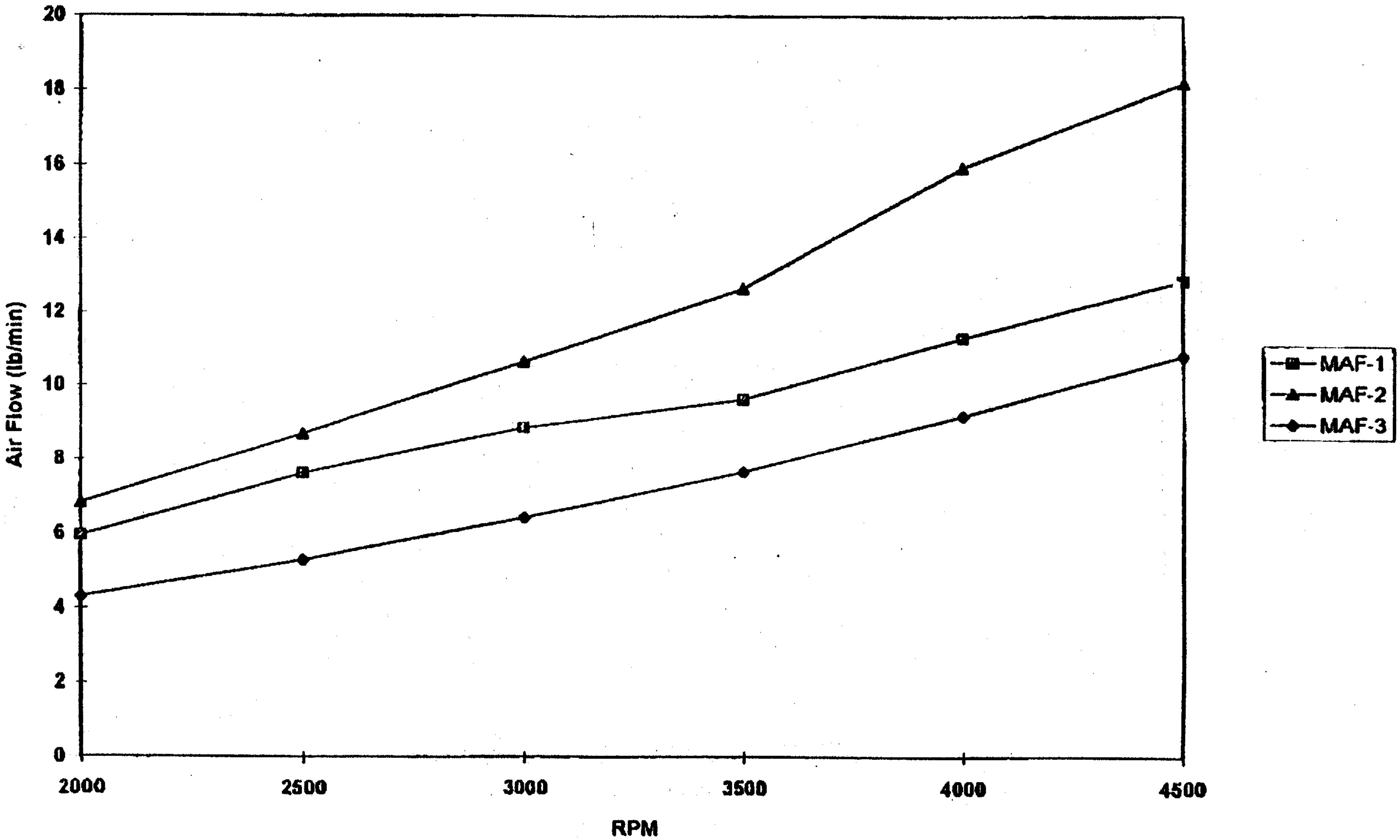


Figure 9. Comparing the HP from the stock Ranger with the turbo and supercharged hydrogen fueled Ford Rangers.

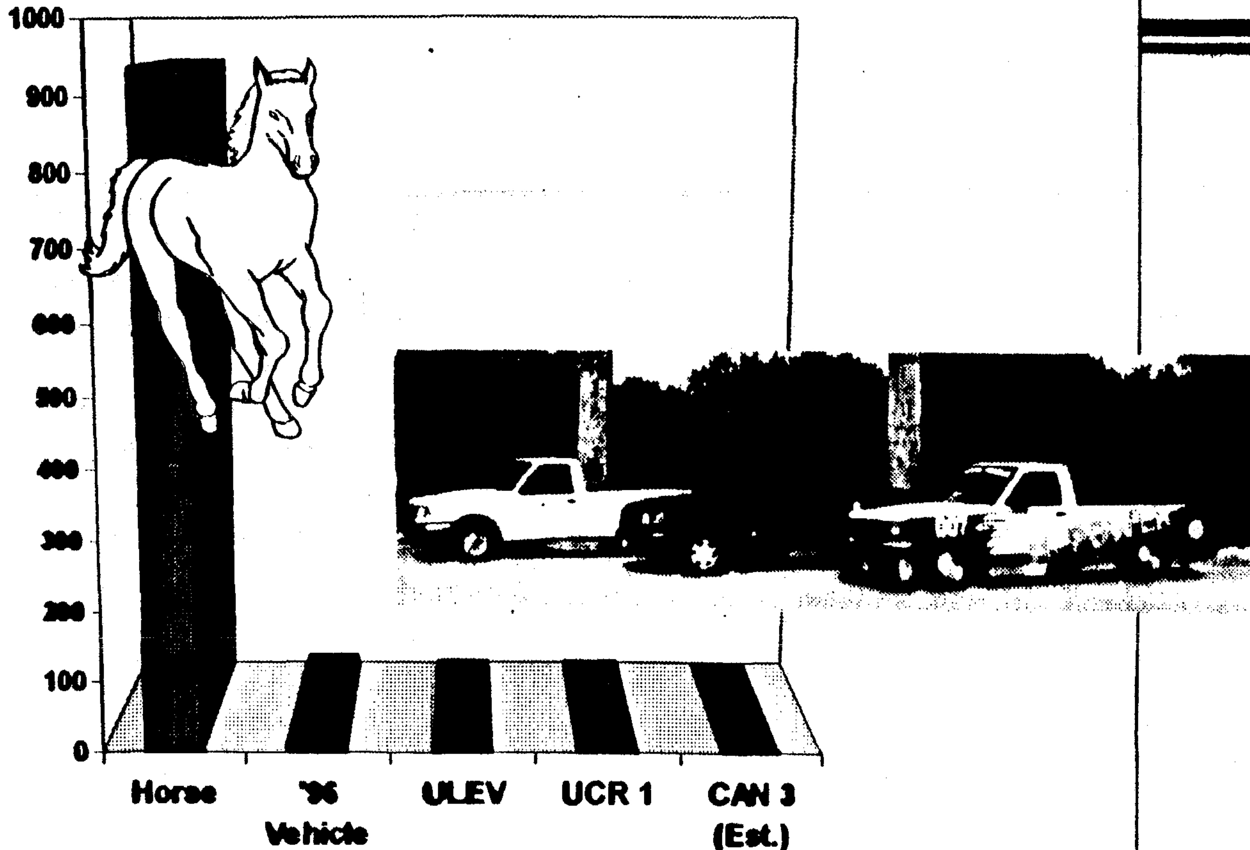
Xerox CAN1, CAN2, CAN3
Manifold Air Pressure Comparison

