**A Project of the
Urban Consortium
Energy Task Force of
Public Technology, Inc.**

City and County of Denver

Technical Comparison Between Hythane, CNG and Gasoline Fueled Vehicles

Steven J. Foute, Ph.D., Project Director

Deborah Kielian, Project Manager

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CITY AND COUNTY OF DENVER

**TECHNICAL
COMPARISON
BETWEEN HYTHANE,
CNG AND GASOLINE
FUELED VEHICLES**

**URBAN CONSORTIUM
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URBAN CONSORTIUM

Public Technology, Inc. (PTI), is the non-profit technology organization of the National League of Cities (NLC), the National Association of Counties (NACo), and the International City/County Management Association (ICMA). PTI's mission is to bring technology to local governments. Through collective research and development efforts in its member jurisdictions, PTI creates and advances technology-based products, services, and enterprises for all cities and counties.

Four active task forces, each composed of members of PTI's Urban Consortium (UC)—which represents fifty of the nation's largest and most progressive cities and urban counties—drive PTI's research and commercialization efforts. One of these task forces is the Urban Consortium Energy Task Force (UCETF), which was established to address critical energy needs of urban America.

THE URBAN CONSORTIUM ENERGY TASK FORCE

The UCETF is the nation's most extensive cooperative local government program to improve energy management and technology applications in local governments. Its membership is composed of local government officials from America's large urban centers. The four major goals established by UCETF members are to:

1. Pursue collaborative solutions to interrelated energy, environment and economic development issues at the local level;
2. Improve energy efficiency, reduce costs and develop revenue from local energy assets;
3. Promote practices and efforts at the local level to assure that energy and environmental considerations are broadly integrated into local decision-making, and to address the interrelationships between energy, environment and economic policies; and
4. Act as the implementation arm for NLC and NACo policies.

Under an annual program partly funded by the U.S. Department of Energy (USDOE), a number of city and county projects propose to meet UCETF objectives. Projects selected for each year's program are organized in thematic units, such as Utilities/Buildings, Transportation, Sustainable Communities, and Technology Transfer, to assure effective management and ongoing peer-to-peer exchanges. The results of these research projects are documented in reports such as this one, and made available for broad dissemination among other local governments through PTI.

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The statements and conclusions contained herein are those of the grantees and do not necessarily represent the official position or policy of the U.S. Government in general or USDOE in particular.

**PUBLIC
TECHNOLOGY,
INC.**

1301 Pennsylvania Ave., NW
Washington, DC 20004-1793
202.626.2400
800.852.4934
FAX 202.626.2498

TECHNICAL COMPARISON BETWEEN HYTHANE, CNG AND GASOLINE FUELED VEHICLES:

*Energy Task Force of the
Urban Consortium*

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**Project Director
Steven J. Foute, Ph.D.**

**Project Manager
Deborah Kielian**

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PREFACE

This Final Report documents the findings of a two-year project, which commenced in 1991 to research the emission reducing capabilities of an alternative vehicular fuel called Hythane™. Alternative fuels such as Hythane (15% hydrogen, 85% compressed natural gas, measured by volume) offer a 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 fuel neutrality, that is, the examination of all 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.

During 1991, the Denver Hythane Project focused on the preparation of field and laboratory tests designed to compare the tailpipe emissions of Hythane, compressed natural gas (CNG) and gasoline, in the hopes of demonstrating the applicability of Hythane as an alternative vehicle fuel. The project began with the development of a partnership among various entities who shared a common vision and who 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 conversion technology. In addition, the activities of the past two years have included the preparation of a Hazard and Operability (HAZOP) Study, a Driver's Training and Safety Manual, and an investigation into a National Hythane Strategy. Additional studies on range, fuel composition and quality assurance, oil analyses and engine degradation, performance testing, acceleration and driveability were also examined.

TECHNICAL COMPARISON BETWEEN HYTHANE, CNG AND GASOLINE

Chapter 1

1a. ABSTRACT

The City and County of Denver, in cooperation with the Urban Consortium Energy Task Force of Public Technology, Inc. has completed a unique two-year research and development project designed to test and compare the technical merits of three transportation fuels. Comparisons of the tailpipe emissions from Hythane—a new, blended, alternative motor fuel comprised of 85% compressed natural gas (CNG) and 15% hydrogen measured by volume—to the emissions from gasoline and 100% CNG were conducted. This project has been one of the first pioneering studies of a hydrogen blended fuel and, through its success, has prompted eight additional Hythane research projects to date.

Phase I of the project provided results from the Federal Test Procedure (FTP) testing of a light duty pick-up truck operating on Hythane. The purpose of this testing was to quantify any decrease in tailpipe emissions and to determine whether Hythane could meet the California Ultra Low Emission Vehicle standard (ULEV) for light duty trucks.

