Urban Consortium for Technology Initiatives

THE ENERGY TASK FORCE OF THE URBAN CONSORTIUM FOR TECHNOLOGY INITIATIVES

The Urban Consortium for Technology Initiatives (UC) is composed of over forty of the largest cities and urban counties by population in the United States. The Consortium provides a unique forum to define urban problems common to its member governments and to develop, apply, transfer and commercialize technologies and innovative management techniques to address those problems.

With staff, management and business services provided by Public Technology, Inc., the Urban Consortium carries out its work through special projects and Task Forces that focus on specific functional areas of local government management. The UC Energy Task Force is the nation's most extensive cooperative local government program to improve energy management and technology applications in cities and urban counties. Its membership is composed of local government officials from twenty of America's largest urban centers.

The members of the UC Energy Task Force define annual work programs to meet three specific objectives:

- o definition of critical urban energy problems;
- o development of technologies and management practices to resolve these problems; and
- o transfer of resulting solutions to Urban Consortium and other local governments.

Proposals to meet the specific objectives of these annual work programs are solicited from the full UC membership. Projects based on these proposals are then selected by the Energy Task Force for direct conduct and management by staff of city and county governments. Projects selected for each year's program are organized in thematic units to assure effective management and ongoing peer-to-peer experience exchange, with results documented at the end of each program year.

This approach for the definition of priorities and the selection, conduct and documentation of applied research projects by staff from participating local governments is a unique strength of the UC Energy Task Force -- a "user-driven" focus to assure that projects conducted by city and county staff will produce results that effectively meet energy management needs critical to local governments.

PUBLIC TECHNOLOGY, INC. (PTI)

Public Technology, Inc. (PTI), is the research development and commercialization arm of the National League of Cities and ICMA, and a non-profit association of local governments dedicated to improving services and increasing efficiency through the use of technology and management systems.

PTI works with and supports its members in solving widespread and urgent problems facing local governments. This support is handled through a four-tier, interconnected series of service centers, which provide state-of-the-art information, electronic and personal networking with local governments and technical specialists, direct consultation and training with PTI staff experts, and practical research.

To ensure that its programs and research have the widest possible benefit, PTI is guided by a strategic plan that emphasizes partnerships with private industry, expertise in multi-disciplinary technologies, training in the art of change management, and participation in the international arena of local government to further the search for technological and management solutions.

Member cities and counties provide PTI's core financial support. Grants and contracts from foundations, Federal agencies, and corporations also support PTI activities.

PTI's activities are carried out from offices located in Washington, D.C. and Long Beach, California. International coordination is handled through an affiliate in London, England. PTI was founded in 1971 by the major associations of state and local governments.

Costis Toregas, President

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TECHNICAL COMPARISON BETWEEN HYTHANE, CNG AND GASOLINE FUELED VEHICLES

Energy Task Force
of the Urban Consortium

CITY AND COUNTY OF DENVER
Alternative Fuels Unit

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PREFACE

This Interim Report documents the progress to date on this two-year Alternative Fuel project scheduled to end in early 1993. Alternative fuels used for vehicles, such as Hythane, offer a very strong potential to aid in the reduction of auto emissions and to reduce US dependence on foreign oil supplies. Local governments can play an instrumental role in realizing this potential through practical applied research and highly visible projects utilizing alternative fuel concepts and technology options. These projects place a strong emphasis on the examination of all potential alternative fuels. In addition, they can provide a support system based on partnership activities among cities and counties, utilities and other relevant private sector organizations that have matching interests.

Denver has a special interest in alternative fuels because of the location of the city and its history of poor air quality. During 1991, the Denver Hythane Project focused on the preparation of a field test designed to compare the tailpipe emissions of Hythane, (85% compressed natural gas and 15% hydrogen measured by volume), Compressed Natural Gas (CNG) and gasoline, in the hopes of demonstrating the applicability of Hythane as an alternative fuel.

The project began with the development of a partnership among various companies who shared a common vision and offered their expertise to alter the course of deteriorating air quality. Their efforts included the formulation of an emissions testing protocol, the design and building of a research scale Hythane fueling facility, selection of test vehicles, and research into the refinement of vehicle fuel conversion technology. In addition, activities of the past year include preparation of a Hazard and Operability (HAZOP) Study and an investigation into a National Hythane Strategy. Work initiated in the first year on range, fuel composition and quality assurance, engine degradation, acceleration and driveability will continue during the second year of the project (1992).

ACKNOWLEDGEMENTS

Thanks are due to the financial partners who have graciously supported our efforts: the Urban Consortium Energy Task Force, Public Technology, Inc, (PTI), Public Service Company of Colorado, and Air Products and Chemicals, Inc.

Special thanks are also offered to Hydrogen Consultants, Inc. (HCI) for providing technical leadership, acting as general contractor for the project and greatly contributing to the Fueling Station design.

We would also like to acknowledge the following: the Colorado Department of Health (CDH) Laboratory for their analytical contributions and the CDH Aurora Emissions Technical Center for their technical input and facilities utilized for the Federal Test Procedure (FTP) testing process. Their work performance and dedication to the project have proved invaluable to the success of the venture thus far.

Our thanks also go to Stapleton International Airport for providing two of the project test vehicles and offering their location as a possible site for the Fueling Station; Public Service Company of Colorado for providing one of the test vehicles; the Denver Water Board for their help in the early stages of the project; and to CSU for lending us their encouragement throughout the project.

Specifically, our gratitude goes to the colleagues who provided their energy, enthusiasm, and expertise to this project:

AIR PRODUCTS AND CHEMICALS, INC.

Venki Ramen Dan Fields Bob Walsh James Helms

AURORA EMISSION TECHNICAL CENTER

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Finally, our thanks go to the Environmental Health Services project staff members for the City and County of Denver, including Deb Kielian, John Lepley, Mike Merino and Mike Rohrs, who were instrumental to the success of this project, especially in the latter stages.

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CHAPTER 1 OVERVIEW

1a. ABSTRACT

The City and County of Denver, in cooperation with the Urban Consortium Energy Task Force and Public Technology, Inc., has embarked on a two-year research and development project to test and compare the technical merits of a new, blended, alternative motor fuel--Hythane--which is comprised of 85% compressed natural gas (CNG) and 15% hydrogen, measured by volume.

Phase I of this research project included Federal Test Procedure (FTP) analyses conducted in Colorado and California on a converted Chevrolet S-10, pick-up truck. Results from these tests indicate that Hythane has the potential to meet or exceed the California Ultra-Low Emission Vehicle (ULEV) standard. Because only electric vehicles are currently able to meet the ULEV standard, the potential of hydrogen-fueled vehicles to also meet this standard is significant: Hythane may be the transition to such an eventuality.

These initial test data encouraged the development of a plan designed to launch Phase II of the project from theory into reality. Several parameters had to be studied and teams from both the private and public sectors worked together to formulate a plan for which there was no existing protocol. The work accomplished during the 1991 year to meet these requirements includes the following:

1. Development of a team that could provide financial and technical support for the length of the project;

2. Development of a test protocol including the type of test required and frequency, and the selection of vehicles;
3. Securing a source for Federal Test Procedure (FTP) testing and additional lab testing in kind;
4. Building a Fueling Station that fit into the guidelines of the project and that is specific for Hythane;
5. Choosing a Fueling Station site which was convenient in regards to both location and access to supplies required;
6. Negotiating insurance coverage for the Fueling Station and site; and
7. Researching and submitting the necessary applications for permitting.

Three identical 1991 Chevrolet 4x4, 3/4 ton, pick-up trucks with 5.7 liter engines were chosen. The three vehicles are dedicated to operate on a single fuel only; one on unleaded gasoline, one on CNG, and one on Hythane. Up to 52 FTP tests, 40 aldehyde analyses and 40 BTEX (Benzene, Toluene, Ethyl-Benzene and Xylenes) are to be conducted over 12 months. In addition, non-methane hydrocarbon (NMHC) estimates will be calculated by subtracting methane from Total Hydrocarbon results. Performance testing and evaluation of vehicle will also be conducted.

As a testimony to the interest in this fuel, several other hydrogen/CNG projects around the country have been initiated or conceived since the inception of this project. With such interest and continued testing, Hythane may facilitate emission reductions and improve air quality not only in the Denver metropolitan area, but also throughout the nation.

1b. PROJECT PURPOSE

The Denver Hythane Project has been launched for several reasons. First, it is theorized that natural gas and hydrogen can act symbiotically--one complimenting the other --to produce a more efficient burning fuel. Natural gas plays a positive role in the fuel partnership by contributing cost advantage, domestic availability, and existing infrastructure to the scenario.

Another potential benefit of Hythane use--extending the supply of natural gas--can be accomplished if hydrogen is formed from renewable energy sources rather than natural gas reformation. Although natural gas is clean-burning, there is still a need to lower the carbon monoxide (CO), hydrocarbon (HC) and nitrogen oxide (NO_X) levels to accommodate the present and projected low emission standards in effect throughout the nation. The addition of hydrogen to vehicle fuels may provide a viable solution in attaining these lower emission levels. As air quality requirements become more stringent over time, Hythane may be viewed as a bridge to vehicles which run on pure hydrogen--an ultra-clean, renewable fuel source.

1c. GENERAL BACKGROUND

The City and County of Denver has a long standing interest and involvement in environmental issues. One reason for this has been the historically poor--but dramatically improving--air quality of the city, a result of natural geographic factors and man-made sources of pollution.

There are three general natural phenomena that contribute to Denver's air quality problems. First, the City sits in a river trough adjacent to the eastern slope of the Rocky Mountains and is subject to thermal inversions on many winter days. In addition, the air has less oxygen at Denver's altitude of 5280 feet, impairing the complete combustion of gasoline, which results in excess emissions of carbon monoxide and other pollutants. Finally, wind from the constant horizontal flow of air masses during specific seasons can cause emissions to be carried away one day and then return several days later.

An explanation of human involvement in the pollution story has been understood for decades, however, a short elaboration on Denver's dilemma may be in order. There is a high concentration of motor vehicles in the Denver area, and the use of coal as an industrial and heating fuel is extensive. The heavy use of woodburning stoves for heating homes during the winter months is another contributing factor. Additional concerns such as excess dust and particulate matter generated by not only construction but also by street sanding and the use of recreational and transportation vehicles in a semi-arid locale, all contribute to the pollution in Denver's skies.

As a result of these combined factors, the United States Environmental Protection Agency (USEPA) has classified the Denver area as a moderate carbon monoxide (CO) and particulate matter (PM10) nonattainment area, and transitional ozone (O_3) attainment area. Because of these classifications, the City and State have developed and implemented many strategies to reduce emissions from stationary and mobile sources. Some of the mobile source strategies include the use of oxygenates (MTBE and ethanol blends) during the four winter months, a leaded gas ban, inspection and maintenance programs, alternative fuel requirements for fleets, and a time limit on idling vehicles.

The area has also developed a Pollutant Standard Index for CO, PM10, and O_3. If an increase of pollutants above the acceptable levels listed in this index is predicted, a high pollution day is "called", triggering a number of mandatory and voluntary programs including woodburning bans and no-drive days respectively. In addition, a Visibility Standard Index, the first of it's kind in the nation, is also used to determine a high pollution day.

Because the vehicle miles travelled are expected to more than double between the years 1995 and 2010, however, the region is in need of additional ways to attain and maintain air quality standards. Hythane and other alternative fuels are seen as potential, partial solutions to the Denver air quality problem.

1d. REPORT ORGANIZATION

The report is organized into six sections, including the front matter, an overview, the project description, research results, a technology transfer section and finally, the appendices. The front matter includes the preface, acknowledgements, and table of contents.

Chapter 1 provides an overview of the project, including an abstract, purpose and background of the project, and description of the contents of this report.

Chapter 2 provides a description of the project research, including committee participation, vehicle selection, origination of the Hythane blend, and the emissions test plan. In addition, the fueling facility development is discussed with respect to design and fabrication and the requisite permitting processes. Chapter 2 also presents a Hazard and Operability (HAZOP) Study for the use of Hythane, emissions test results and performance data.

Chapter 3 discusses the research results of the project to date, including the emissions data for the Chevrolet S-10 pick-up. There is also a "lessons learned" section and a discussion on the Hythane market barrier assessment scheduled to take place in 1992.

Chapter 4 addresses ways in which technology transfer has been promoted in the project. Denver hopes to work in collaboration with the National Renewable Energy Lab (NREL) by contributing Hythane emissions data to the Lab's Alternative Fuels Data Bank. Because of NREL's status as a national Laboratory and it's accessibility to various segments of the energy/fuels community, it has the opportunity to provide maximum exposure for these data.

Appendix A lists the specifications for the three test vehicles and for the conversion kit. Appendix B includes the specs for the FuelMaker^{TM}, a natural gas compressor. Appendix C contains an in-depth description of the permitting and tank location criteria for the Fueling Station. Appendix D contains the Hazard and Operability Study trouble-shooting guide. Appendix E includes the letter requesting a waiver from the anti-tampering provision to the Environmental Protection Agency, and several newspaper and magazine articles from the project's "Clip File" are listed in Appendix G. Appendix F lists the complete LA-4 short test emission results.