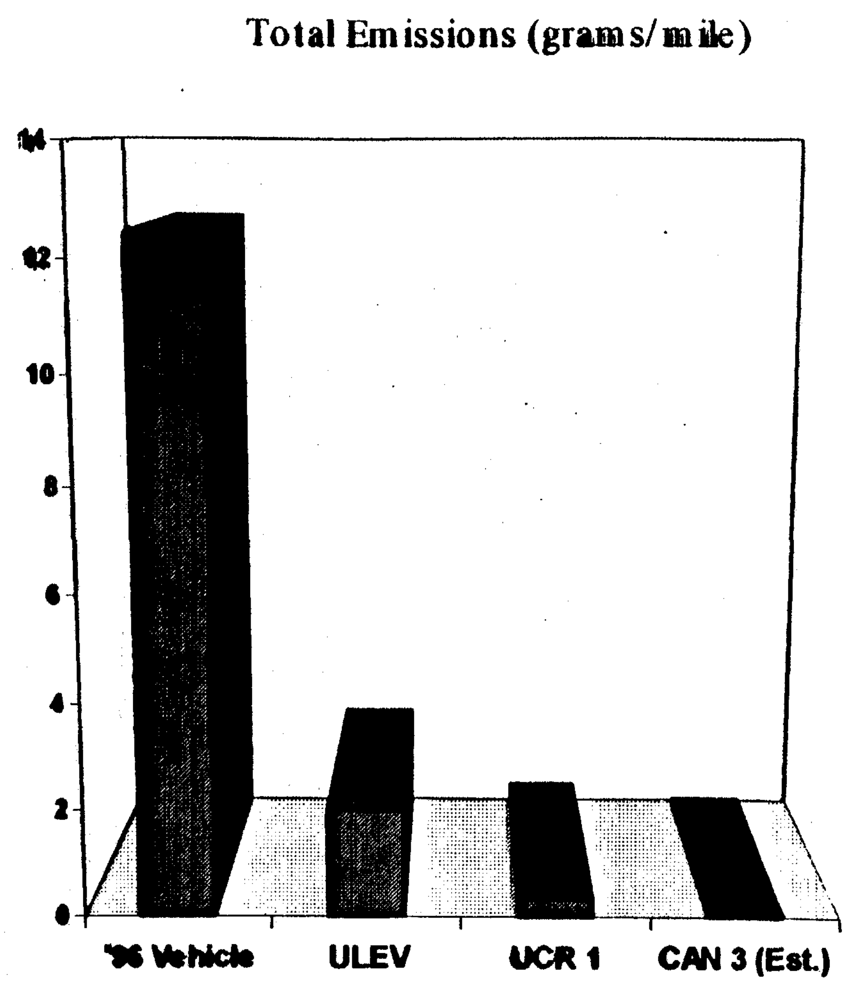


Xerox CAN1, CAN2, CAN3 Air Flow Comparison



Total Emissions (grams/mile)




Total Emissions (grams/mile)
14
12
10
8
6
4
2
0
'96 Vehicle
ULEV
UCR 1
CAN 3 (Est.)

CLEAN AIR NOW/XEROX SOLAR POWERED HYDROGEN GENERATING FACILITY AND HYDROGEN POWERED (UTILITY) VEHICLE FLEET. AN HYDROGEN FUEL TECHNOLOGIES DEMONSTRATION PROJECT EL SEGUNDO, CALIFORNIA

NHA Annual U.S. Hydrogen Meeting, 1995

James J. Provenzano
Clean Air Now
Santa Monica, CA 90401
(310) 394-1214, (310) 917-4426 Fax

Abstract

Clean Air Now, a California non-profit, public interest and advocacy corporation, has received funding from the White House Technology Reinvestment Project, the state of California, and its project partners to deploy solar hydrogen technologies at the Xerox Corporation facilities in El Segundo, California.

By September 1995, Clean Air Now, along with project participants (U.S. Department of Energy, Xerox, South Coast Air Quality Management District, The Electrolyser Corporation, Praxair, Inc., Solar Engineering Applications Corporation, Advanced Machining Dynamics, Energy Technology Engineering Center/Rockwell, University of California at Riverside, W. Hoagland & Assoc., Inc., Touchstone Technologies, and the City of West Hollywood) will have installed one of the major components of the developing hydrogen infrastructure in southern California.

The project consists of a stand-alone photovoltaic-electrolysis system capable of producing 400 SCFH of hydrogen, 13,000 SCF of storage @ 5,000 psi, and 73,000 SCF of storage @ 2,000 psi, three retrofitted ICE utility pickups, and data acquisition capability. The project scope also entails a comprehensive public awareness campaign, a detailed systems safety analysis and review, an insurance industry review, and the integration into other hydrogen generation and transportation technologies programs.

All participants feel that programs such as the Clean Air Now project will lead to greater public acceptance of hydrogen technologies and their use in the mainstream transportation sector.

Why is Xerox doing this? - Because Xerox Corporation is a progressive, proactive and environmentally sensitive company that promotes entrepreneurship and empowerment throughout its operations. This philosophy, along with a strong Corporate Environmental Policy, paved the way for the introduction of this ground breaking, non-core business, demonstration project. Social and environmental responsibility are no longer considered mutually exclusive, but imperative, to a healthy long-term bottom line. Hydrogen technologies will be playing a more significant role in allowing companies to fulfill that promise.