During Phase I, FTP analyses were conducted in both Colorado (high altitude testing) and California (sea level testing) on a converted Chevrolet S-10, pick-up truck by Hydrogen Consultants (HCI), the Colorado Department of Health (CDH) and the California Air Resource Board (CARB). HCI shared with the City and County of Denver the results from these tests which indicated that Hythane had the potential to not only meet the ULEV standard, but to exceed it. Currently, the only other non-electric vehicle which is capable of meeting the ULEV standard is Chrysler's natural gas vehicle.

There was additional interest in the role Hythane could play as a transitional fuel in the introduction of hydrogen. The passage of the more stringent California Zero Emission Vehicle (ZEV) standard, which requires zero tailpipe emissions, can currently be met only with electric vehicles. Hydrogen, a renewable energy carrier, may soon be categorized as a ZEV fuel by the South Coast Air Quality Management District. This factor may encourage the use of Hythane as a transportation fuel that not only meets the ULEV standard, but may provide the bridge necessary to the eventual widespread use of hydrogen.

The encouraging data from Phase I launched the next phase of the project from theory into reality. Phase II began with the purchase of three identical 1991 Chevrolet 4x4, 3/4 ton, pick-up trucks with 5.7 liter engines. The three vehicles were dedicated to operate on a single fuel only; one on unleaded gasoline, one on CNG, and one on Hythane. Thirty nine FTP tests (counting duplicates), 21 Hot-505 runs (a "shortened" FTP test), 24 aldehyde and 18 BTEX analyses (benzene, toluene, ethyl-benzene and xylenes) were conducted over the two year period. In addition, non-methane hydrocarbon (NMHC) estimates were calculated by

OVERVIEW

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subtracting methane from total hydrocarbon results. Performance testing and drivability surveys were also conducted.

The emission results from Phase II indicate that the major difference between Hythane and CNG is Hythane's potential to deliver lower CO emissions at the expense of a small increase in NO_x when the fuel is at a stoichiometric equivalence ratio. However, a slight increase in CO emissions from Hythane—through the enrichment of the fuel-to-air equivalence ratio—results in NO_x emissions equal to those achieved by using 100% CNG with no hydrogen additive. In other words, for the same amount of NO_x , CO emissions are significantly decreased when comparing Hythane to natural gas. The project results also demonstrated that through an effective training program and adherence to established safety regulations, the safe operation of both a Hythane fueling station and a vehicle converted to operate on gaseous fuels is possible.

A summary of the Phase II accomplishments over the past two years 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 and schedule representing the testing frequency and analyses conducted;
3. Determination of the type of vehicles best suited for gaseous fuels and a plan for acquiring those vehicles;
4. Securing a source for Federal Test Procedure (FTP) testing and additional lab testing in kind;
5. Engineering and building a fueling facility that fit into the guidelines of the project and that was specific for Hythane;
6. Choosing a fueling station site which was convenient in regards to both location and access to supplies required;
7. Negotiating insurance coverage for the fueling station and site;
8. Developing a Hazard and Operability Plan and a Driver's Training/Safety Manual;
9. Obtaining the necessary City permits or approvals (e.g. from the Fire and Building Departments);
10. Reconfiguring present engine and conversion kit design to supplement and aid the technology of converting a vehicle to burn both natural gas and Hythane; and
11. Reevaluating testing methodology and developing protocol to improve the accuracy of present methods.

The completion of the Denver Hythane Project has provided valuable data as the basis for further research into the effectiveness and feasibility of introducing Hythane as an alternative transportation fuel. In fact, the Denver Hythane Project has gained national and international interest and a compendium of programs have since developed to further explore the benefits of Hythane. A brief overview of these projects is outlined in subsequent chapters.

1b. PROJECT PURPOSE

The Denver Hythane research project was launched for several reasons. First, it was theorized that compressed natural gas and hydrogen can act symbiotically—one complementing the other—to produce a fuel which burns more efficiently; second, Hythane incorporates the introduction of a renewable, sustainable energy source—hydrogen; and finally, Hythane could aid in extending the US supply of natural gas.

THE DENVER HYTHANE

PROJECT HAS GAINED

NATIONAL AND

INTERNATIONAL INTEREST

Although natural gas is already clean-burning, research to prove the first supposition—that a blend of hydrogen and natural gas could burn cleaner than natural gas alone—would not only provide a cleaner burning fuel to enhance air quality, but it would meet the increasingly stringent air quality standards. Hythane's second contribution may be the role it plays as a transitional fuel in the introduction of pure hydrogen: an ultra-clean, renewable fuel source. Natural gas plays a positive role in the fuel partnership by contributing cost advantage, domestic availability, and existing infrastructure.