CHAPTER 2 PROJECT DESCRIPTION

2a. PROJECT ORGANIZATION AND TASK DESCRIPTION

The City and County of Denver, with the assistance of several public and private entities, has developed an alternative fuel research program designed to test the merits of Hythane--a motor fuel blend of 85% compressed natural gas (CNG) and 15% hydrogen, measured by volume. Three dedicated-fuel test vehicles operating on Hythane, CNG and gasoline respectively, will be tested and compared for various parameters throughout the two year project.

This project has evolved into a testimony of the strength of a cooperative effort among many parties, connected by their common interest in the potential of Hythane as a fuel. The project enjoyed the financial support of two private sector partners, Public Service Company of Colorado and Air Products and Chemicals, Inc., as well as the participation of two City agencies, Stapleton International Airport and Denver Health and Hospitals (DHH), which is managing the project. Hydrogen Consultants Inc., one of the premier hydrogen research companies in the nation, was involved as the general contractor; and the Colorado Department of Health (CDH) Emissions Technical Center contributed their expertise in emissions testing. The California Air Resources Board (CARB) provided emissions testing for the initial Federal Test Procedure (FTP). A complete description of this test procedure is found in Chapter 3 on pages 25 and 26, under the caption *3a. Emissions Testing*.

Because the project required the expertise of many different parties, much of the work was carried out by committees. Four committees were formed to address vehicle selection, the formulation of an emissions testing plan, fueling logistics and permitting. Coordination was also needed between the fleet managers from Stapleton Airport and Public Service Company to monitor the test vehicles' mileage levels.

2b. VEHICLE SELECTION

The vehicle obtained for Phase I of the project is owned by Hydrogen Consultants, Inc. (HCI) in Littleton, Colorado. The pick-up is a Chevrolet S-10, 2.5 liter, V6, 5-speed with a rear axle ratio of 3.73 and a fuel tank capacity of 20 gallons. Before the FTP testing began, an IMPCO conversion kit was installed to allow fuel consumption of either natural gas or Hythane. An Englehard monolithic catalytic converter and heated oxygen sensor were retrofitted in October of 1991 to increase the efficiency of a gasoline engine using hythane as an alternative fuel.

Phase II planning took place during an initial project meeting in November 1990. Certain parameters for the project were established at that time. It was determined that to ensure accuracy and comparability, the test vehicles should:

- -be the same make and model;
- -have similar mileage;
- -have similar duty cycles; and
- -have automatic transmissions.

It was also decided that the project should involve the testing of at least three vehicles:

- -one gasoline vehicle to serve as a baseline/control;
- -one CNG vehicle; and
- -one Hythane vehicle.

Because Public Service Company of Colorado (PSCo), Stapleton Airport and the Denver Water Board all expressed an interest in supplying vehicles for the testing, their respective "rolling stocks" (vehicles already in operation) were reviewed in an attempt to locate three identical vehicles. It was concluded that the vehicles needed by the project were not available in these fleets, so the focus shifted to new vehicles either on order or capable of being ordered.

Stapleton supplied the Hythane and unleaded gasoline vehicles and Public Service the CNG vehicle. Since GMC had plans to manufacture in 1992, a 5.7 liter, dedicated-CNG truck, and comparability to these trucks at a future date may well be desirable, three identical 1991, 5.7 liter Chevrolet 4x4 3/4 ton pick-up trucks were ordered. They arrived in July, 1991, and began accumulating mileage so that EPA LA-4 testing could begin once 100 miles had been logged. (An extensive explanation of this procedure can be found on page 12). Specifications for these vehicles and the conversion kits are listed in Appendix A.

2c. EMISSION TESTING

The Denver Hythane Project emission testing plan has several components and, at present, two phases. Phase I was conceived during the research stage of the project in 1990, and the emission testing was initiated in early 1991. At project start, it was determined that data were necessary to help substantiate the theory that Hythane was a cleaner burning fuel than gasoline, resulting in lower emission levels. Results from both sea level and high altitude testing centers were obtained during Phase I.

The Phase I vehicle is a 1991 Chevrolet, S-10 pick-up truck. It is owned by Hydrogen Consultants, Inc., and was FTP tested at high altitude (the Colorado Department of Health, CDH Emission Technical Center in Denver) and at sea level (California Air Resources Board and IMPCO in California). A table of the complete analysis of results and a full discussion of these results is in Chapter 3--*Summary and Results*.

Phase II, which was initiated during late 1991 and is expected to continue through early 1993, is the main emissions testing component of the Denver Hythane Project. This phase consists of a comparison of the three Chevrolet pick-up trucks discussed in *Vehicle Selection*, with each vehicle operating on a different fuel. FTP and laboratory testing will be performed throughout the Phase II testing, scheduled for completion in January, 1993. Table 1 listing the sampling schedule and the parameters to be analyzed can be found on page 11.

Phase II Hythane Vehicle

TABLE I

DENVER HYTHANE PROJECT EMISSIONS TESTING PLAN

PHASE II

02/18/92

Vehicle Ownership	Stapleton Airport No. 42	Stapleton Airport No. 43	Public Service Company
Test Fuel	Gasoline	Hythane (Hy5[1])	CNG

EMISSIONS TESTING

Stage	**Screening Test--100 Miles** LA4	Gas Vehicle- Baseline	Gas (Conv Vehicle) Baseline	Gas (Conv Vehicle) Baseline
A	**YEAR 2- 1992 8-10K Miles[2]** **February 12**	(Gas) FTP-2 (THC) Aldehydes- 2 BTEX-2 Methane by GC- 2	(Gas, CNG, Hy5) FTP-6 (THC) Aldehydes-6 BTEX-6 Methane by GC-6	(Gas, CNG, Hy5) FTP-6 (THC) Aldehydes-6 BTEX-6 Methane by GC-6
B	**12-14K Miles [2]** **May**	(Gas) FTP-2 (THC) Aldehydes-1 BTEX-1 Methane by GC-1	(Hy5, CNG) FTP-4 (THC) Aldehydes-2 BTEX-2 Methane by GC-2	(Hy5, CNG) FTP-4 (THC) Aldehydes-2 BTEX-2 Methane by GC-2
C	**16-18K Miles[2]** **August**	(Gas) FTP-2 (THC) Aldehydes-1 BTEX-1 Methane by GC-1	(Hy5, CNG, Gas) FTP-6 (THC) Aldehydes-3 BTEX-3 Methane by GC-3	(Hy5, CNG, Gas) FTP-6 (THC) Aldehydes-3 BTEX-3 Methane by GC-3
D	**YEAR 3- 1993 20-22K Miles[2]** **January**	(Gas) FTP-2 (THC) Aldehydes-2 BTEX-2 Methane by GC-2	(Hy5, CNG, Gas) FTP-6 (THC) Aldehydes- 6 BTEX-6 Methane by GC-6	(Hy5, CNG, Gas) FTP-6 (THC) Aldehydes- 6 BTEX-6 Methane by GC-6

Notes:

- Duplicate sampling will be performed on each test.
- Each test consists of 4 sections:
  1) Cold Start
  2) Cold Stabilized
  3) Hot Start
  4) Background (BTEX background will not be measured as it is below measurement levels)

1. Hy5: This is a short hand method of referring to Hythane, which is 5% Hydrogen measured by energy content.

2. Exact Mileage to be noted in final report.

This table was developed by members of the Hythane project during the latter part of 1990 and early 1991. It was designed to provide the framework for a flexible testing plan allowing the possibility of changes, should they be required, as the project progresses. For example, the reproducibility of results, reanalyzing outlying test numbers (outlying denotes numbers falling outside the norm), or time constraints that may alter the lab's schedule are all variables which can affect this plan. Therefore, the schedule should be viewed as a goal, and alterations may occur only if the additional laboratory information or other circumstances warrant.

The testing plan design mandates duplicate sampling and testing for each test performed on each vehicle to assure reproducibility. This is a quality control process which enables accurate assessment of the results, and is one method of attaining precision in laboratory and instrument performance. These additional data points may also offer valuable comparisons of emissions between Hythane and CNG.

A critical aspect in determining the emissions testing plan was establishing a vehicle baseline during a "Screening Phase". This baseline, in effect, would demonstrate that there were no outliers in the three research trucks, i.e., that none of the vehicles had atypical emissions for a vehicle of that type. This would help assure that subsequent comparisons of the trucks operating on their respective fuels would be valid.

To effectively begin this Screening Phase, the vehicles were operated on gasoline for a distance of 100 miles, and an LA-4 test was run on each vehicle. The LA-4 test (named for the location where the test originated--Los Angeles), involves a hot screening method in which the vehicle engines are already warm, so there are no cold start or cold operation emissions. Such hot tests are typically performed before significant resources and time are devoted to more costly FTP testing. (These test results can be found in Chapter 3, *Summary and Results*, under 3a).

FTP testing will begin during Stage 'A', using gasoline as the fuel for all three vehicles. The three research pick-ups will have been operating on gasoline during this 8-10,000 mile interval. This stage is scheduled to be completed during the month of February, 1992. Additional tests performed according to the emissions testing plan involve the analyses of aldehydes (formaldehyde, acetaldehyde and acrolein), and hydrocarbons, (Benzene, Toluene, Ethyl benzene, and Xylenes; often referred to as BTEX). An estimated non-methane hydrocarbon analysis (NMHC) will be derived by analyzing emissions for methane on a gas chromatograph and subtracting this number from the Total Hydrocarbon (THC) results obtained from the FTP testing. This procedure will be conducted at each interval as well.

In the final steps of Stage A, the Hythane and CNG vehicles will again be tested for all chemical parameters while operating on their respective fuel; Hythane and CNG. In the last step, a set of FTP's will be run with the Hythane truck operating on CNG and the CNG truck operating on Hythane. This is another step to assure that the laboratory analyses reflect the respective fuel characteristics and are independent of factors the vehicles may introduce. It should be noted that the vehicles are dedicated to one fuel, however for testing purposes, the Hythane and CNG truck are capable of running on either fuel--Hythane or CNG.

Referring to Table 1, this process translates into six FTP's, six BTEX, six methane analyses, and six aldehydes. (Duplicate analyses to be run on each of the three fuels).

The analyses will be conducted in a similar manner for the subsequent three stages.

The number of tests conducted during Stage A (8-10,000 miles) emphasizes the importance of establishing a comprehensive analytical baseline to which data obtained later in the project can be compared. The project design also indicates that the testing conducted during Stage D (20-22,000 miles), should be the same as Stage A. This was based upon the assumption that scientific observations of wear, performance, and amount of emission reduction can be accomplished after operating the test vehicles on alternative fuels after a significant period of time and significant miles have been logged.

Fewer tests will be performed during stages B (12-14,000 miles) and C (16-18,000 miles) to account for the limited laboratory time available for this special project, and due to budget limitations. Stages B and C are specifically designed to facilitate an understanding of what effects the interim mileage have on emission reduction.

The project team had also envisioned a third phase of emissions testing which would be conducted by the Auto/Oil Air Quality Improvement Research Program. The Auto/Oil Program is comprised of Ford, GM, Chrysler and a consortium of oil companies. They are funding a multi-million dollar effort to test the emissions of various reformulated and alternative fuels. However, ongoing discussions with a program representative have determined there is not sufficient interest at this time.

2d. PERFORMANCE

The Phase I vehicle (Chevy S-10 pick-up truck) was taken to the Bonneville Salt Flats during the week of August 18-24 of

1991 and tested on Hythane and CNG. The vehicle produced a top speed of 84 mph on both Hythane and CNG.

The Phase II vehicles will also be performance tested after the first series of emission tests, scheduled to take place in February, 1992 at approximately 8,000 miles. The tests will include the quarter mile and the 0-60 mph runs at Bandimere Speedway in Morrison, Colorado. Top speed may also be determined if a suitable site can be found.

Vehicle range is another topic that will be determined in 1992 from the data collected during the length of the project. The mileage gathered from the driver's log books will provide the necessary statistics for computing miles per equivalent gallon for all three fuels.

2e. FUELING FACILITY DEVELOPMENT

The selection of a fueling site was a key component to the success of this project. It needed to be convenient for the fueling of the Hythane vehicle, and acceptable for permitting with the Denver Fire Department. Two sites were considered for the location of the fueling facility: Stapleton International Airport and Air Products and Chemicals, Inc. (Air Products) site, both located in Denver. Some of the advantages associated with the use of the respective sites are outlined below:

STAPLETON:

1. Use of Stapleton would simplify the permitting process (i.e., a CNG Fueling Station is presently operating on site).

2. Stapleton is a more convenient location for the Hythane test vehicle--owned by Stapleton.

AIR PRODUCTS

1. Use of Air Products site eliminates the need to transport hydrogen to Stapleton as it could be dispensed to the Hythane vehicle on-site.

2. Air Products' personnel are familiar with safety and maintenance issues concerning hydrogen and other gasses necessary for the project which would minimize training and safety concerns.

The preferred location was the Air Products site, but an issue of liability prevented an early decision. (This issue will be discussed later in this chapter). The Air Products site at 5285 Joliet Street in Denver was eventually selected.