Clean Air Now/Xerox Solar Powered Hydrogen Generating Facility and Hydrogen Powered (Utility) Vehicle Fleet

An Hydrogen Fuel Technologies Demonstration Project,
El Segundo, California

Presented at the National Hydrogen Association's *S*ixth Annual U.S. Hydrogen Meeting

March 8, 1995

James J. Provenzano
Managing Director,
Clean Air Now,
Los Angeles, CA

Presentation Outline

- **Project overview**
  - Funding Entities and Partners
  - Scope
  - Scheduling
  - Outputs
- **Corporate Perspective**
  - "Why *is* Xerox doing this?"
  - Enabling Corporate Policy and Management
  - Benefits/Hurdles
- **Developing Infrastructure Tie-in**

Where is the $ coming from?

- The White House Technology Reinvestment Project
  - Regional Alliance Deployment Project
  - Defense Conversion Appropriations
  - 1993-1994 Budget
  - Administered 8/11/94 through the DOE
- CA AB2766 funding
  - State pollution abatement program
  - Administered '94 by the SCAQMD
- Clean Air Now cofund
  - Funded entity
  - Project direction, administration, management, Xerox agent
- Project Partners' cofund

Project Partners

- Clean Air Now (CA non-profit corporation)
- US Department of Energy
- South Coast Air Quality Management District
- Xerox Corporation, Corporate Strategic Services
- The Electrolyser Corporation, Buffalo, NY
- Praxair, Inc., Tarrytown, NY
- Solar Engineering Applications Corp., Santa Clara, CA
- Advanced Machining Dynamics, Highland, CA
- Energy Technology Engineering Center/Rockwell/DOE, Canoga Park, CA
- City of West Hollywood
- W. Hoagland & Associates, Inc., Boulder, CO
- Touchstone Technology, Inc., Northridge, CA
- U. C. Riverside
- Matrix Construction & Engineering, San Marcos, CA

Some Project Aspects

- Stand-alone "off the grid" system
  - including compression (8-12kW) (280-320SCFHw/cycling)
  - only data collection/monitoring will be on grid
- Round the clock use, "where the rubber meets the road", by Xerox Maintenance personnel
- Lynch CVI unit technology for ICE retrofits
- Start w / 3 - 2.3L 4 cyl Ford Ranger pickups
- Vehicle improvements
  - Supercharged in lieu of Turbo (low-end torque)
  - Increase stroke/bore to 2.9L
  - Higher rear end ratio (4.10:1 or better)
- Station available to outside interests i.e. Ballard, other fleets, South Bay, LAX, etc.
- Project construction completed by 9/95

Some Project Outputs

- Systems performance testing & analysis
- Systems emissions testing / data acquisition
- Validation & certification by CARB
- Public awareness campaign w/ partners
- Safety & Failure Mode Analysis & Review documents
- Insurance industry rating (potential)

Xerox & Site Benefits to the Project

- Xerox self insured
- "Top down" commitment to the environment
- Xerox site engineers have track record w / El Segundo / trusted by Fire Department
- Senior site management are engineers and knowledgeable about technologies
- Xerox familiar w / H2 handling & use on site
- El Segundo familiar w / H2 - SCE & others
- E, H & S resources and internal review process lent to the project
- Hurdles are internal politics/non-core business issues inter-operations

DRIVING TOWARDS RENEWABLE ENERGY
Encouraging the use of Hydrogen Fuel in Automobiles

By Chris Buntine

Final Paper
June 10, 1995

Politics, Institutions and the Environment
Department of Urban Planning
School of Public Policy and Social Research
University of California, Los Angeles

Introduction

It's a well known fact that walking around the streets of Los Angeles can be dangerous. The threat of crime is well known and heavily publicized to the degree that some refuse to venture out onto the streets altogether. But while crime is on the rise in some areas there is another threat which is not as well known but just as deadly. To most residents its merely a brown haze which is usually brushed aside in the name of progress. I am of course referring to smog which continually hangs over the city eroding the health of each and every one of us.

Every day vehicles in Los Angeles County travel over 17 million miles and busily spray toxic chemicals over the city. While substantial improvements have been made in air quality due to the Clean Air Act it remains heavily polluted. Though emissions from stationary sources have been subject to increasingly stringent controls, curtailing emissions from mobile sources has proved more difficult. But there is a bright light on the horizon which may remove the need for gasoline and has the potential to provide a genuinely clean and renewable energy source. The answer is found in Hydrogen, the most common element on earth. It can be derived from water, burn it and it produces water. It's a cycle so simple that it almost defies belief and the technology to achieve it has already arrived.

Although the prospect of a limitless non-polluting power source should be enough to make society shout for joy, breaking the present addiction to gasoline is difficult and painful. Alternative fuels face not only a lack of infrastructure but also a powerful oil industry determined not to lose its market share. The auto industry has also stubbornly resisted any change and together with the oil industry has taken to lobbying the government for reduced air quality regulation. Recent pressure from these and other industries complaining about the cost of regulation has forced the Government to rethink its role. In response the 104th Congress has begun dissassembling environmental regulation which has taken 25 years to establish.

The use of renewable Hydrogen holds incredible promise as a clean energy source but lacks any sizable constituency to promote it. It is crucial that the Federal Government begin to take an active role in promoting its use. Recognizing the advantages of Hydrogen, countries like Japan and Germany have begun investing heavily in research and development into both large scale power stations and vehicles. With the current lack of funding for Hydrogen energy in the U.S., there is a very real risk that opportunities for new jobs and industries will be lost. All the while millions of Americans continue to suffer a plethora of unnecessary chronic and acute health effects.

In this paper I outline the benefits of using renewable Hydrogen vehicles in preference to other alternative fuels which are currently being promoted. I examine relevant State and Federal policies with a particular focus on the Zero Emission Vehicle requirement in California. In conclusion I make a number of recommendations as to the changes which need to be made to encourage the use of renewable Hydrogen vehicles.