NATURAL GAS PLAYS A
POSITIVE ROLE IN THE FUEL
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ADVANTAGE, DOMESTIC
AVAILABILITY, AND
EXISTING INFRASTRUCTURE

The third potential benefit of Hythane use is extending the supply of natural gas. This can be accomplished if hydrogen is formed from renewable energy sources rather than natural gas reformation. Refinement of the solar electrolysis technology presently available may provide the science necessary for a sustainable, renewable hydrogen supply.

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 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, because of the lower total pressure at Denver's altitude of 5280 feet (which represents an approximate 19% decrease in oxygen molecules as compared to sea level), the complete combustion of gasoline is impaired and results in excess emissions of carbon monoxide and other pollutants. Finally, wind from the horizontal flow of air masses during specific seasons can cause certain 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 use of woodburning stoves for heating homes during the winter months has been 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 (O₃) attainment area. Because of these classifications, governmental agencies in Denver and the state of Colorado 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, a time limit on idling vehicles, a program to decrease the number of vehicles with visible tailpipe emissions and a "Green Fleets" plan for the city's municipal fleets.

The area has also developed a Pollutant Standard Index for CO, PM10, and O₃. 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

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bans and no-drive days, respectively. In addition, a Visibility Standard Index, the first of its kind in the nation, is used to determine a high pollution day.

Although these programs have contributed to decreasing air pollution in the Denver metropolitan area, the vehicle miles travelled are expected to more than double between the years 1995 and 2010, and the region will need 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, the purpose and background of the project, and a description of the contents of this report.

Chapter 2 provides a description of the project research, including committee participation, vehicle selection, origin of the Hythane blend, and the emissions test plan as well as the steps taken to modify the gaseous fueled engines and conversion kits. A discussion on the fueling facility is presented with respect to design, fabrication, requisite permitting processes, insurance and liability issues and fueling station modifications. Chapter 2 also describes the Hazard and Operability (HAZOP) Study for the use of Hythane, emissions test results, performance data, and a short discussion on the Driver's Safety Manual. A public relations section describes the various seminars and conferences attended and the presentations given during the two year study.

Chapter 3 reviews the research results of the project, including a description of the Phase I and Phase II emissions data and the subsequent conclusions. A "lessons learned" section is included in the last portion of this Chapter.

Chapter 4 addresses ways in which technology transfer has been promoted in the project. Denver's attempts to work in collaboration with the National Renewable Energy Lab (NREL) by contributing Hythane emissions data to the Lab's Alternative Fuels Data Bank are also discussed.

Appendix A lists the specifications for the three test vehicles and for the conversion kit. **Appendix B** includes a chart listing the emission test dates and odometer readings for the vehicles and **Appendix C** lists the results of the performance tests. Specs for the FuelMaker™, a natural gas compressor used in the fueling station are in **Appendix D** and an in-depth description of the permitting and tank location criteria for the fueling station are found in **Appendix E**. **Appendix F** contains the Safety Manual, **Appendix G** includes the oil wear test data; **Appendix H** includes a driver survey given to the Hythane vehicle drivers; **Appendix I** contains the complete Hazard and Operability Study trouble-shooting guide. **Appendix J** displays the Hythane brochure created during the project; **Appendix K** includes the letter requesting a waiver from the anti-tampering provision to the Environmental Protection Agency; and **Appendix L** lists the complete FTP emission testing results (Contact Deborah Kielian for a copy of Appendix L).

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

TECHNICAL COMPARISON BETWEEN HYTHANE, CNG AND GASOLINE

Chapter 2

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. Through a cooperative effort from the project participants, this program was designed to explore the potential Hythane offers in reducing tailpipe emissions for motor vehicles.

Two private sector partners, Public Service Company of Colorado and Air Products and Chemicals, Inc., provided financial support; Stapleton International Airport provided the test vehicles and technical support; and the Denver Public Health Department (DPH) managed 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, under the caption *3a. Emission Testing*).

Because the project required expertise in a variety of areas, much of the logistical 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. The fleet managers from Stapleton Airport and Public Service Company of Colorado also coordinated their efforts and schedules to monitor the test vehicles' mileage levels. An in-depth discussion of the work completed by the four committees is reviewed in the following sections.