The fueling facility is now completely assembled and ready for operation. The heart of the station is a Sulzer brand FuelMaker™ natural gas (NG) compressor which was originally designed for the residential market; specifications are listed in Appendix B. Other components of the facility include a ten bottle storage cascade to provide for a fast fill system, a blender where the two fuels are mixed together in the correct proportions before they are compressed, two dry test meters, a buffer tank, cooler and check valves on the storage cascade.

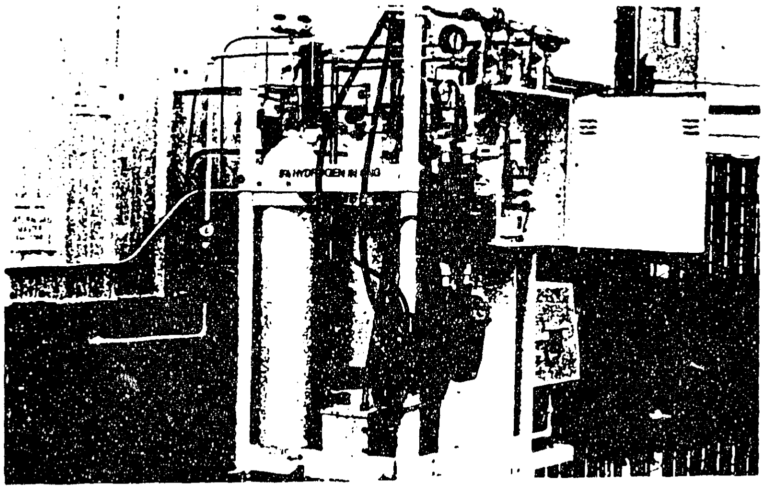
The dry test meters track the amounts of hydrogen and natural gas entering the system, check the water content of the fuels, and provide for a check relating to the operation of the blender. The buffer tank is provided according to "good engineering practices" to dampen or remove compressor pulsations which if left unchecked could alter the ratio of hydrogen to CNG. The correct hydrogen to natural gas (NG) ratio is verified by an on-line thermal conductivity comparator. Two flammable gas detectors are located at the cascade and control system to signal any leakage.

The compressor also has an internal cooling mechanism to insure that hot gas is not supplied to the cascade. (Hot gas is another factor that could alter the ratio of hydrogen to CNG, as higher temperatures affect the pressure of the gas). Check valves located within the cascade system insure that the pressure of each tank is independent and not linked to the other tanks in the storage system, thereby allowing a more consistent fueling pressure. The Hythane fuel is provided to the vehicle via a flexible hose connected to the cascade.

Presently, there is low pressure natural gas service to the site as well as liquid hydrogen storage. Existing lines provide for underground transport of CNG. The hydrogen will be introduced to the Hythane fueling facility (which is external to the Air Products building), at 50 psig (pounds per square inch gauge) from a seven bottle hydrogen storage system (which is in the Air Products building). The natural gas will initially enter the facility at approximately 20 psig. After the fuel is mixed, it will contain 15% hydrogen and 85% CNG, measured by volume. It should be noted that this mixture can also be measured by energy content as 95% CNG and 5% hydrogen.

Approximately 1750 standard cubic feet of Hythane gas (5.5 cubic feet water volume) is needed to fuel the Hythane vehicle at each fill. When the Fueling Station initially becomes functional--at the test start--and on a monthly basis thereafter, the fuel mixture will undergo laboratory analysis at Public Service Company before the vehicle is fueled to confirm the correct composition and quality.

The facility's storage system is designed to store fuel at a maximum pressure of 2900 psig. This will result in a vehicle tank pressure of 2400 - 2900 psig due to ambient temperature variations and the fueling schedule. A photograph of the portable Fueling Station is below. The fueling facility schematic is shown on page 19.



Photograph of the first Hythane Fueling Station. A blending system (center) controls the proportions of hydrogen and natural gas entering the FuelMaker™ compressor (right). Hythane is stored at up to 2900 psi in steel cylinders (left).

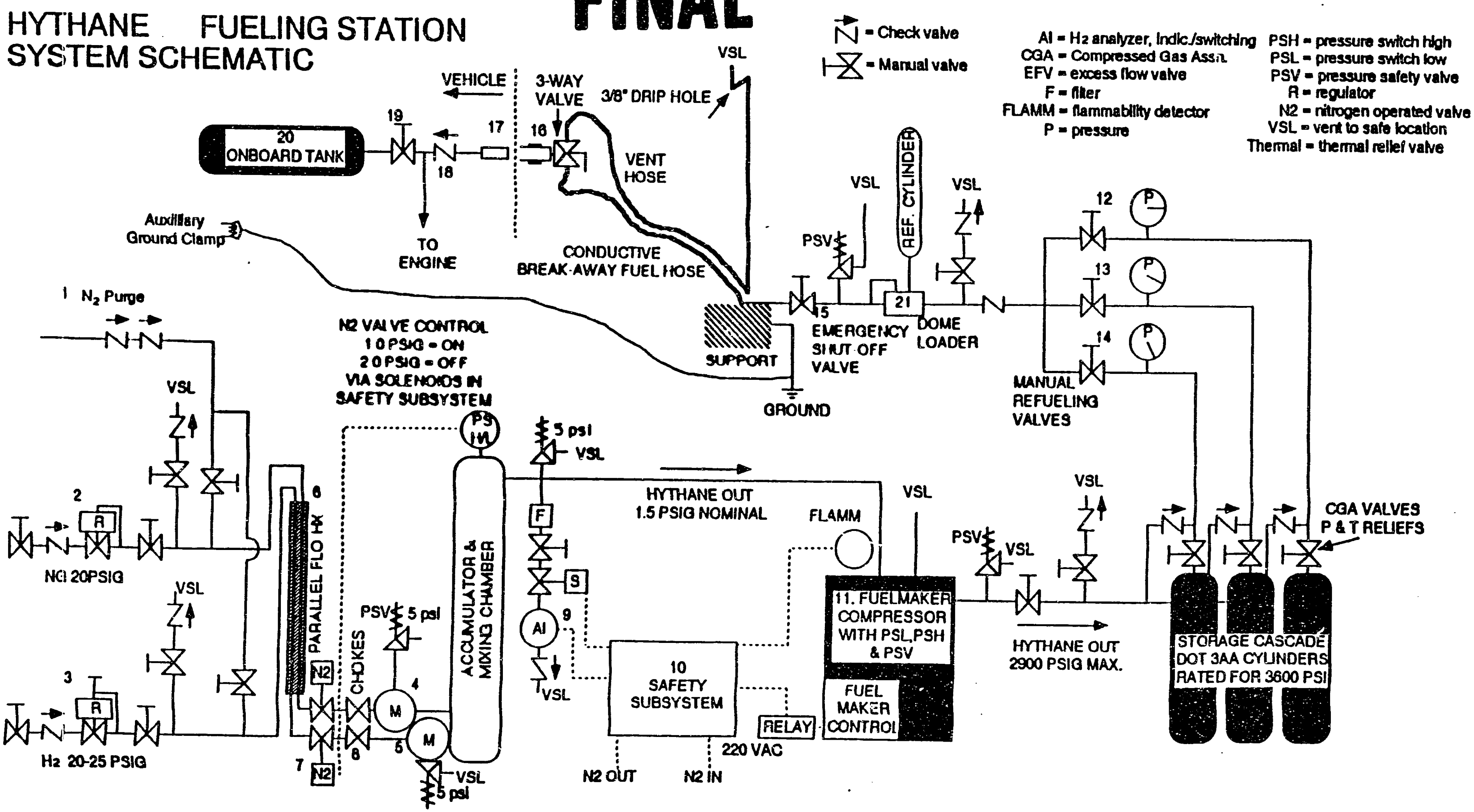
Permitting

The use of pressurized containers introduces the issue of permitting. The Denver Fire Department's permitting guidelines for fuel storage tanks generally fall into two areas--location of the fueling tanks, and the installation of the tanks themselves. The basic requirements for each are discussed in Appendix C. These guidelines have been met and approved by the Denver Fire Department.

The Fire Department will also participate in the testing of gaseous fuel lines supplying CNG and hydrogen to the Fueling Station. The Fueling Station will have pressure testing done on all lines connecting to fuel sources by Public Service Company of Colorado.

HYTHANE FUELING STATION SYSTEM SCHEMATIC

FINAL



The electrical permit will be obtained by HCI. Preparation of the ground, pouring a cement foundation, and surrounding the location with a chain link fence are also responsibilities of HCI and necessary for the final permitting process.

The Building Division was also contacted concerning the necessity of obtaining a building permit. It was determined that no building permit was required for the Fueling Station, as it was considered to be a piece of equipment rather than a building.

Insurance/Liability

During mid-1991, liability concerns surrounding the fueling of vehicles were raised by Air Products. Initial efforts focused on obtaining a contract among the major project participants--Air Products, the City of Denver and HCI. Air Products' primary request was to be "held harmless" in the event that an accident should happen involving the vehicle or during a fueling operation. The City, however, is prohibited by City Charter from indemnifying any entity.

The suggestion was then offered to purchase a special insurance policy exclusively for the Denver Hythane Project. Since HCI already had an insurance policy for their operations with half a million dollars in liability coverage, the first course of action was for them to inquire about expanding the coverage to one million straight liability and four million umbrella liability coverage. This additional coverage would be expressly for the activities of the Denver Hythane Project, and would be paid for by all three parties.

HCI's insurance broker submitted 16 insurance applications, and received 16 declinations. The reasons centered around the fact that the particular combination of project participants was unusual, i.e. a major corporation (Air Products), a municipality (City of Denver) and a small R&D organization (HCI). Other concerns reflected questions about testing a new and experimental technology and fuel. There was further concern that a "project" could not be insured.

Because of the problems encountered, it appeared as though the best way to solve this dilemma was to locate the station at the alternative site: Stapleton International Airport (SIA). Management at SIA was interested in locating the Fueling Station on airport property because it would make fueling the Hythane vehicle much easier, and they were eager to offer their continued support since they had been involved in the project since its inception. Yet there also appeared to be liability concerns with this site, as Air Products' personnel would not be readily available to monitor the fueling and maintenance operations.

After weighing the options of both facilities, Air Products agreed to withdraw their request for a hold-harmless agreement and/or an insurance policy from the City and County of Denver (the City). Instead, the City and Air Products agreed to proceed with a letter of understanding and an agreement that the City would assist Air Products in obtaining a similar letter or arrangement from HCI.

2f. VEHICLE FUEL USE, DRIVER SURVEY, MAINTENANCE TRACKING

<u>Vehicle Fuel Use</u>

In order to track the amount of fuel and motor oil used by each vehicle for the duration of the project, a logbook with standardized formatting will be used by each operator to record the date, mileage, and amount of fuel pumped at each fueling. Public Service Company will record the data for the CNG test vehicle and Stapleton will record the data for the unleaded gasoline and Hythane vehicles. From these data, both the range of each vehicle and the cost per gallon of fuel can be calculated, and a comparison between fuel types made. Logs have been kept since the trucks began acquiring mileage and will continue throughout the project.

Driver Survey

A driver survey will be developed during 1992 to record the opinions of the drivers concerning various factors. The ease of fueling, operation of an alternatively fueled vehicle and general impressions will be some of the questions addressed. Concerns regarding driver/operator education, fueling procedures, and vehicle safety will also be detailed during the project.

Maintenance

Maintenance intervals are scheduled at approximately 4, 8, 12, 16 and 20,000 miles. A complete servicing will be done at these intervals. These services will include oil and filter changes using 15w40 Pennzoil, air filter change, and chassis lubrication. Oil samples will be taken at each oil change and Oil Wear Tests will be conducted for comparability studies. These services will be reported at the time of their completion.

2g. HAZARD AND OPERABILITY STUDY

Before the Fueling Station was built, it was determined that information should be researched about the potential hazards associated with this new blended fuel. A Hazard and Operability Study was determined to be the best means of accomplishing this goal. The complete plan is in Appendix D. This plan includes a procedural flow chart used to trouble shoot potential problems in order to determine the degree of hazard and methods to mitigate any problems.

Air Products' team members, with input from HCI developed the HAZOP Plan. Early in the HAZOP review, it was determined that the 15% hydrogen and 85% NG would not differ significantly from CNG in leakage or flammability characteristics. Although the ignition energy of hydrogen is only about 1/17th that of CNG, and the flammability limits of hydrogen are about ten times wider than CNG, the 85% concentration of CNG will essentially dominate the flammability characteristics of Hythane.

The safety characteristics of the FuelMaker™ NG compressor are satisfactory for Hythane, and the safety characteristics required in the regulations of the National Fire Protection Association for fueling CNG vehicles are also satisfactory for Hythane. Nevertheless, for additional safety, a number of features which are normally associated with the use of hydrogen equipment were added to the design of the Denver Hythane Fueling Station.

Differentiating between a minor problem and an emergency is a prime consideration for the HAZOP Plan. To elucidate the primary hazards of the Hythane Fueling Station, the following list details the major concerns:

1. Leaks (and the associated possibilities of a fire);
2. Overpressurization of equipment; and
3. Intrusion of air into the system due to the presence of partial vacuums.