Choking to death

Imagine if it was proposed to bring a fuel into our cities which was carcinogenic, highly explosive and gave off toxic fumes. 9 million pipes would be spread throughout the city which would spray these toxins over everyone and everything. Believe it or not that is the current situation in today's cities. While clean air regulations have resulted in considerable improvements in the quality of Los Angles' air, Federal air quality standards are still exceeded for 50% of the year[1]. In some areas in the Los Angeles basin schoolchildren have been found to have a 20% reduction in lung capacity. A recent study into the health effects from traffic and smokestacks found that residents of the nation's most polluted cities are 15 to 17 percent more likely to die prematurely that in cities with the cleanest air [2]. In some cases the figures may be even higher due to the conservative estimates made in linking disease to air quality. The major byproducts emitted from automobile exhausts are ozone, volatile organic compounds (VOC's), oxides of nitrogen (NOX), particulate matter (PM10), carbon monoxide (CO) and lead. While the presence of lead has decreased markedly due to the introduction of unleaded gasoline it still remains a problem due to the continuing use of old model cars. Ozone has been found to severely impair lung function and is often accompanied by chest pain, coughing, nausea and lung congestion [3]. A study by the American Lung Association in October 1994 found that 21 percent of summertime asthma hospitalizations are possibly linked to the presence of ozone. The effects of VOC's are difficult to estimate. However, in the right conditions these combine with NOX to form ozone. NOX has been found to lower resistance to respiratory infections and can cause acute respiratory disease in children. PM10 is defined by the EPA as being smaller than 10 microns (half the size of a human hair) and can be breathed deeply into the lungs. It is a major byproduct of diesel and has been associated with lung cancer and cardiopulmonary disease. CO is commonly known to be extremely toxic and impairs the body's ability to carry oxygen. Its presence can threaten sufferers of cardiovascular disease and can effect motor skills, visual perception and work capacity. Not only do these pollutants effect our health but they

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[1] Tom Soto, *Clean Air Mandates Mean A Boon For Los Angeles* Business, Los Angeles Business Journal, March 21 - 27, Vol 16, No. 11, 1995

[2] Curt Suplee, *Dirty Air Can Shorten Your Life, Study Says*, The Washington Post, Friday, March 10, 1995

[3] Jason Gardner, *Transportation, Air and Health*, The Neighborhood Works, December 1994

result in considerable contamination to the environment. In some parts of Los Angeles the soil adjacent to high volume freeways has been classified as contaminated. Mobile sources are estimated by the EPA to contribute 50% of the CO, 27% of NOX and 27% of VOC's. While emissions from today's cars equipped with sophisticated pollution control technology have been significantly reduced, this has been offset by an increase in the vehicle miles being travelled. In Chicago hydrocarbon emissions fell by 50 percent from 1970 to 1990, however vehicle miles doubled during the same period [1]. Despite increases in fuel economy the basic law of the conservation of matter still applies to modern vehicles. This means that for every pound of gasoline used one pound is released into the environment. The use of pollution control devices simply moves the pollutants from one medium to another, ultimately ending up in landfills. Using this kind of analysis, based on a fuel economy of 20 miles/gallon and a distance of 12,000 miles over 11 years (the average life expectancy of a car), the average passenger vehicle will release at least 28 tones of pollution. This provides ample evidence that there is an urgent need for cleaner fuels of which hydrogen provides the most promise.

Renewable Hydrogen Vehicles

> *I believe that water will one day be employed as a fuel, that hydrogen and oxygen will constitute it, used singly or together, will furnish an inexhaustible source of heat and light.* - Jules Verne, Mysterious Island

Hydrogen was discovered in 1783 by a French Chemist and was aptly named from Greek words meaning 'water producer'. In 1988 over one billion cubic meters of Hydrogen were being produced annually in the U.S. The most common methods for production involve extraction

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[1] Scott Bernstein, *Imagining Equity: Using ISTEA and the Clean Air Act*, Environment and Development, December 1993

from hydrocarbons such as methane, gasoline, fuel oil, crude oil and coal. An alternative but more costly means involves electrolysis, where Hydrogen and Oxygen are split by passing an electric current, derived from a solar source, through water. A third method produces Hydrogen directly when sunlight strikes the surface of a semiconductor, exciting electrons which then break water into its component parts. Of these three methods the last two provide a means by which renewable energy from the sun can be converted into Hydrogen.

The stored Hydrogen can then be combined with Oxygen to form water, in the process releasing energy. There are two ways that this can take place that hold great potential for vehicles. The first is to use it to fuel combustion in a conventional engine with some modifications. The second is to use it in a fuel cell where it combines with oxygen to produce an electric current. A fuel cell produces zero emissions while combustion produces only very low quantities of NOX. It is also possible to mix natural gas with Hydrogen; however this increases emissions. One of the major differences between Hydrogen and gasoline is its energy density. Liquid Hydrogen has 2.5 times the energy density by weight but only 0.25 times the energy density by volume. This yields a weight advantage but it also gives rise to the need for bulky tanks. Considerable research is being undertaken to discover new ways of storing hydrogen at a higher density. One of these methods involves using metal hydrides to absorb the Hydrogen where on heating, it is released.

One of the characteristics of deriving energy from Hydrogen is very high efficiency. All chemical and mechanical processes have a theoretical efficiency limit but this is usually not reached due to practical restrictions. This means that for an electric vehicle recharged by a gas fired power station at 36% efficiency, which transmits high voltage at 92% efficiency, inverts to DC at 98%, charges the batteries at 88% and drives the wheels at 98%, the overall efficiency is approximately 28% [1]. Hydrogen can be produced by electrolysis at 75% efficiency, transported at 99%, and consumed in a fuel cell at 45% giving it an overall efficiency of 35%, considerably above that of electric vehicles. When considering only the economy of the car itself a fuel cell driven car is up to 2.5 times more efficient than gasoline [2]. Of particular interest is the fact that a gallon of water has approximately the same energy content as a gallon of gasoline.

While it is highly flammable the risk is significantly less than for gasoline. When the Hindenburg exploded in 1937 filled with Hydrogen most of the victims died due to the fall rather than the explosion. It will not ignite at concentrations less than 4% by volume whereas gasoline fumes will ignite at as little as 1.5%. One of the major advantages of Hydrogen is its buoyancy and diffusivity. Being the lightest element it rises rapidly after a leak and disperses up to three times faster than natural gas. Most importantly Hydrogen is non toxic which is illustrated by the fact that we continue to breath it at a concentration of 0.2% throughout our lives.

While the primary reasons for using Hydrogen are environmental, there are considerable economic benefits that it would create. Presently a large proportion of gasoline is imported which makes it susceptible to price increases and a poses a threat to national security. Hydrogen could be produced where it is required and is merely dependant on a supply of water. The availability of Hydrogen at a stable price would make it considerably easier for business to plan for future energy costs. Local availability would also mean political independance, freeing up foreign policy from a wealth of constraints. The creation of an industry based on Hydrogen production would create high paying jobs, increase exports and foster high technology research.

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[1] Clean Air Now / Xerox Solar Hydrogen Vehicle Project - Executive Summary, Proposal

[2] Tom Harkin, *Proposal for a Sustainable Energy Future Based on Renewable Hydrogen*, Executive Summary, December 1992

The Clean Air Now / Xerox Solar Hydrogen Vehicle Project

To demonstrate the potential of Hydrogen powered vehicles, Clean Air Now (CAN) a non-profit organization initiated a project in partnership with Xerox and a number of other companies. The project is funded by the White House Technology Reinvestment Project with a small amout of funding coming from the South Coast Air Quality Management District. Beginning in August 1994 the aim of the project has been to produce a Hydrogen combustion engine retrofit for conventional gasoline powered vehicles. The Hydrogen is renewably produced using photovoltaics and water electrolysis. While the first retrofit cost almost $250,000 in development, the cost for subsequent vehicles has dropped considerably to $50,000 and according to Paul Staples, Vice Chairman of CAN, with mass production a retrofit would eventually cost between $4,000 and $5,000. While the storage of Hydrogen can be difficult due to its tendency to migrate through the walls of storage tanks this has been overcome using a tank constructed of a combination of aluminum and fiberglass. The range currently available from these tanks is 200 miles however with the use of fuel cells this would increase to 600 miles. While it currently costs $2.50/gallon of gasoline equivalent this cost would easily drop to $0.69/gallon with large scale development. Due to the high range of flammability, Hydrogen combustion can take place efficiently at much lower temperatures than conventional vehicles which reduces the energy lost as heat. This lower operating temperature also decreases the wear and tear which prolongs the life of the engine. This means that even at $2.50/gallon Hydrogen is competitive with gasoline. It must also be remembered that the current price of gasoline does not incorporate many external costs. According to Dr. Robert Zweig, Chairman of CAN, if the defense and social costs are included gasoline costs us $5.75 per gallon[1].

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[1] Hydrogen Today, *Clean Energy for a Better World*, American Hydrogen Association, Vol 4, No. 1 1993 (internet version)

Prior to beginning the Xerox project CAN trialed a number of other Hydrogen vehicles. One such demonstration involved a Dodge D50 pickup which used the direct injection of Hydrogen which had emissions less toxic than the city air. As a test a man ran one mile breathing through a face mask connected to the tailpipe of the truck with Dr. Zweig measuring his vital signs along the way. Needless to say the man survived with no adverse health effects.

Other Alternative Transportation Fuels

There are a number of other alternative fuels which can be used to reduce emissions with which Hydrogen must compete. A number of these are still derived from petroleum but are considerably cleaner. These consist primarily of Natural Gas, Methanol/Ethanol, Reformulated Gasoline, Battery and Flywheel. Of these only battery and flywheel powered vehicles can be classified as zero emission and only if they have been charged using renewable energy.

Natural Gas - An organic compound which occurs primarily as Methane but contains small amounts of ethane, propane and butane. It is stored in underground rock formations under pressure and is extracted by drilling wells. There are more than 200,000 producing wells in the United States and it is estimated that these wells will be able to supply 85% of the National demand at current consumption rates by the year 2000 [1]. Natural Gas in an inherently cleaner fuel than petroleum due to its greater purity. Tests comparing a natural gas vehicle against a gasoline vehicle of the same model have shown a 78% reduction in CO and an 85% reduction in NOX. Natural Gas Vehicles are presently available off the shelf from a large manufacturers

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[1] *Natural Gas Vehicles: The Decision Starts Here*, Southern California Gas Company, 1995

such as Chrysler and Ford. In addition conventional vehicles can be converted to run on natural gas.

Reformulated Gasoline - This can be used with virtually no major changes in conventional vehicles. Arco's most advanced RFG is claimed to reduce hydrocarbon emissions by 28 %, CO by 25%, NOX by 26%, VOC's by 36% and is estimated to cost approximately $0.15 / gallon more than conventional gasoline[1].

Methanol / Ethanol - These fuels have similar characteristics to Natural Gas but result in slightly increased emissions. Ford has produced what it refers to as the flexible fuel vehicle which can run on methanol and ethanol as well as various mixtures with unleaded gasoline. Already 7,500 such vehicles have been produced.

Battery - Considerable research has gone into developing more efficient batteries to enable electric vehicles to become feasible. While a variety of types exist, the primary technologies are nickel-cadmium and lead-acid. The design is significantly different to that of a conventional vehicle in that it only requires a battery pack and electric motor. Unfortunately the battery packs tend be heavy and at this stage can only provide a travelling range of between 60 and 140 miles. While it is difficult to estimate the emissions from power stations which are required to charge the vehicles, Southern California Edison claims that they are 98% cleaner than a conventional vehicle.

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[1] *Reformulated Gasoline May Be Best Choice*, Energy Conservation News, No. 3, Vol 17, April 1995, (internet version)

Flywheel - This constitutes an alternative form of energy storage using a high speed flywheel. Using lightweight composite materials and ultra-low friction magnetic bearings these wheels can be made to spin at 200,000 rpm when fully charged. Theoretically this is a highly efficient method of storing energy and computer simulations have predicted a vehicle range of 600 miles, however the technology is still in the initial stages of development.

California's Mandate for Zero Emission Vehicles

The driving force behind standards for clean air is the Federal Clean Air Act which was introduced in 1970. This act was amended in 1990 in an attempt to introduce tougher air quality standards. Each year every U.S. city is tested for ozone, carbon monoxide and particulate matter and compared to the National Ambient Air Quality Standards. According to this comparison L.A. is an extreme nonattainment area for Ozone. Under the act the EPA is required to develop national standards for clean air however the responsibility for meeting these standards falls on the states. In 1987 the Coalition for Clean Air in conjunction with the Sierra Club sued the EPA for not meeting these standards. The result was a court order for the EPA to introduce a Federal Implementation Plan (FIP). However this can be overcome if the State produces its own State Implementation Plan (SIP). At present California has been granted a two-year delay to enable it to produce an effective SIP as this is preferable to coming under the jurisdiction of the FIP. In an attempt to meet state clean air requirements the California Air Resources Board has introduced the Zero Emission Vehicle (ZEV) requirement. Under this rule all cars and trucks marketed in California by major automobile manufacturers in 1998 must consist of at least 2% ZEV's increasing to 10% in 2003. In addition manufacturers must meet a fleet average emission requirement using any combination of transitional low-emission vehicles (TLEV's), low emission vehicles (LEV's), ultra low-emission vehicles (ULEV's) and ZEV's. The average emission level will be reduced each year, dropping by 75% between 1994 and 2003. This has in essence become a de facto mandate for electric vehicles. Industry is currently pushing for a 49 state plan which would not include California and is considerably less stringent.