These primary hazards are counteracted by the addition of the following features:

1. Leaks within the compressor will be detected by the flammable gas detector head which is located in the vicinity of the outlet cooling air stream of the FuelMaker™ compressor. Leaks from any other equipment will be minimized by detection in the earliest stages. This is accomplished by using a hand-held flammable gas detector which will be passed by each mechanical joint and valve packing in the system on a periodic basis (approximately every three weeks). The Hythane mixture will be odorized due to the 85% NG, measured by volume, meeting the odor regulations for NG;

2. The NG feed is overpressure protected by the gas company. The hydrogen feed is overpressure protected by Air Products. The FuelMaker™ has an internal pressure switch to shut itself down and has a built-in relief valve. An additional relief valve was added downstream of the FuelMaker™ to prevent overpressurization of the compressor outlet or the storage cylinders.

In the very remote chance that a vehicle storage tank was under excess pressure, connected to the Fueling Station, and the gas back-flowed from the vehicle into the Fueling Station, the station has a pressure safety valve and other check valves for protection;

3. Vent lines from all vent valves and relief valves are taken to a single vent header pipe at a safe overhead location. The vent is directed straight upward and includes both a weep hole and a manual drain to prevent freezing of accumulated (rain) water. The single vent header incorporates a very small nitrogen purge in order to keep

air out of the vent pipe (since it will contain a flammable gas while venting).

The only items which will be permitted to vent at the station are the standard fire fuse (melt-out) plugs in the top of each hydrogen storage cylinder. They will only vent if the storage cylinders are exposed to fire;

4. Partial vacuums must be prevented in order to prevent air intrusion into the system. The FuelMaker™ has a built-in safety system to prevent this should the pressure fall to 1.0 psig; and

5. The hydrogen analyzer and the flammable gas meter are placed within a warmed cabinet. A small nitrogen purge is provided in this cabinet to insure that, should the analyzer leak, the instruments would not become ignition sources. An asphyxiation warning sign will be placed on the cabinet door.

During the summer of 1991, HCI utilized both this Plan and information submitted by Air Products to begin construction of the Hythane Fueling Station. To the greatest extent possible, commercially available, off-the-shelf components were utilized for the Fueling Station.

CHAPTER 3 RESULTS AND SUMMARY

3a. EMISSIONS TESTING

Phase I

In the FTP testing conducted in January and February of 1991, the Phase I vehicle (Chevy S-10 pick-up truck) had a factory stock catalyst in place--a three-way catalyst--designed to reduce carbon monoxide, nitrogen oxides and hydrocarbons. This testing was performed at altitude at the Colorado Emissions Technical Center in Aurora, Colorado. Testing at sea level was performed in California at the California Air Resources Board (CARB) and IMPCO.

The second round of testing was conducted in October and November of 1991, at which time the Chevy S-10 was equipped with a different catalyst--one designed specifically to reduce the methane prevalent in CNG emissions. HCI was able to test this special catalyst by requesting a waiver from the anti-tampering provisions as promulgated by the Environmental Protection Agency (EPA). (See Appendix E for a copy of the letter requesting the waiver).

The testing data in both cases was favorable, and tended to substantiate the premise that some emission results from using Hythane would improve as compared to gasoline or CNG. Although a tuning error periodically caused slightly lean operation, the results corroborated that it was possible to obtain low levels of nitrogen oxides (FTP composite, 0.21 g/mi). Table 2 on page 29 lists these test results. To explain the separate phases mentioned in Table 2, a step by step description of the testing parameters is detailed below. These phases categorically list the process used during the Federal Test Procedure.

The data compiled during Phase A represents emission results obtained during a Cold Start; a phase which requires the vehicle to remain inoperative for a minimum of 8 hours and a maximum of 12 hours. During the next step of this phase the vehicle is tested on a dynamometer during a low acceleration cycle, which has been incorporated into a computer program and designed to duplicate a typical start and stop course through an urban neighborhood. This phase takes 505 seconds to complete.

Phase B is termed a Cold Stabilized Start and is the most stable phase of the FTP testing, which is reflected in the lower emission results in Table 2. This stability is attributed to the vehicle already operating for 505 seconds, allowing the engine an opportunity to warm up and operate more efficiently. The vehicle runs through the drive cycle on the dynamometer for 868 seconds, at which time the engine is turned off and a 10 minute "Cold Soak" or resting phase is observed before beginning with Phase C.

Phase C is termed a Hot Start. The computer simulation for this stage involves a drive cycle identical to Phase A, but at a higher acceleration. As with Phase A, the cycle lasts 505 seconds.

The FTP composite is an average of these three phases. Table 3 on page 30 lists averaged emission results for gasoline, CNG and Hythane for comparison.

TABLE 2

HYTHANE FTP EMISSION RESULTS/PHASE I (GRAMS/MILE)

TEST SITE	TEST DATE	THC	CO	NOx
FTP COMPOSITE: avg of Phase A, B, and C				
CDH	1-91	0.43	1.61	0.37
IMPCO	1-91	0.51	0.96	0.21
CARB	2-91	0.48[1]	0.66	0.20
CDH	10-91[2]	0.60	0.14[3]	0.56[3]
CARB	11-91[2]	0.51	0.14[4]	0.21[4]
PHASE A				
CDH	1-91	0.91	3.04	0.93
IMPCO	1-91	1.02	2.54	0.58
CARB	2-91	0.95[1]	1.60	0.59
CDH	10-91[2]	0.81	0.55[3]	0.52[3]
CARB	11-91[2]	0.73	0.34[4]	0.33[4]
PHASE B				
CDH	1-91	0.24	0.86	0.18
IMPCO	1-91	0.33	0.53	0.08
CARB	2-91	0.23[1]	0.28	0.06
CDH	10-91[2]	0.49	0.00[3]	0.48[3]
CARB	11-91[2]	0.35	0.06[4]	0.14[4]
PHASE C				
CDH	1-91	0.44	1.94	0.33
IMPCO	1-91	0.47	0.56	0.17
CARB	2-91	0.52	0.52	0.18
CDH	10-92[2]	0.66	0.09[3]	0.73[3]
CARB	11-91[2]	0.65	0.15[4]	0.25[4]

1 CARB used a Flame Ionization Detector correction factor of 1.21 to account for methane in THC. The above is uncorrected. CARB actually reported 0.40 THC g/m avg. of 3 FTP's.

2 With heated O_2 sensor & Englehard monolithic catalytic converter.

3 Tuning error caused slightly lean operation. (Two lean spots were found during the drive from CA: one at 40-50 mph cruise and another at low RPM).

4 Idle screw reset. First adjustment since Jan 1991.

TABLE 3

EMISSION RESULTS FOR GASOLINE, CNG, HYTHANE AND HYDROGEN*

	THC	NMHC	CO	NOx
GASOLINE		.59	14.1	2.2
CNG	0.53	0.01	2.96	0.9
HYTHANE TRUCK (CARB, 1991)	0.49	0.01	0.7	0.2
PURE HYDROGEN (GM, 1972)	<0.01	<0.01	< 0.01	0.2

*Units are expressed as Grams per Mile

Preliminary testing also shows that Hythane meets or exceeds Ultra Low Emission Vehicle (ULEV) standards at sea level for NMHC, CO and NOx (see Table 4), and meets the CO ULEV standard at high altitude. The CO composite at high altitude is 0.14 grams/mile (g/mi) as compared to the ULEV standard of 1.7 g/mi. The high altitude NOx and NMHC measurements achieve the Transitional Low Emission Vehicle (TLEV) and the Low Emission Vehicle (LEV) standards respectively. (Compare Table 2 with Table 4). Although CNG alone lowers air pollutants, it appears that Hythane offers further improvement for CO and THC.

TABLE 4

EMISSIONS STANDARDS - CURRENT AND PROPOSED*

	THC	NMHC	CO	NOx
Current Federal Light Truck	0.97	0.8	10.0	1.2
Proposed California "TLEV"	0.15	0.125	3.4	0.4
Proposed California "LEV"	0.09	0.075	3.4	0.2
Proposed California "ULEV"	0.05	0.040	1.7	0.2

*Units are expressed as Grams per Mile

Phase II

To provide comparability of the emissions data for Phase II, steps were taken to insure that there were no outliers in the group of vehicles, i.e., that none of the vehicles had atypical emissions for a vehicle of that type. To accomplish this, an LA-4 emissions test procedure was conducted on all the vehicles, once they had accumulated 100 miles operating on gasoline. The results indicated that the vehicles were within the normal range of emissions as Table 5 shows (see page 32). The complete test results are listed in Appendix F.

Table 6 (see page 32), shows the current acceptable emission levels for non-methane hydrocarbons (NMHC), carbon monoxide (CO), and nitrous oxides (NO_X) for light duty trucks. As seen when comparing Table 5 to Table 6, all results fell within the federal standards. For example, the highest numbers obtained for any of the test vehicles for THC was 0.38 g/mi. The federal emission standard for THC is 0.97 g/mi. In comparing CO, the highest result for all three test vehicles was 1.58 g/mi; with the standard at a maximum of 10.00 g/mi. The highest nitrogen oxides (NO_X) level was 0.93 g/mi with the standard at 1.2 g/mi.

All three of the Phase II vehicles accumulated their initial miles on gasoline to insure the proper operation of the catalyst. This refers to the concept that until a catalyst has accumulated at least 4,000 miles, it is considered to be "green". (As of December 1991, approximately 8,000 miles had been driven on each truck). This initial accumulation of miles on gasoline was also designed to provide a gasoline baseline for FTP testing. Results for this first phase of testing should be available in March 1992.

TABLE 5

LA-4 EMISSION RESULTS AT 100 MILES*

	THC	CO	NOx
Gasoline Vehicle No 42			
7-10-92	0.09	1.58	0.93
Duplicate Analyses 7-18-91	0.08	1.44	0.89
Hythane Vehicle No 43			
7-10-91	0.04	0.33	0.77
Duplicate Analyses 7-18-91	0.05	0.57	0.75
CNG Vehicle PSCo			
7-17-91	0.38	0.52	0.66
Duplicate Analyses 7-17-91	0.04	0.39	0.87

*Vehicles operating on unleaded gasoline fuel
Units are expressed as Grams per Mile

TABLE 6

FEDERAL EMISSION STANDARDS*

	THC	NMHC	CO	NOx
Current Federal Light Truck	0.97	0.8	10.0	1.2

*Units are expressed as Grams per Mile

3b. HIGHLIGHTS AND LESSONS LEARNED

1. One of the major "lessons learned" relates to liability concerns associated with testing a new fuel and designing a research-scale fueling facility. An attempt to address the interests of all parties by engaging in a partnership evolved into an understanding of the upside potential, as well as the downside risks. The concern over fueling and operational safety did not surface until well into the project, causing considerable delay. Although it is very difficult to anticipate problems, an attempt should be made between all parties to be candid and forthcoming about concerns and opportunities. Such issues need to be addressed early on--preferably as the research plan is being designed and negotiated.

2. All parties in a clearly public/private research project such as this need to be fully aware of the costs they are being asked to bear with full realization that there are likely to be cost overruns. These are not money-making ventures.

3. Ownership of hardware and any other "property" needs to be discussed and agreed to initially and each time a major decision is made. Specifically, either the designation of an owner of the Hythane Fueling Station or a decision to dismantle the station will need to be addressed. A written agreement needs to be included in either contract language, as a letter of understanding, or a memorandum to the file and acknowledged by all participants.

4. Applications for waivers involving state agencies or the EPA involved a time consuming process, although not a complicated one. Compilation of information concerning the need for a waiver was the first required step. For this particular project, a special project exception form to

Regulation 14 was requested from the Colorado Department of Health (CDH). This form was completed and submitted with a list of mechanical and electrical parts constituting the IMPCO conversion kit, a list of pertinent information concerning the three research vehicles, and a description of the basic project design. This information was sent to both the CDH Air Pollution Control Division and to the EPA for approval.

5. Technical lessons include a progressively increasing understanding of how to convert a gasoline powered engine to perform efficiently on an alternative fuel. The utilization of the Englehard monolithic catalytic converter to decrease hydrocarbon emissions often found in CNG emissions and the use of a heated oxygen sensor to more accurately determine the air/fuel ratio aided in increasing the performance of the vehicle engines operating on alternative fuels.

CHAPTER 4. TECHNOLOGY TRANSFER

4a. INNOVATION AND APPLICATION

This project has shown innovation by putting together a team consisting of federal, state and local governments with large and small private research and development companies and a public utility. This team developed a research project based on the concept that the blending of two fuels may potentially offer advantages not available to either independently. In so doing, two industries--natural gas and hydrogen--now share a common ground upon which to collaborate in a mutually beneficial opportunity. Because hydrogen is potentially renewable (solar electrolysis), this combination of hydrogen and CNG may be a transitional, clean-burning, practical alternative fuel.

The results may also demonstrate to fleets in the Denver metro area that Hythane has very attractive operating characteristics and is worth integrating into their fleets. Lower emission results may encourage the use of Hythane by local natural gas retailers at retail fueling facilities.

Alternative fuel data are transferable to other jurisdictions where CNG vehicles are in operation. Local fleets, along with private businesses considering options to comply with clean air legislation, may benefit from standardized Hythane data. Denver Hythane emissions data will be transferable to low and high altitude cities since data have been collected at the Colorado State Emissions Technical Center (high altitude) and the California Air Resources Board (sea level).

As a side note, Denver has been selected as one of 12 international cities to participate in the 10-year Urban CO_2

Reduction Project with the International Council on Local Environmental Initiatives (ICLEI) under the auspices of the United Nations. Since CO_2 production is directly related to the combustion of fossil fuels, and UCETF projects also seek to minimize the use of these fuels, an ICLEI/UCETF partnership would appear to be beneficial.

4b. FRAMEWORK FOR A NATIONAL HYTHANE STRATEGY

The American Gas Association, (AGA), Natural Gas Vehicle Coalition (NGVC), the National Hydrogen Association, the National Renewable Energy Laboratory (NREL) and others have shown an interest for a more coordinated effort to explore the potential of Hythane.

A national strategy for the introduction of Hythane into the transportation fuel network could help avoid the generation of inaccurate or incomplete data by varied interests. Since the inception of the Denver Hythane Project, several other related R&D projects have been triggered across the country. A nationally coordinated R&D/Commercialization Plan for Hythane could also help to further the early entry of this fuel into the marketplace.

The tasks relating to the development of this strategy include formalizing a collaborative relationship with National Renewable Energy Laboratory (NREL) so that a standardized data protocol can be developed. Should NREL be chosen as the lead agency in a Hythane/CNG Commercialization Plan, their cooperative efforts with other agencies and organizations will insure that emissions data collected is consistent.

Another goal in this strategy is to incorporate project data into NREL's alternative fuels data bank. Comparable research data could be added to and offered to users of this clearing-house. Staff could also advise interested parties on other research efforts which could lend support to their proposals.

Issues related to the incorporation of Hythane into the CNG infrastructure fueling network will also be examined. By reviewing the logistics of fueling, any necessary research needed to accommodate the process of blending hydrogen with CNG could be ascertained. Components in the network which are not hydrogen-compatible will also be identified and alternative approaches recommended if necessary.

Public perception of Hythane is another parameter to be assessed. Denver proposes to sponsor a Hythane Seminar where a short questionnaire will be disseminated to ascertain any present biases toward the fuel in terms of safety and acceptability. Fleet managers and other interested parties will attend. Denver project staff will also develop a Hythane Fact Sheet for distribution. This seminar will be held solely by Denver, or possibly in conjunction with Colorado's "Clean Air Colorado" organization.

During a Public Technology Inc./UCETF technical meeting in Detroit, project staff met with the Chair of the Speciation Procedure Development Committee regarding the incorporation of Hythane into Phase II of the Auto/Oil Air Quality Improvement Research Program's emissions testing program. Using slides and technical information supplied by Denver, the Chair, Mr. Schuetzle, formally presented Hythane before the Consortium on October 28, 1991. Despite Mr. Schuetzle's enthusiasm, the final decision on the inclusion of Hythane by the consortium was negative.

At a baseline level, these efforts have and will continue to assist in Hythane commercialization. Further progress will be made in this area as decisions are made, additional funding becomes available, and/or implementation measures are taken.

APPENDIX A

Specifications on GM Trucks
Specifications on Conversion Kit

SPECIFICATIONS FOR THREE TEST VEHICLES

VEHICLE INFORMATION:

	Hythane vehicle	CNG vehicle	(Information only) Gasoline vehicle
	VEHICLE NO. 1	VEHCILE NO. 2	VEHICLE NO. 3
MAKE	Chevrolet	Chevrolet	Chevrolet
MODEL	pickup truck 3/4ton 4X4	same	same
YEAR	1991	same	same
VIN	1GCGK24K6ME200129	1GCGK24K4ME127245	1GCGK24K2ME201990
LICENSE #	Denver 3819	690 AA4-PU	Denver 3818
VEH. I.D. #	W-1-43	15-151	W-1-42
ENG. DISPL.	5.7 Liter	same	same
# OF CYL.	V-8	same	same
FUEL SYS. TYPE (ORIG.)	Throttle Body Fuel Inj	same	same
CONVERSION DATE	February 1992	February 1992	NA

HYDROGEN CONSULTANTS INCORPORATED

12420 N. Dumont Way, Littleton, Colorado, 80125
Phone: (303) 791-7972 • Fax: (303) 791-7975

PURCHASE ORDER

90 — 0340

HCI JOB NO. 520.31

ORIGINATOR'S NAME G. Egan

TO
Central Motive Power, Inc.
6301 N. Broadway
P.O. Box 17128 T.A. 80217-0128
Denver, CO 80216
428-3611

SHIP TO
Hydrogen Consultants, Inc.
12420 N. Dumont Way
Littleton, CO 80125

DATE OF ORDER	DATE REQUIRED	SHIP VIA	F.O.B.
11/7/91	ASAP	UPS	
ORDERED VIA phone (PHONE / FAXED PO / MAILED PO)	QUOTATION NO. verbal-Rube	TERMS Net 30	[XX] FOR RESALE [ ] FOR USE

	QUANTITY ORDERED	QUANTITY RECEIVED	PLEASE SUPPLY ITEMS LISTED BELOW		
1	2		FB-300 AM-50-2 carburetors	55.38	110.76
2	2		PEV-1 3.7-6" H_2O Column Springs	.41	.82
3	2		S2-109 2.7-3.85" Extra Springs	2.96	5.92
4	2		Fuel Lock-off Solenoid Valves VFF 30-2	31.06	62.12
5	2		AFCP-1 Fuel Control Processors	187.50	375.00
6	2		PEV-1 Regulators	58.34	116.68
7	4		G-121 Solenoid Valves	18.14	72.56
8	2		A1-16-1 Adaptors	11.82	23.64
9	2		AA-2-49 Filler	11.45	22.90
10					
11					
12			Subtotal		790.40

NOTES
This Purchase Order Replaces PO 90-0337
dated 11/4/91-DO NOT DUPLICATE

TAX EXEMPT # 2203954
TAX
SHIPPING
TOTAL 790.40+ shipping

PURCHASE AUTHORIZED BY: Greg Egan

IMPORTANT ! OUR ORDER NUMBER MUST APPEAR ON INVOICES, PACKAGES & CORRESPONDENCE.
PLEASE INFORM HCI IF UNABLE TO DELIVER BY DATE REQUIRED.

APPENDIX B

Specifications on FuelMaker™

Specifications

FuelMaker natural gas vehicle refueling appliance, Model C3

Gas

Inlet pressure
- minimum 1.7 kPa (7 in. water)
- maximum 20 kPa (2.9 psig)

Discharge pressure
- standard 20 MPa (2900 psig) at 20°C (68°F)
- optional 16.5 MPa (2400 psig) at 20°C (68°F)

Flow Rate
- minimum 2.7 Nm^3/hr @ 20°C and 1.7 kPa inlet
- maximum 4.5 Nm^3/hr @ –40°C and 20 kPa inlet
- nominal 3.0 Nm^3/hr (approx. 1.8 SCFM)

Electrical

Voltage
230 volt, single phase, 60 Hz (50 Hz optional)

Motor
1.5 hp, TEFC

Power Requirement
maximum 1.8 kw

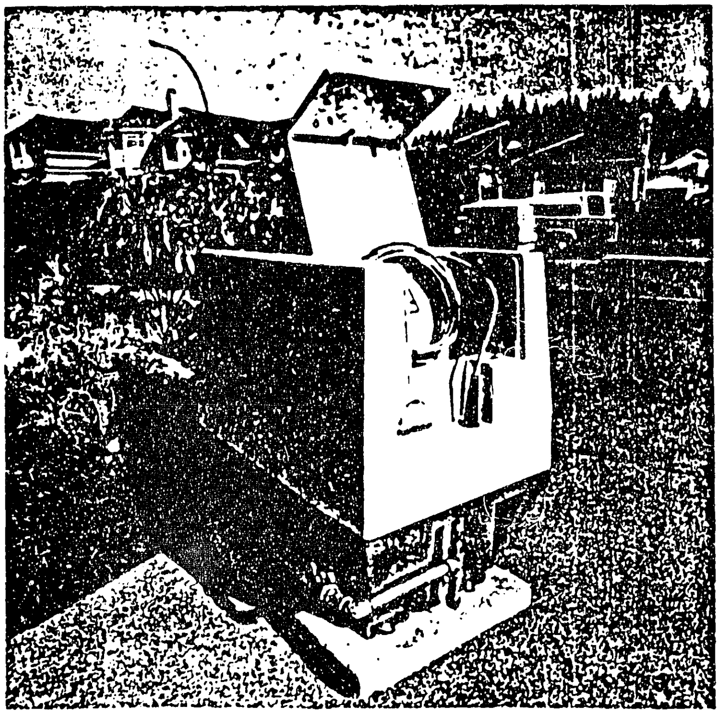
Mechanical

Dimensions
700 mmL x 473 mmW x 730 mmH
(27.5"L x 18.6"W x 28.7"H)

Weight
66 kg (145 lbs.)

Noise
45 dbA at 5m (open field condition)

Ambient temperature
–40°C to +40°C (-40°F to +104°F)



APPENDIX C

Permitting/Tank Location Guidelines

Permitting the Fueling Facility

Tank Location Guidelines

Denver Fire Department permits will not be granted if there would be substantial risk to life, safety, or property, within 500 feet of the proposed location.

Plans must be reviewed in advance by the Fire Department for approval. Information needed is as follows:

Plot plans for proposed Fueling Station, showing the location of all on site buildings, storage tanks, and capacity of each storage tank.

Also, the following is required of all property within 500 feet of the proposed fuel storage tank installation:

1. Plot plan of all surrounding property;
2. Occupancy type of each building, i.e., hotel, office, retail sales;
3. Type of building construction for each building;
4. Number of floors above ground and below ground;
5. Plot plan showing all wall openings in buildings adjacent to the station; and
6. Documentation satisfactory to the Fire Dept. that in the event of a release of any or all of the product on the premises, the concentration will not exceed one half of the LEL (Lower Exposure Limit) at the nearest residential or special use occupancy.

Other restrictions covering compressed natural gas tanks relate to the concept of "protected use." A protected use is defined as any residential use, hospital, auditorium or other building used for public assembly. A protected use must be a minimum of 1,000 feet from tanks containing compressed natural gas or from a vehicle fueling operation that uses above-ground tanks.

Tank Installation Guidelines

The Fire Department requires that all installations comply with local, State and Federal regulations. The requirements are as follows:

1. Installation location information (name, address phone number of business);
2. Installer information (name, address, and phone number of installer);
3. Name of tank manufacturer and distributor.

Additionally, details of the installation plan itself are to be submitted on a drawing done to legible scale and include the following:

A) Tank location on property;
B) Tank depth of bury;
C) Tank slab and tie down, if applicable;
D) Tank piping including fill vent and vapor recovery;
E) Corrosion protection, if applicable;
F) Flex connectors and swing joints;
G) Overfill protection;
H) Leak detectors, if applicable;
I) Pumps;
J) Emergency shut off valve, if applicable;
K) Secondary containment, if applicable; and
L) Vapor monitoring, if applicable.

Of course, some of these requirements would not apply to above-ground Hythane tanks or cascades, for example, parameter B describing details concerning the depth to which an installation should be buried.

In conclusion, the Fire Department must be supplied with two sets of drawings that demonstrate compliance with their requirements relating to location and installation. The project drawings submitted to the Department have used Air Products' site drawings as a base and have shown additional detail relating to the actual location of the fueling facility and the hydrogen, nitrogen and natural gas lines on the property. Hydrogen Consultants, Inc., the general contractor on the project, has provided plumbing, electrical and specific guidelines for placement of the fence which will surround the fueling facility.

Fire Department requirements for locating compressed gas fueling tanks are given in the Fire Department Guideline for Public Distribution, Fire Department Requirements for Fuel Storage tanks, Zoning Districts B-2, B-A-2, B-3, B-A-3, B-4, B-A-4, B-5, B-7, B-8, revised 1/91, and in the Code in Sec. 59-413(7)c-1, Limitations on External Effects of Uses. Guidelines for the installation of the Fueling Station tanks are given in the Fire Dept. handout Denver Fire Department Tank Installation Guidelines, 10/25/89.

APPENDIX D

Hazard and Operability Study

HAZARD REVIEW OF THE DENVER HYTHANE (5% HYDROGEN IN NATURAL GAS) FUEL STATION

BY

J. G. Hansel — Sr. Engineering Associate, Engineering Safety Department, Air Products and Chemicals, Inc., Allentown, PA

G. W. Mattern — Mgr. of Safety, Industrial Gas Division, Air Products and Chemicals, Inc., Allentown, PA

with contributions from:

F. E. Lynch — President, Hydrogen Consultants, Inc., Littleton, CO

Overview

The Air Products team members conducted the hazard review along with the engineering of the fuel station during the spring and summer of 1991. Frank Lynch of Hydrogen Consultants, Inc. provided input in the hazard review and provided the bulk of the engineering of the Hythane fuel station. As much of the fuel station as possible would be assembled from commercially available components. The heart of the station is a Sulzer-brand FuelMaker natural gas (NG) compressor. Sulzer is a world class company with decades of (general) compressor design and operating experience.

The design of the Hythane fuel station itself is inherently simple, including the use of choked flow orifices to proportion the 5% H_2 content.