While Hydrogen fuel cells do offer the prospect of zero emissions the current technology has not yet reached the point where it will be a viable alternative to conventional gasoline vehicles. In effect the mandate has kickstarted an electric vehicle industry especially in California. While all the major automobile manufacturers readily oppose the requirement they have at the same time invested heavily in developing battery technology. In 1990 General Motors unveiled the 'Impact', an electric two seater car with a range of 120 miles and an acceleration of from zero to 60 mph in 8 seconds. A number of attempts have come from other manufacturers since then such as Chrysler and Toyota to name but a few. In 1992 a non-profit Californian consortium consisting of over 60 public and private entities know as CALSTART was formed. Its intent was clearly stated by three goals: to create high quality jobs, to clean the state's air and to improve California's global competitiveness. It is based on the premise that California is ideally placed to become a world leader in an advanced transportation industry. The state already has considerable resources due to the presence of the aerospace industry and much of this technology is directly transferrable to transportation. CALSTART is one of the strongest advocates of EV's and has even gone so far as to form a special coalition to wage a highly visible campaign against the big three auto manufacturers, GM, Ford and Chrysler, who have been lobbying for the requirement to be dismantled

However while EV's do offer some benefits there is considerable evidence that they are not the best answer to the current air pollution problem. One of the main arguments being put forward against EV's is that the technology is not yet adequately developed. While the ZEV mandate does not come into effect until 1998 the time required for production will mean that mass production models will rely on technology which is available today. Despite advances being made in battery technology EV's still only have a range of up to 120 miles, have poor acceleration and commonly require around 8 hours to charge. In addition the claims of manufacturers rarely take into consideration the use of air conditioning or radio's and assume no congestion and no stop start driving conditions. There is also the distinct possibility that the market for EV's will be extremely limited. A recent study of buyer's behavior revealed an increasing preference for sports utility vehicles which are by nature high performance [1]. A study by the Reason Foundation states that while most daily commutes are less than 100 miles, consumers consistently demand a range above 150 miles [2]. The large number of batteries required also adds to the cost. Due to continual use batteries are not predicted to last as long as is typical in a conventional car. This means that owners of EV's will have to replace battery packs every two to three years at a cost of over $3,000. This is in considerable conflict with CARB's claim that battery lifetimes will be at least 5 years by 1998 and will only cost $6,500 over the lifetime of the vehicle [3]. While the actual price of EV's soon to be released on the market are not yet available, estimates predict that cars such as the GM Impact will cost at least $25,000 [4]. It is even possible that the high price of EV's will result in increased air pollution. In

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[1] N.M. Arguea, C. Hsiao, G.A. Taylor, *Estimating Consumer Preferences Using Market Data-An Application to U.S. Automobile Demand*, Journal of Applied Econometrics, vol 9, 1994, p.1

[2] Peter Gorden, Harry W. Richardson, *The Case Against Electric Vehicle Mandates In California*, Reason Foundation, Policy Study No. 189, May 1995

[3] Staff Report, *1994 Low Emission and Zero-Emission Vehicle Program Review*, Mobile Source Division, California Air Resources Board, April 1994

[4] *Los Angeles Times*, October 11, 199

an attempt to meet the ZEV mandate, manufacturers may have to'subsidize prices by increasing the price of conventional vehicles. This may mean that consumers may not be as able to readily afford to buy a replacement conventional vehicle and will hang onto their cars for longer. This will increase the amount of older cars on the road which typically have higher emissions.

The ZEV requirement has proved particularly shortsighted in the case of the Xerox Solar Hydrogen project. While the retrofitting of conventional vehicles for Hydrogen will considerably reduce emissions, they will not be eliminated. Only EV's fall under the category of zero emission, which gives auto manufacturers no choice as to how to fill the requirement. Estimates have been made by CARB for emissions associated with the use of electric vehicles but these ignore a number of key factors. They assume that charging will take place at night which will use surplus power that is available from power plants without the need for any increase in production. While emissions from battery recycling has been estimated, emissions due to the increased manufacture of batteries is not. EV's presently use between 28 and 32 batteries per vehicle and it has been calculated that, assuming the 10% ZEV requirement is met, the number of spent batteries generated in California would increase by a factor of 10 to 20.9 million annually[1]. This will require an increase in emissions from lead smelting facilities, most of which are already out of compliance at present levels of production. These emissions will be localized and have the potential to severely impact the surrounding residents. Such a trade off is an environmental justice issue and cannot be justified. The life cycle implications of battery recycling are likewise not considered. While lead can be 98% recycled the acid and plastic cannot. The usual procedure is to neutralize the acid and dispose of it as wastewater whereas the

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[1] Julie Roque, *Pollution Prevention for Emerging Industries*, Reducing Toxics - A New Approach to Industrial Decision Making. Edited by Bob Gottlieb, Island Press, 1995, p306

plastic is landfilled. While there are lifecycle implications to be considered in a Hydrogen vehicle these will be significantly less. CAN has argued heavily for CARB to increase the ZEV emissions requirement. In response CARB has increased this to 0.05 g/mile to allow for the use of Hydrogen combustion powered vehicles. According to Mr Staples the project has a strong chance of meeting this level however he argues that it should be much higher if it is to fairly reflect emissions from electric vehicles.

There is no doubt that while the ZEV requirement has been instrumental in focussing industry on alternative vehicle technologies, major changes must be made to promote Hydrogen technology. The deadline is too early and has resulted in funding being channelled into EV's in a desperate attempt to develop a commercially viable product by 1998. This should be increased to the year 2000 to allow Hydrogen technology, which offers a renewable long term solution, to enter the market.[1] This would avoid wasteful investment in battery technology which at best will only be an intermediary step. Admittedly a substantial amount of the research into electric cars can be directly carried over to Hydrogen. For example light weight chassis designs and break energy recovery systems will prove just as valuable in a Hydrogen vehicle. The ZEV emission level should also be increased to ensure that products such as CAN's Hydrogen vehicle can be seriously considered by manufacturers. The main aim of the ZEV should be to encourage the use of Hydrogen as a combustion fuel until fuel cells are adequately developed. Although it is argued that government should not be in the business of choosing technologies this should not be the case for Hydrogen where the incredible emissions benefits can only be utilized by the erection of large scale infrastructure such as photovoltaic energy facilities and pipe distribution systems.