Early in the hazard review it was determined that the 5% H_2 in 95% NG would not differ significantly from NG in leak or flammability characteristics. Although the ignition energy of H_2 is only about 1/17th that of NG, and the flammability limits of H_2 are about ten times wider than NG, the NG at 95% concentration will essentially totally dominate the flammability characteristics of Hythane. Thus the safety characteristics of the FuelMaker NG compressor would also be satisfactory for Hythane, and the safety characteristics required in NFPA 52 for fueling compressed natural gas (CNG) vehicles would also be satisfactory for Hythane. Nevertheless for additional safety a number of safety features will be added to the design of the Denver Hythane fuel station <u>which are normally associated with the use of hydrogen equipment.</u>

Description of Hythane Fueling System

The system is shown in the attached [HCI] figure which has an instrument code in the upper left corner. The figure is followed by a page of notes on the Hythane station.

The NG and H_2 enter the system at the left side of figure regulated in the range of 20 to 25 psig. Regulated N_2 is also available for purging, as shown. The NG and H_2 then (separately) enter a parallel flow heat exchanger to insure that both gases are at equivalent temperatures. Each gas then passes through a choked flow orifice (choke) 8 and then into an accumulator/mixing chamber at 1.5 psig. A side stream of the resulting Hythane enters an analyzer 9 (AI), whereas the main Hythane stream is then fed into the Sulzer FuelMaker, the output of which is 2900 psig maximum--and then placed into storage cylinders. The output of the cylinders leads to the vehicle fill hose. The vehicle connection and the vehicle fuel hose connection are both shut-off (double shut-off). In addition the connecting coupling is a breakaway type.

The level of safety designed into the Hythane fuel station will exceed the requirements of NFPA 52 and meet the more strict safety criteria of Air Products and Chemicals, Inc. The primary hazards are:

1) leaks (and the associated possibilities of a fire),

2) overpressurization of equipment,

3) safe location of vents,

4) instrusion of air into the system due to the presence of partial vacuums.

These primary hazards are counteracted by the following considerations:

1) leaks within the compressor will be detected by the flammable gas detector head which will be added in the vicinity of the outlet cooling air stream of the FuelMaker compressor. Leaks from any other equipment will be minimized by detecting leaks in their earliest stages. This is accomplished by using a hand-held flammable gas detector which will actually be passed by every mechanical joint and valve packing in the system on a periodic basis (approximately every three weeks). The Hythane will be odorized due to the 95% NG.

2) Overpressurization

   The NG feed* is overpressure protected by the gas company. The H_2 feed* is overpressure protected by Air Products and Chemicals. Full pressure failure of either Regulator 2 or 3 will not overpressure any components up to the chokes at 8. Relief valves at 5 psig have been placed on the dry test meters. Further, the PSH/L on the accumulator/mixing chamber will trip at 2 psig and close the N_2 activated solenoids at 7, as well as stop the FuelMaker. The accumulator/mixing chamber is also protected by a relief valve at 5 psig. The pressure rating of the dry test meters is 10 psig.

   The FuelMaker has an internal PSH to shut itself down and has a built-in relief valve. An additional relief valve will be added downstream of the FuelMaker to further prevent overpressurization of the compressor outlet or the storage cylinders.

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* To the left of Regulator 2 and 3.

In the very remote chance that a vehicle storage tank with excess pressure would be connected to the fuel station, and the flow were to back flow from the vehicle into the fuel station, the fuel station would be protected by the PSV and check valve to the right of hand valve 15.

3) Vent lines from all vent valves and relief valves will be taken to a single vent header pipe at a safe overhead location. The vent will be directed straight upward and will include both a weep hole and a manual drain to prevent freezing of accumulated (rain) water, as shown in the attached sketch. The single vent header will incorporate a very small N_2 purge in order to keep air out of the vent pipe (since it will contain a flammable gas while venting).

   The only items which will be permitted to vent locally are the standard fire fuse (melt-out) plugs in the top of each H_2 storage cylinder. They will only vent if the storage cylinders are exposed to fire.

4. Partial vacuums must be prevented in order to prevent air intrusion into the system. To accomplish this protection, the FuelMaker has a built-in PSL, and an additional PSH/L will be added on the accumulator/mixing chamber. The latter will shut the N_2 activated (solenoids) at 7 and shut off the FuelMaker if the pressure falls to 1.0 psig.

5. The hydrogen analyzer 9 and the flammable gas meter* will be placed within a warmed cabinet. A small N_2 purge will be placed in this cabinet to be sure that if the analyzer were to leak that the instruments would not become ignition sources. An asphyxiation warning sign is required on the cabinet door.

The "What-If" analysis below identifies a number of relatively smaller hazards and how they are mitigated, starting with the feed H_2 and NG.

What-If	Hazard/Consequence	Mitigating Means
A valve on the N_2 purge system is left open.	NG or H_2 could back flow into N_2 system. [Two purge valves would have to be left open in order to partially contaminate NG with H_2 or vice versa. Check valves on NG and H_2 supply prevent large scale contamination of either fuel source].	Double check valves and a hand valve in the N_2 line will prevent this.

* As noted above the H_2 leak detector head will be placed above the FuelMaker compressor.

What-If	Hazard/Consequence	Mitigating Means
Regulator 2 or 3 drifts such that flow through either choke is off spec.	5% H_2 will drift upward or downward. Significant upward drift begins to be a hazard (increased) flammability relative to pure NG).	The H_2 analyzer (AI) will detect high or low H_2 and shut the N_2 activated solenoids at 7 as well as shut-down the FuelMaker. The AI will be calibrated weekly.
Parallel flow heat exchanger is exposed to fire.	Not a significant hazard because no significant volume.	If solenoid 7 remains open (normal operation) fire venting will occur via PSV in the accumulator/ mixing chamber. Fire surrounding the latter is also protected via this PSV.
Analyzer flow stops due to plugged line to analyzer.	Not a hazard unless % H_2 drifts at the same time.	Filter F in the analyzer line will reduce plugging. [The solenoid in the analyzer line shuts-off analyzer flow when the FuelMaker is not operating.]
One or more CGA valves on storage cylinders is closed.	No hazard.	
Cross flow occurs between cylinders due to error in valve operating sequence.	No hazard, but the cylinder cascade system would not be as effective.	The three check valves (one on each cylinder feed line) will mitigate cross flow.
Driver fails to attach ground wire to vehicle before fueling.	No hazard as the fuel hose is also conductive.	
Driver fails to detach fuel hose prior to driving away.	Full hose breaks with a Hythane release and a potential fire.	Fuel hose and vent hose have breakaway (shut-off) couplings. Check valve 18 on the vehicle will prevent loss of fuel from vehicle tank. Hoses have extra strong support at fuel station end.
Driver fails to switch 3-way valve to vent prior to disconnecting quick disconnect on the fuel hose (at the vehicle).	Full Hythane pressure is in the disconnect fitting but the inventory is extremely low (due to double shut-off).	Driver must wear safety glasses while refueling (total time while he/ she is outside of the truck).

What-If	Hazard/Consequence	Mitigating Means
Vehicle fuel tank is full of air when Hythane is added.	Potential explosion could occur.	It is unlikely that the vehicle tank would contain air because the vehicle would not be able to drive to the fuel station with air in the tank. Even if it contained air the large amount of fuel added would soon exceed the upper flammability limit. Further, the explosion* pressure would probably not rupture the vehicle tank.

* Mixture would have to ignite while within the flammable range (thus initially at low pressure).

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HYTHANE STATION NOTES

1. Nitrogen purge is used to eliminate air from the system prior to introducing fuel gases.

2. Public Service 20 psig regulated NG supply.

3. Hydrogen supply at 20-25 psig--adjustable to trim the H_2/NG blend ratio.

4. Temperature-compensated dry test meter for NG.

5. Temperature-compensated dry test meter for H_2.

6. Parallel flow heat exchanger equalizes NG & H_2 temperatures.

7. Pair of (solenoid) [N. actuated] valves for on-off switching of NG & H_2 flows.

8. Choke orifices regulate the blend ratio and flow (also see 3 above).

9. H_2 % analyzer monitors the blend ratio and sends hi/lo warning to system controller.

10. System Controller supplements the Fuel Maker built-in controls and causes safe shut down if blend is out of limits or if flammable gas is detected.

11. "Fuel Maker" compressor with built-in hi/lo pressure switches and safety relief valves.

12. First of three valves opened and closed in sequence during refueling.

13. Second of three valves opened and closed in sequence during refueling.

14. Third of three valves opened and closed in sequence during refueling.

15. Emergency shut-off valve located near the refueling location. A sign points out the location and gives safety instructions.

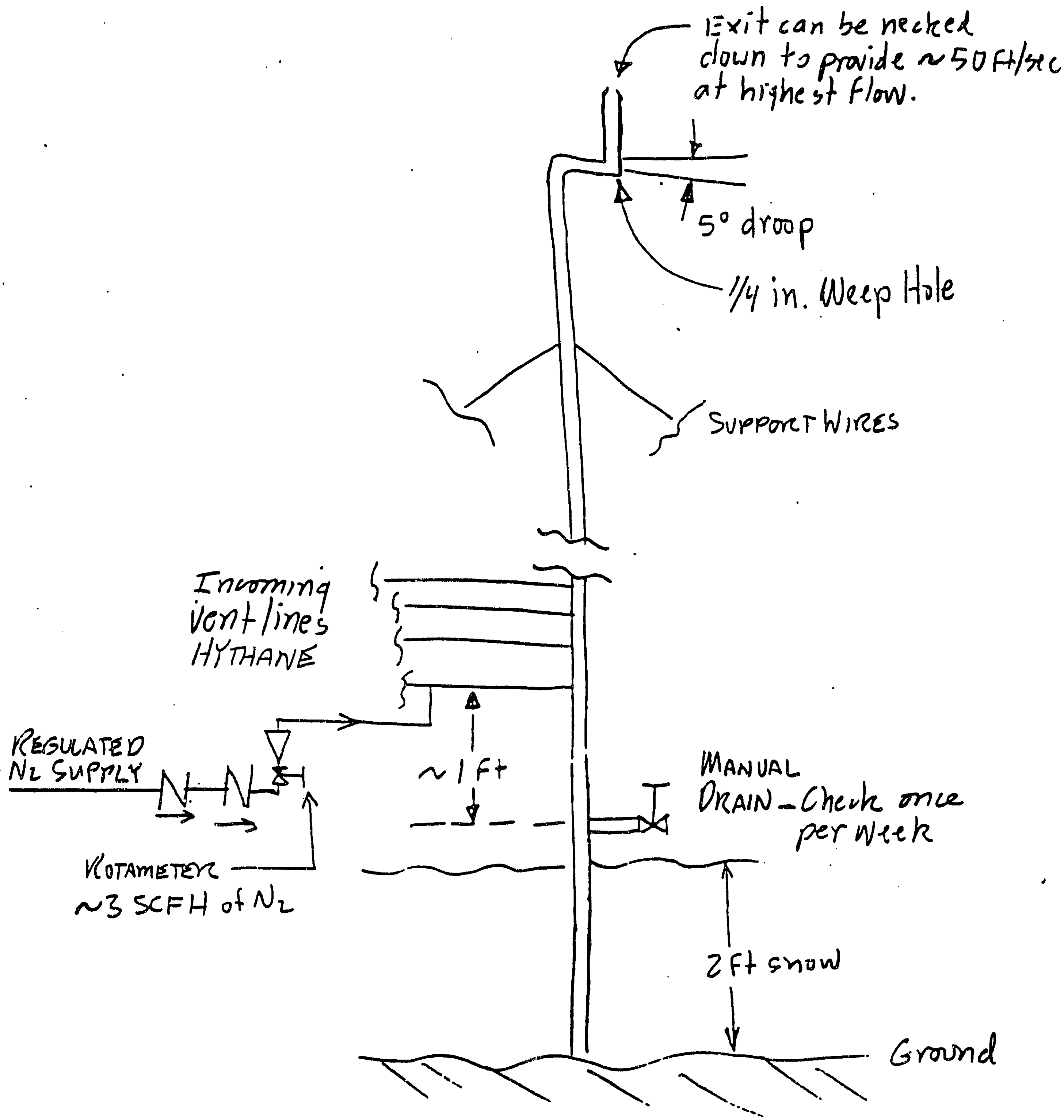
16. Female quick-connect on refueling hose.

17. Male quick-connect on vehicle.

18. Check valve as per NFPA 52.

19. Manual shut-off as per NFPA 52.

20. Aluminum onboard storage tank rated for 3000 psi.



Exit can be necked down to provide ~50 ft/sec at highest flow.
5° droop
1/4 in. Weep Hole
SUPPORT WIRES
Incoming Vent lines HYTHANE
REGULATED N2 SUPPLY
~1 ft
MANUAL DRAIN - Check once per week
ROTAMETER ~3 SCFH of N2
2 ft snow
Ground

APPENDIX E

Letter for Anti-Tampering Provisions Waiver

WELLINGTON E. WEBB
Mayor

CITY AND COUNTY OF DENVER

DEPARTMENT OF HEALTH AND HOSPITALS
ENVIRONMENTAL HEALTH SERVICE

605 BANNOCK STREET
DENVER, COLORADO 80204-4507
(303) 893-7003

February 18, 1992

William L. Miron
Air Pollution Control Specialist
Air Pollution Control Division
Colorado Department of Health
4210 East 11th Avenue
Denver, Colorado 80220-3716

Re: Regulation 14 Exception - Supplemental Information

Dear William:

Conversion of Vehicle No. 1 for hythane fuel use and Vehicle No. 2 for compressed natural gas (CNG) fuel use resulted in installation of mixers (carburetors) with serial numbers as follows:

Vehicle No. 1 (hythane) has serial number 190220; Vehicle No. 2 (CNG) has serial number 190125.