Partnership for a New Generation of Vehicles

In 1993 the Federal Government created a joint partnership with Chrysler, GM and Ford known as the Partnership for a New Generation of Vehicles (PNV). The aims of the partnership were: to create advanced manufacturing techniques, develop new technologies to reduce emissions and to design prototype engines with three times the fuel efficiency. While this is an important step in creating an environment where government and industry can work cooperatively it does little to promote research into renewable fuels such as Hydrogen. The partnership is non binding as each party has merely signed a "Declaration of Intent". While industry welcomes this type of voluntarism it lacks the leverage to ensure that air quality will increase. Most of the research work taking place under the umbrella of PNV focusses on new lightweight materials and pollution control technology. This has been encouraged by granting access to various aerospace technologies by the Federal Government. While tripling fuel efficiency would produce benefits in the short term even the CEO at Chrysler, Robert Eaton argues that kind of goal "may be beyond what is reasonable and realistic"[1]. Even if such a goal were achieved such vehicles would not be acceptable under the ZEV mandate.

The PNV is more of a publicity stunt than any real attempt to solve air pollution problems. It illustrates the lack of real vision by the Clinton administration in choosing to remain committed to conventional polluting technologies. Rather than making the necessary steps to advance pollution prevention PNV focuses on control and enables manufacturers to continue to refine a technology which is essentially the cause of all major air pollution problems.

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[1] *Clean Car Effort Carries Many 'Ifs"*, Los Angeles Times, October 4, 1994

A Policy Framework for Renewable Hydrogen

Funding

Much of the hope for speeding up the adoption of renewable Hydrogen lies in the allocation of funding by the Department of Energy (DOE). In 1979 funding for research and development into renewable energy was $1.27 billion but has since declined to $289 million for the 1995 financial year (all figures converted to 1992 dollars)[1]. Total funding for Hydrogen has remained at approximately 10 million dollars for the last three years. However this is about one-ninetieth of what is spent on petroleum research [2]. The total budget for DOE stands at $18.6 billion with $10 billion going for nuclear-weapons research and cleanup. Hydrogen funding almost pales into insignificance when it is compared to the current Japanese plan for a 28 year multibillion dollar global hydrogen program. Funding for Hydrogen was only introduced in 1990 as part of a 5 year research bill known as the Matsunaga Act named after Spark M. Matsunaga, an avid proponent of Hydrogen. Robert Walker, who represents Pennsylvania in the House, played an important role in bringing the Matsunaga Act to fruition. Walker remains committed to Hydrogen and has recently introduced the Hydrogen Futures Act of 1995. This bill, which is still being debated in the Senate, sets funding at $25 million for 1996 to grow to $40 million in 1998. Despite the fact that this involves an increase of 150% this is still far below what is needed to really put Hydrogen fuel on the map. In a 1992 report *Proposal for a Sustainable Energy Future Based on Renewable Hydrogen*, Senator Tom Harkin proposed increasing Hydrogen funding to $110 million by 1995. In accordance with this Hydrogen would

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[1] Fred J. Sissine, *Renewable Energy: A New National Commitment?*, Solstice - Center for Renewable Energy and Sustainable Technology, August 26, 1994

[2] Alan Weisman, *The Last Best Hope On Earth*, Los Angeles Times Magazine, March 19, 1995

supply 1% of the nations energy needs by the year 2000 and 13% by the year 2020. Harkin proposes that this funding should be split equally between Hydrogen energy for large scale power plants, and fuel cells, which would be primarily for transportation. While Nuclear Fusion also holds great promise for providing renewable energy, this is not expected to be a practical alternative untill at least the year 2040. It is essential that funding be increased to a level that is compatable or higher than what is allocated to other forms of alternative energy. The basis should not be short term results but rather be founded on a vision for a sustainable future. An increase in funding could easily be accomplished by cutting funding for petroluem or nuclear research.

A Hydrogen Consortium

One of the most important requirements for a move to Hydrogen is the creation of an organization which would champion the cause and promote awareness. In a testimony on Capitol Hill in July of 1994, Frank Lynch of Hydrogen Consultants stated that "A joint Government/Industry consortium is needed to expedite demonstration projects. The purpose of the Consortium is to catalyze and focus a diverse base of support for hydrogen energy". This would take the form of a Hydrogen Research Council or even a Hydrogen Development Corporation. There are presently a number of bodies which are already concerned with Hydrogen. Under DOE there is the Hydrogen Technology Assessment Panel (HTAP) which allocates all Hydrogen funding. There is also the American Hydrogen Association (AHA) and the National Hydrogen Association (NHA). However HTAP focusses only on research and is does non constitute a serious attempt at promoting renewable Hydrogen. The AHA and NHA are often more directly aligned with the Chemical industry which has traditionally produced

Hydrogen from non-renewable sources such as petroleum and natural gas, and as a result have little to gain from the production of renewable Hydrogen.

The creation of a consortium based on renewable Hydrogen would be consistent with the goals outlined in a report on National Environmental Technology Strategy. In this report it is stated that "The federal Government can encourage increased industry investment in technology demonstration through cost-shared programs and other incentives provided in partnership with the private sector" [1]. Partnerships are increasingly being advocated as a means of harnessing the initiative of industry. Such a strategy would definitely be of great benefit in ensuring demonstration projects are developed. At present most research is government funded whereas the actual commercialization is handled by industry. There is a considerable gap in responsibility when it comes to development and demonstration. It is most important that these steps are given considerable support for projects involving renewable Hydrogen vehicles. An illustrative example would be the Xerox Hydrogen Project which is on a large enough scale to be properly tested and for investors to gain confidence in the outcome.

There are a number of Government strategies which specifically seek to support the demonstration of environmental technologies. In his State of the Union address in 1993, President Clinton announced the Environmental Technology Initiative (ETI), aimed at promoting the development of new technologies across a range of sectors. This is backed by the National Environmental Technology Act and allocated $36 million dollars in the 1994 financial year to be administered by the EPA. The specific objectives of the Initiative are: to restructure the regulatory and compliance framework to promote innovation, to support environmental

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[1] *A Bridge to a Sustainable Future - National Environmental Technology Strategy*, National Science and Technology Council, p 39, 1994

technology developers, to invest EPA funds in promising technologies and to accelerate the diffusion of innovative technologies. Other programs such as the Business Innovation Grant (BIG) and the State Program Fund (SPF) sponsored by the DOE provides flexible grant funding to small to medium sized businesses. These funds are specifically to promote environmental technologies and will be targeted at projects which promise near term commercialization. In order to aid companies in finding demonstration and testing sites the Government has recently introduced the interagency Rapid Commercialization Initiative (RCI). This program is to be coordinated by the Department of Commerce and is similar to those programs previously mentioned in its intent to ensure that environmental technologies reach the market. These aims are also encompassed in the Technology Reinvestment Project (TRP) administered jointly by the EPA and the Commerce Departments National Institute of Standards and Technology (NIST). The funding and aims of each of these projects should become the responsibility of a Hydrogen consortium. This would enable greater coordination for maximum exposure and technical advancement. Increased exposure is essential to gain access to the kind of investment that is necessary for the mass production of renewable Hydrogen vehicles.