Thank you for associating this information with our Regulation 14 Exception Application.

Baseline laboratory testing is now being completed on the three test vehicles and we are scheduled to begin actual fuel tests by fueling said vehicles on their respective fuels the week of February 24, 1992. Please advise me immediately, by calling 893-7450, if you require any further action or information from any Denver Hythane Project participant before we proceed with actual test work.

Thank you for your cooperation and assistance.

Very truly yours,

John J. Lepley
Acting Project Manager

cc: Frank Lynch/Greg Egan, HCI
Terry Henry, Stapleton Airport
Mark Hennesy, PSCo
Bob Walsh, APC

COLORADO
DEPARTMENT
OF HEALTH

4210 East 11th Avenue
Denver, Colorado 80220-3716
Phone (303) 320-8333

Telefax Numbers:
Main Building/Denver
(303) 322-9076

Ptarmigan Place/Denver
(303) 320-1529

First National Bank Building/Denver
(303) 355-6559

Grand Junction Office
(303) 248-7198

Pueblo Office
(719) 543-8441

ROY ROMER
Governor

JOEL KOHN
Interim Executive Director

RECEIVED
FEB 27 1992

February 25, 1992

City and County of Denver
Department of Health & Hospitals
Denver, CO 80204-4507

Attention: John Lepley

Dear mr. Lepley:

Enclosed is the "approved" special project exception form for the conversion of the Denver Hythane Research Project to an alternate fueled vehicle for a planned demonstration.

This exception to Regulation No. 14 is valid from this date through March 31, 1993 for the purposes stated on the application.

As a reminder, this exception does not constitute an alternative to the required certification of kits to be installed permanently on this or any other vehicles.

If there are any changes in your proposed program, please submit those changes to the AIR Pollution Control Division in writing for approval.

If you have any questions, please call 331-8548 for assistance.

Sincerely,

William L. Miron
Air Pollution Control Specialist
Air Pollution Control Division

WM/am 020/pg 2.

Encl.

COLORADO DEPARTMENT OF HEALTH
4210 E. 11TH AVENUE
DENVER, COLORADO 80220

AQCC REGULATION NO. 14
SPECIAL PROJECT EXCEPTION FORM

APPLICANT INFORMATION:

NAME (CONTACT PERSON): Steven J. Foute, Director, Environmental Programs

COMPANY NAME: City & County of Denver, Department of Health & Hospitals

ADDRESS: 605 Bannock Street, Room 333 **PHONE:** (303) 893-6243

Denver, CO 80204 **DATE:** January 29, 1992

CONVERSION SITE INFORMATION:

COMPANY NAME: Hydrogen Consultants Incorporated

ADDRESS: 12420 N. Dumont Way, Littleton, CO 80125 **PHONE:** (303) 791-7972

CONTACT PERSON: Frank Lynch

PROJECT NAME (IF APPLICABLE): Denver Hythane Research Project

PROJECT DESCRIPTION AND PURPOSE: Research the advantages/disadvantages of hythane (CNG-hydrogen mixture) as a motor vehicle fuel, vis a vis CNG and gasoline, based on extended use of identical vehicles having comparable use, operation and maintenance over the life of the vehicles.

PROJECT DURATION:
FROM (DATE): February 1992 **TO (DATE):** March 31, 1993

Steven J. Foute
APPLICANT'S SIGNATURE

Jerry Gallagher PhD William L. Rixon 2/4/92
APCD APPROVAL SIGNATURE

AQCC REGULATION NO. 14
SPECIAL PROJECT EXCEPTION FORM

VEHICLE INFORMATION:

	Hythane vehicle	CNG vehicle	(Information only) Gasoline vehicle
	VEHICLE NO. 1	**VEHCILE NO. 2**	**VEHICLE NO. 3**
MAKE	Chevrolet	Chevrolet	Chevrolet
MODEL	pickup truck 3/4ton 4X4	same	same
YEAR	1991	same	same
VIN	1GCGK24K6ME200129	1GCGK24K4ME127245	1GCGK24K2ME201990
LICENSE #	Denver 3819	690 AA4-PU	Denver 3818
VEH. I.D. #	W-1-43	15-151	W-1-42
ENG. DISPL.	5.7 Liter	same	same
# OF CYL.	V-8	same	same
FUEL SYS. TYPE (ORIG.)	Throttle Body Fuel Inj	same	same
CONVERSION DATE	February 1992	February 1992	NA

	VEHICLE NO. 4	**VEHCILE NO. 5**	**VEHICLE NO. 6**
MAKE			
MODEL			
YEAR			
VIN			
LICENSE #			
VEH. I.D. #			
ENG. DISPL.			
# OF CYL.			
FUEL SYS. TYPE (ORIG.)			
CONVERSION DATE			

CONVERSION KIT INFORMATION:

KIT MANUFACTURER (BRAND NAME): IMPCO

MODEL NAME (IF APPLICABLE): ____________

MODEL NUMBER: ____________

LIST INDIVIDUAL COMPONENTS & MODEL #'S (MIXER, REGULATOR,ETC.) AS APPLICABLE: See Attachment A for a complete list of components for conversions.

Mixer (carburetors) serial numbers: 190220 (vehicle # 1) and 190125 (# 2)

See Attachment B for the oxygen feedback loop device to be installed for optimum engine performance with selected fuels.

[signature] 1/28/92
APPLICANT'S SIGNATURE

[signature] PhD
[signature] 2/4/92
APCD APPROVAL SIGNATURE

APPENDIX F

LA-4 Short Hot Emissions Results

COLORADO DEPARTMENT OF HEALTH - APCD, MSS
VEHICLE EMISSION TECHNICAL CENTER
EPA - LA4 TEST PROCEDURE
07-17-1991 ACS Nov.1984

RECEIVED
MAY 11 1992

FUEL TYPE: UNLEADED

Test Number	:1286	Control Number	: 2500
Tech/Driver	:TMP/MS	Run Number	: 1
Odometer	:784	Make/Model	: CHEVY/PU/PSCo
Model Year	:1991	Program	: CNG
Inertia Weight	:5500	Barometer	: 24.68
HP ACT/IND	:17.5/ 15	Transmission Type	:AUTO
Vehicle ID Number	:1GCGK24K4ME12745		
Comments	:GASOLINE BASE-LINE		

	Phase 1	Phase 2	Phase 3
SAMPLE / AMBIENT (scfh)	25.0 / 16.0	25.0 / 16.0	0.0 / 0.0

PHASE	INTEGRATED DRY BULB	INTEGRATED DEW Pt.	MAXIMUM DRY BULB	MAXIMUM DEW Pt.	MINIMUM DRY BULB	MINIMUM DEW Pt.
1	76.94	53.98	77.27	54.02	75.59	53.85
2	77.27	54.07	77.61	54.20	74.92	53.67

Ph	HC(gms)	CO(gms)	NOx(gms)	CO2(gms)	HC(gpm)	CO(gpm)	NOx(gpm)	CO2(gpm)
1	0.134	1.727	3.341	2461.349	0.037	0.479	0.927	683.1[illegible]
2	0.150	2.189	1.612	2965.492	0.038	0.562	0.414	761.3[illegible]

Phase	Volume(ft3)	Time(sec)	FE(mpg)	TDT(mi)	NOx Kf	Bag DF	Humidity
1	2984.076	504.880	12.807	3.603	1.0012	8.236	75.25
2	5120.603	869.000	11.563	3.895	1.0023	11.618	75.49

***********	HC (g/m)	CO (g/m)	NOx(g/m)	CO2(g/m)	FE(mpg) ***********
FINAL	0.038	0.522	0.561	723.819	12.164
	********	********	********	*********	********

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COLORADO DEPARTMENT OF HEALTH - APCD, MSS
VEHICLE EMISSION TECHNICAL CENTER
EPA - LA4 TEST PROCEDURE
07-17-1991 ACS Nov.1984

FUEL TYPE: INDOLENE

Test Number	:1287	Control Number	: 2500
Tecn/Driver	:TMP/MS	Run Number	: 2
Odometer	:800	Make/Model	: CHEVY/PU/PSCo
Model Year	:1991	Program	: CNG
Inertia Weight	:5500	Barometer	: 24.69
HP ACT/IND	:17.5/ 15	Transmission Type	:AUTO
Vehicle ID Number	:1GCGK24K4ME12745		
Comments	:GASOLINE BASE-LINE		

	Phase 1	Phase 2	Phase 3
SAMPLE / AMBIENT (scfh)	25.0 / 16.0	25.0 / 16.0	0.0 / 0.0

PHASE	INTEGRATED DRY BULB	INTEGRATED DEW Pt.	MAXIMUM DRY BULB	MAXIMUM DEW Pt.	MINIMUM DRY BULB	MINIMUM DEW Pt.
1	77.94	55.16	78.62	55.25	76.60	54.90
2	77.94	~~70.33~~ 55.20	78.28	139.27	76.60	-40.31

Ph	HC(gms)	CO(gms)	NOx(gms)	CO2(gms)	HC(gpm)	CO(gpm)	NOx(gpm)	CO2(gpm)
1	0.116	1.197	4.188	2449.640	0.032	0.332	1.162	679.3[illegible]
2	0.145	1.717	3.058	2959.901	0.037	0.440	~~0.784~~ 0.573	759.2[illegible]

Phase	Volume(ft3)	Time(sec)	FE(mpg)	TDT(mi)	NOx Kf	Bag DF	Humidity
1	2974.935	504.960	13.041	3.606	1.0172	8.228	78.60
2	5105.415	869.010	11.667	3.898	1.3993	11.600	~~135.72~~ 79.79

***********	HC (g/m)	CO (g/m)	NOx(g/m)	CO2(g/m)	FE(mpg)	***********
FINAL	0.035	0.388	~~0.966~~ 0.867	720.893	12.289	
	********	********	********	*********	********	

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COLORADO DEPARTMENT OF HEALTH - APCD, MSS
VEHICLE EMISSION TECHNICAL CENTER
EPA - LA4 TEST PROCEDURE
07-18-1991 ACS Nov.1984

FUEL TYPE: INDOLENE

Test Number	:1139	Control Number	: w1-43
Tech/Driver	:TMP/MDM	Run Number	: 1
Odometer	:128	Make/Model	: CHEVY/PU
Model Year	:1991	Program	: alt. fuel
Inertia Weight	:5500	Barometer	: 24.6
HP ACT/IND	:17.5/ 15	Transmission Type	:AUTO
Vehicle ID Number	:1GCGK24K6ME200129		
Comments	:HYTHANE-BASELINE ON GASOLINE		

	Phase 1	Phase 2	Phase 3
SAMPLE / AMBIENT (scfh)	25.0 / 16.0	25.0 / 16.0	0.0 / 0.0

PHASE	INTEGRATED DRY BULB	INTEGRATED DEW Pt.	MAXIMUM DRY BULB	MAXIMUM DEW Pt.	MINIMUM DRY BULB	MINIMUM DEW Pt.
1	77.94	57.63	78.62	57.76	76.26	57.41
2	77.94	57.85	78.62	58.11	76.60	57.41

Ph	HC(gms)	CO(gms)	NOx(gms)	CO2(gms)	HC(gpm)	CO(gpm)	NOx(gpm)	CO2(gp
1	0.168	1.443	3.789	2610.304	0.046	0.400	1.051	724.0
2	0.128	1.012	1.989	3166.687	0.033	0.260	0.511	813.4

Phase	Volume(ft3)	Time(sec)	FE(mpg)	TDT(mi)	NOx Kf	Bag DF	Humidity
1	2983.310	504.900	12.235	3.605	1.0565	7.764	86.38
2	5111.196	868.960	10.895	3.893	1.0602	10.878	87.08

***********	HC (g/m)	CO (g/m)	NOx(g/m)	CO2(g/m)	FE(mpg) ***********
FINAL	0.039	0.327	0.770	770.433	11.501
	********	********	********	*********	********

COLORADO DEPARTMENT OF HEALTH - APCD, MSS
VEHICLE EMISSION TECHNICAL CENTER
EPA - LA4 TEST PROCEDURE
07-18-1991 ACS Nov.1984

F[illegible] TYPE: UNLEADED

Test Number	:1139	Control Number	:	wi-43
Tech/Driver	:TMP/MDM	Run Number	:	2
Odometer	:140	Make/Model	:	CHEVY/PU
Model Year	:1991	Program	:	alt. fuel
Inertia Weight	:5500	Barometer	:	24.61
HP ACT/IND	:17.5/ 15	Transmission Type	:	AUTO
Vehicle ID Number	:1GCGK24K6ME200129			
Comments	:HYTHANE-BASELINE ON GASOLINE			