The Importance of Regulation

There is a danger in relying too much on the widespread adoption of voluntary programs. Many supporters of environmental technologies are too eager to let the market decide on the direction of policy. One example which illustrates the reluctance of industry to voluntarily improve the environment is that of tetraethyl lead (TEL). While the extremely toxic effects of lead were recognized in 1920 when the use of TEL was adopted it was not until the 1970's that its use was phased out. Even then the phase out only occurred as it proved incompatible with the use of a catalytic converter which was introduce following the creation of the Clean Air Act[1]. While industry continues to bemoan the requirements of regulation such as in the ZEV it is obvious that without it there would be little impetus to achieve environmental improvement. The schizophrenic nature of the automobile industry undermines any opposition to environmental regulation. While devoting considerable resources to attacking the ZEV mandate, significant technological advances have been made by these same companies in response to regulation, proving that vast improvements can be achieved.

The end of the pipe approach found in the Clean Air Act is not the only direction regulation may take. An alternative method of encouraging the adoption of Hydrogen is to require use by fleet operators. Under the Energy Policy Act of 1992 alternative transportation fuels must be adopted at least in part by certain fleets located in metropolitan areas with a 1980 population or 250,000 or more. This is similar to CARB's ZEV requirement. However it designates the use of certain alternative fuels rather than emission standards. Technology based standards can hinder the development of alternatives. Specifically requiring the use of renewable Hydrogen vehicles is a necessary first step.

Short Term Approaches to Clean Air

It cannot be denied that in the short term there remains a need to cut down air emissions especially in Los Angeles. There are a number of approaches by which this can be achieved which are more cost effective than EV's and more easily achieved. The first of these is accelerated vehicle retirement aimed at removing older cars through purchasing schemes. In

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[1]Robert Gottlieb, Maureen Smith, Julie Roque, *Greening or Greenwashing?*, Reducing Toxics - A New Approach to Policy and Industrial Decision Making, Edited by Robert Gottlieb, Pollution Prevention Education and Research Center, UCLA, Island Press 1995

1990 pre-1971 vehicles accounted for 15% of all emissions from mobile sources in the L.A. Basin[1]. In exchange for pollution credits Unocal set up a program whereby pre 1971 vehicles were voluntarily given up for purchase for $700 and scrapped. By the end of the program over 8,000 vehicles had been scrapped resulting in the removal of nearly 13 million pounds of pollutants from the air. This equates to almost $900 per ton of pollutants. The study by the Reason Foundation claims that for this type of program the cost of removing VOC's is between $4,000 and $5,000 per ton compared to between $29,000 and $108,000 per ton for electric vehicles. State Senate Bill 501 currently being debated, would require air quality management bodies to encourage further programs for the repair or replacement of high pollution vehicles in return for emissions credits. Though the environmental consequences of scrapping so many vehicles should be carefully considered, such a program can result in major short term gains. Unfortunately the benefits are reduced for cars built in 1980 under far stricter emission requirements. Once most pre 1980 cars are removed little benefit would be gained from further vehicle retirement.

Greater adoption of Natural Gas would also bring air quality gains in the short term. Much of the infrastructure is already in place to enable widespread use of natural gas vehicles especially for fleets. The technology has already been proven and has been shown to have a significant market. To further encourage their use purchases should be exempt from sales tax at least until 1998. Such a scheme is already being proposed by the State Government but would only apply to ZEV's.

The most cost effective approach would be to legislate the use of emissions based vehicle registration fees. This would be based on the results of the annual smog check program and so

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[1] Scrap - A Clean - Air Initiative from Unocal, Unocal 1990

would require relatively little cost to establish. If this was to be introduced the certification process for emissions testing and the actual repair would have to be carried out by separate bodies which is not presently required and has already been the subject of intense debate. The possibility of a carbon based tax is claimed by many to be politically impossible however it remains an alternative which should be considered.

Conclusion

The path toward a Hydrogen future is both highly desirable and achievable. According to Cliff Gladstein former President of the Coalition for Clean Air, Hydrogen technology will equal the steam engine in its impact on society. While the escalating need for huge amounts of energy and automobiles is not desirable, Hydrogen provides a clean needle by which to satisfy demand. But Hydrogen faces considerable opposition and lacks the kind of constituency that will be required to topple the petroleum industry. Unfortunately environmental merits on their own are not enough to bring Hydrogen vehicles to the showroom floor. But in the light of the alternative fuel debates that are currently taking place it is crucial that Hydrogen is made a priority. The creation of a Government/Industry consortium which is properly funded and which could encourage demonstration projects is a definite requirement. Modifications to the ZEV which would delay its full implementation and allow the use of Hydrogen combustion would is also necessary. In the meantime the use of more cost effective pollution reduction measures will ensure that industry is not given the chance to relax.

Ultimately a Hydrogen based transportation system does not provide all the answers. The extreme congestion problem that L.A. faces must be tackled through a greater public transportation system and increased focus on telecommunications as a trip reduction measure.

But the promises of Hydrogen are tantalizing and there is little reason to continue to breath toxic air any longer than can be helped.

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is recognized as a leader in
improving air quality, strengthening the local economy, and enhancing
public awareness of alternative fuels
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the United States Department of Energy's
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Date *April 22, 1996*

Signed [signature]

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Mr. James Provenzano
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Dear Mr. Provenzano:

On behalf of the International Energy Agency Hydrogen Executive Committee, I would like to thank you for the wonderful tour of Clean Air Now. The Executive Committee very much enjoyed seeing a complete, working hydrogen facility. It was especially gracious of you to provide the opportunity for our members to ride in the hydrogen vehicles.

Again, we thank you, and all of the Clean Air Now staff, and wish you continued success.

Sincerely,

Carolyn Elam
Executive Secretary
IEA-Hydrogen Implementing Agreement