	Phase 1	Phase 2	Phase 3
SAMPLE / AMBIENT (scfh)	25.0 / 16.0	25.0 / 16.0	0.0 / 0.0

PHASE	INTEGRATED DRY BULB	INTEGRATED DEW Pt.	MAXIMUM DRY BULB	MAXIMUM DEW Pt.	MINIMUM DRY BULB	MINIMUM DEW Pt.
1	78.62	58.07	79.29	58.29	76.60	57.71
2	78.62	57.41	79.62	57.98	76.94	56.53

Ph	HC(gms)	CO(gms)	NOx(gms)	CO2(gms)	HC(gpm)	CO(gpm)	NOx(gpm)	CO2(gp
1	0.201	2.144	3.749	2566.619	0.056	0.594	1.039	711.1[illegible]
2	0.140	2.104	1.840	3105.821	0.036	0.540	0.472	796.5[illegible]

Phase	Volume(ft3)	Time(sec)	FE(mpg)	TDT(mi)	NOx Kf	Bag DF	Humidity
1	2973.186	504.970	12.377	3.609	1.0637	7.867	87.74
2	5096.206	868.990	11.054	3.899	1.0527	11.056	85.65

***********	HC (g/m)	CO (g/m)	NOx(g/m)	CO2(g/m)	FE(mpg) ***********
FINAL	0.045	0.566	0.744	755.496	11.653
	********	********	********	*********	********

COLORADO DEPARTMENT OF HEALTH - APCD, MSS
VEHICLE EMISSION TECHNICAL CENTER
EPA - LA4 TEST PROCEDURE
07-18-1991 ACS Nov.1984

FUEL TYPE: UNLEADED			
Test Number	:1140	Control Number	: W-1-42
Tech/Driver	:MDM/MS	Run Number	: 2
Odometer	:182	Make/Model	: CHEVY/PU
Model Year	:1991	Program	: alt. fuel
Inertia Weight	:5500	Barometer	: 24.6
HP ACT/IND	:17.5/ 15	Transmission Type	:AUTO
Vehicle ID Number	:1GCGK24K2ME201990		
Comments	:HYTHANE-BASELINE ON GASOLINE		

	Phase 1	Phase 2	Phase 3
SAMPLE / AMBIENT (scfh)	25.0 / 16.0	25.0 / 16.0	0.0 / 0.0

PHASE	INTEGRATED DRY BULB	INTEGRATED DEW Pt.	MAXIMUM DRY BULB	MAXIMUM DEW Pt.	MINIMUM DRY BULB	MINIMUM DEW Pt.
1	79.29	56.97	80.30	57.05	77.27	56.53
2	79.96	56.44	80.63	56.88	78.62	55.82

Ph	HC(gms)	CO(gms)	NOx(gms)	CO2(gms)	HC(gpm)	CO(gpm)	NOx(gpm)	CO2(gp
1	0.153	2.084	4.727	2460.824	0.043	0.578	1.312	683.0
2	0.454	8.723	1.915	2979.163	0.116	2.235	0.491	763.3

Phase	Volume(ft3)	Time(sec)	FE(mpg)	TDT(mi)	NOx Kf	Bag DF	Humidity
1	2952.273	504.920	12.307	3.603	1.0458	8.144	84.31
2	5073.442	868.980	11.490	3.903	1.0375	11.423	82.69

***********	HC (g/m)	CO (g/m)	NOx(g/m)	CO2(g/m)	FE(mpg)	***********
FINAL	0.081	1.440	0.805	724.826	12.120	
	********	********	********	*********	********	

COLORADO DEPARTMENT OF HEALTH - APCD, MSS
VEHICLE EMISSION TECHNICAL CENTER
EPA - LA4 TEST PROCEDURE
07-18-1991 ACS Nov.1984

F[illegible] TYPE: UNLEADED

Test Number	:1140	Control Number	: W-1-42
Tech/Driver	:MDM/MS	Run Number	: 1
Odometer	:162	Make/Model	: CHEVY/PU
Model Year	:1991	Program	: alt. fuel
Inertia Weight	:5500	Barometer	: 24.6
HP ACT/IND	:17.5/ 15	Transmission Type	:AUTO
Vehicle ID Number	:1GCGK24K2ME201990		
Comments	:HYTHANE-BASELINE ON GASOLINE		

	Phase 1	Phase 2	Phase 3
SAMPLE / AMBIENT (scfh)	25.0 / 16.0	25.0 / 16.0	0.0 / 0.0

PHASE	INTEGRATED DRY BULB	INTEGRATED DEW Pt.	MAXIMUM DRY BULB	MAXIMUM DEW Pt.	MINIMUM DRY BULB	MINIMUM DEW Pt.
1	78.28	57.63	79.62	57.93	76.60	57.01
2	78.62	56.88	79.62	57.27	76.94	56.18

Ph	HC(gms)	CO(gms)	NOx(gms)	CO2(gms)	HC(gpm)	CO(gpm)	NOx(gpm)	CO2(gp
1	0.261	3.623	5.011	2611.106	0.072	1.003	1.387	722.6
2	0.421	8.227	2.004	3011.148	0.108	2.109	0.514	771.9

Phase	Volume(ft3)	Time(sec)	FE(mpg)	TDT(mi)	NOx Kf	Bag DF	Humidity
1	2971.822	504.900	12.168	3.613	1.0565	7.731	86.38
2	5092.364	868.960	11.367	3.901	1.0444	11.345	84.04

***********	HC (g/m)	CO (g/m)	NOx(g/m)	CO2(g/m)	FE(mpg) ***********
FINAL	0.091	1.577	0.934	748.256	11.738
	********	********	********	*********	********

APPENDIX G

Selected Excerpts from Hythane Clip File

Complete Combustion

Hydrogen and natural gas may be the cleanest fuel yet

Hydrogen has been "the fuel of the future" for 60 years now. Inexhaustible supplies of the combustible element could be obtained by splitting water into its components, and the fuel would be virtually nonpolluting. But proponents are still waiting. Although it works well for rockets, hydrogen has proved troublesome for ground transportation. It is extremely bulky as a gas and becomes liquid only at -423 degrees Fahrenheit. Present supplies of hydrogen, produced primarily from natural gas, cost four to five times as much as gasoline.

Hydrogen may yet win a place as a vehicle fuel. Not by itself, but as an additive in much the same way that alcohol is added to gasoline in the mixture called gasohol. Mixing a bit of hydrogen with compressed natural gas (CNG) could yield the cleanest-burning alternative fuel yet, says Frank E. Lynch, president of Hydrogen Consultants, Inc., in the Denver suburb of Littleton.

Lynch calls his fuel mixture "Hythane" for hydrogen and methane (the principal component of natural gas). Adding hydrogen to virtually any fuel accelerates its combustion, Lynch points out, by reducing ignition delay and increasing flame velocity. "Natural gas burns slowly to a fault," he declares, so even though it is less polluting than gasoline, unburned hydrocarbons and other by products are still released into the atmosphere. A faster start and more efficient burning should reduce emissions.

A feasibility test of Hythane—5 percent hydrogen by energy content, 15 percent by volume—began in January, in Lynch's own pickup truck, modified to run on either Hythane or gasoline. Compared with a CNG pickup tested previously—which carried an admittedly heavier load than Lynch's truck—Colorado Department of Health tests showed Hythane performing well. Hydrocarbon emissions were less than half of those from CNG, and nitrogen oxide levels were 24 percent of those from CNG. CNG was lower on carbon monoxide, however, at 0.086 versus 1.6 grams per mile. The Auto Oil Consortium in Detroit, a group set up by the big three automakers and 14 oil companies to test alternative fuels, plans to test the fuel sometime this year. So do Colorado State University and the California Air Resources Board.

Denver is particularly eager to test Lynch's idea. The city won a citation from the U.S. Conference of Mayors in 1990 for "most improved air quality," but on bad days a pall of brown smog betrays the city's ongoing violations of federal standards for carbon monoxide and particulate matter. Trying to meet air-quality rules, the city already has an extensive alternative-fuels project that includes trucks and vans powered by CNG. "We are going to test as many vehicles as we can with Hythane," says Steven J. Foute, Denver's director of environmental programs.

Colorado's major utility, Public Service Company of Colorado (PSCo.), is interested in Hythane because "hydrogen is a gaseous fuel, compatible with compressed natural gas," notes Bill Warnock, marketing coordinator for alternative fuels. The utility is the principal shareholder in a distributor of CNG started up last year in Denver, the Natural Fuels Corporation. PSCo. plans a marketing study of Hythane-powered vehicles for 1992, if studies confirm the fuel's promise. "The emphasis will be on vehicles that operate within 50 miles of their base," Warnock says.

The vehicles are suited for urban use because the amount of fuel that can be put on board is limited. Pure hydrogen in gaseous form takes up 12.9 times as much space as gasoline required to travel an equivalent distance and 3.8 times as much space as natural gas. Enough Hythane to make a trip of about 200 miles can be packed into a tank 3.4 times the size of an equivalent gas tank—if it is compressed to about 3,000 pounds per square inch.

Where to fill 'er up? For now, just one place in town. Air Products and Chemicals has volunteered its facilities for the test program. The hydrogen will be fed from a so-called tube trailer, a bundle of high-pressure steel tubes that carries industrial gases of many kinds, and blended with natural gas. "There is nothing special about this," says Venki Raman of AP&C. "We handle gases and mix them all the time."

"The significance of Denver's project lies in the backing by the utility and the city," notes Peter Hoffmann, editor of *The Hydrogen Letter* in Hyattsville, Md. "Those commitments give hydrogen real business potential for wider use via a relatively low-tech compromise technology." The "compromise" part of the deal still sticks in his craw. Like Lynch, Hoffmann wistfully describes Hythane as a "bridging" technology to an all-hydrogen energy supply. He admits that everything has to start somewhere. It might as well be a clean start. —*Deborah Erickson* ch Talk

ydrogen has the potential to drive automobiles

Andy Walker

r's Note: EnergyTalk introduces Talk, an in-depth look at energy rvation issues.

-lydrogen holds the promise of a n automotive fuel in both bustion engines and electric ors. This highly flammable ent is obtained by splitting water hydrogen and oxygen using light tolysis), heat (thermal ociation) or electricity trolysis). Hydrogen also can be ined by stripping it from rocarbons such as natural gas. Electrolysis is the most practical iese options, and no pollution is erated when hydroelectric or solar ver supplies the electricity. ording to B. Hoagland of the ional Renewable Energy oratory, electrolysis is currently ut 65 percent efficient.

In a hydrogen-oxygen fuel cell, the gases are recombined in a controlled manner to produce electrical energy and no pollution. In a combustion system, hydrogen is burned with air to produce power, water vapor and a little nitrous oxide.

The safe storage of hydrogen aboard vehicles presents challenges that have limited hydrogen's use for ground transportation. To provide the equivalent energy storage, hydrogen requires up to 10 times the volume of gasoline. Simply compressing the gas to 2,000 to 3,000 pounds per square inch requires bulky tanks.

Liquid hydrogen is easy to store, but it is energy intensive and costly to liquify. Hoagland notes that handling liquid hydrogen at minus 253°C would require robots. An alternative is to combine the hydrogen with a metal powder to form a hydride. This releases heat during fueling, and high-temperature heat must be applied to liberate the hydrogen for use.

Despite these challenges, hydrogen is happening. As reported in *Business Week*, Mercedes-Benz uses metal hydrides to store the hydrogen to power five cars and five vans in a Berlin road test. BMW uses liquid hydrogen in two prototype cars, and Mazda uses metal alloy balls to store hydrogen in a prototype to be unveiled this fall.

Frank Lynch, president of Hydrogen Consultants Inc. of Littleton, Colo., says his company "has produced prototypes including a passenger car that runs on liquid hydrogen, a pickup truck using compressed hydrogen and a mining vehicle using metal hydride storage."

Denver's Department of Health and Hospitals manages a program to investigate the use of hythane, a mixture of hydrogen and compressed natural gas (CNG). Initial results of tests on the modified Chevrolet S-10 pickup show that the mixture of 15 percent hydrogen and 85 percent natural gas by volume reduces ignition delay and increases flame velocity for a 50 percent reduction in hydrocarbon emissions and a 75 percent reduction in nitrogen oxide emissions over CNG alone.

The second phase of the project compares the emissions of a gasoline vehicle, a hythane vehicle and a CNG vehicle over a period of 20 months. Phase III involves testing of dedicated (not dual-fueled) vehicles using either CNG or hythane from major automobile manufacturers.

Steve Fout, director of the program, says the short-term goal of the project is to show that blended hydrogen is a competitive fuel option. A long-term goal of the participants is to extend the non-renewable CNG supply and ease the transportation sector into a renewable hydrogen-based economy. ✦

Report and Information Sources

Additonal copies of this report, "Technical Comparison Between Hythane, CNG and Gasoline Fueled Vehicles" are available from:

Publications and Distribution
Public Technology, Incorporated
1301 Pennyslvania Avenue, N.W.
Washington, D.C. 20004

For additonal information concerning this project, please contact:

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Department of Health and Hospitals
City and County of Denver
605 Bannock Street
Denver, CO 80204-4507
(303)893-6243

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