2b. VEHICLE SELECTION

The pick-up truck used for Phase I testing is owned by Hydrogen Consultants, Inc. (HCI) located in Littleton, Colorado. This research vehicle is a Chevrolet S-10, 2.5 liter, 4 cylinder, 5-speed pick-up truck with a rear axle ratio of 3.73 and a fuel tank capacity of 14 gallons. During 1990 and 1991, the S-10 engine was modified by HCI to operate on either natural gas or Hythane. These modifications included installation of the supply tank, IMPCO conversion kit, heated oxygen sensor and an Englehard monolithic catalyst to increase the efficiency of a gasoline engine using gaseous fuels. All of the Phase I modifications and the resulting analyses were accomplished with internal research funding by HCI, and donated testing by CDH, CARB, IMPCO and the National Center for Vehicle Emissions Control (NCVEC), located in Ft. Collins, Colorado. HCI shared the results from this research with the City and County of Denver and Phase II of the project was launched.

PROJECT DESCRIPTION

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Phase II planning began in November 1990 during which time various technical, scheduling and operational guidelines were established. One of the first categories researched was to determine which vehicles were best suited for the project. To insure accuracy of testing and vehicle comparability, it was decided that the vehicles should:

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

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

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

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. Three identical vehicles matching the established requirements were simply not available, so the focus shifted to new vehicles either on order or capable of being ordered.

GMC had plans to manufacture (in model year 1992) a 5.7 liter, dedicated-CNG truck which presented a unique opportunity for future comparisons between the research vehicles and these dedicated-CNG trucks. Based on both the pre-established vehicle requirements and the high probability that valuable information could be obtained from a comparison of the research vehicles and dedicated GMC trucks, three identical 1991, 5.7 liter Chevrolet 4x4 3/4 ton pick-up trucks were ordered. Stapleton purchased the two vehicles which were to operate on unleaded gasoline and Hythane, and PSCo purchased the vehicle which would operate on CNG.

The vehicles 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 testing can be found in the section entitled *Testing Schedule Description*.) Specifications for these vehicles and for the conversion kits which were used to modify the two gaseous fueled vehicles are listed in Appendix A.

2c. EMISSION TESTING

Testing Plan History

The Denver Hythane Project emission testing program consisted of two phases. At the project start, Phase I data was collected to substantiate the premise that Hythane was a cleaner burning fuel than gasoline or CNG, and could result in lower emission levels. If the Phase I data supported this concept, Phase II—an extensive research plan incorporating additional testing of vehicles and fuels—would begin.

Emission testing for Phase I began in early 1991 with FTP testing of a 1991 Chevrolet, S-10 pick-up truck owned by Hydrogen Consultants, Inc (HCI). HCI tested the vehicle while operating on Hythane at high altitude [at the Colorado Department of Health, (CDH) Emission Technical Center in Aurora] and at sea level [at the California Air Resources Board (CARB) and IMPCO in California]. The results HCI obtained were favorable indicating that all Hythane FTP emission results were lower when compared to gasoline and some emissions were lower

when compared to CNG. The complete results from high altitude and sea level testing centers and a related discussion are in Chapter 3—*Summary and Results*.

Due to the encouraging data from Phase I, Phase II—the main emission testing stage of the Hythane Project—began in late 1991 with final testing completed in March of 1993. This phase compared the emission results obtained from the three Chevrolet pick-up trucks discussed in *Vehicle Selection*. Each pick-up operated on a different fuel: one on gasoline, one on Hythane, and one on CNG with FTP testing periodically scheduled throughout the approximately 22,000 miles each vehicle was driven. A photograph of the Hythane vehicle is presented below.

Testing Schedule Description

The original Phase II emission test schedule was designed to incorporate possible changes as the research project progressed. Indeed, changes became necessary in the middle of 1992 due to delays in choosing a refueling station site, hectic work schedules with the Aurora Emissions Tech Center, difficulties scheduling the research vehicles for the lengthy and time consuming FTP testing, alteration of some of the testing instrumentation and methods, and complications with the operational consistency of the conversion kits. A revised testing matrix was developed in July, 1992 utilizing a much more efficient schedule. Table 1 on page 12 displays the most recent testing matrix used which includes the sampling schedule, pollutants analyzed, and mileage. The odometer reading and emission test dates for each vehicle may be found in Appendix B.

The emission schedule began with "screening phase" testing of all three pick-up trucks to establish a vehicle baseline. This baseline information, in effect, demonstrates that there were no outliers in the three research trucks, i.e., that none of the vehicles had atypical emissions during an evaluated drive cycle for a vehicle of that type. This helped to assure that subsequent comparisons of the three different fuels would be valid and not represent an idiosyncrasy of the manner in which any one of the trucks operated.

To begin this screening phase, the three vehicles operated on gasoline for a distance of 100 miles, at which point an LA-4 dynamometer test was run on each vehicle. (The test results,

EACH TEST PICK-UP OPERATED

ON A DIFFERENT FUEL: ONE

ON GASOLINE, ONE ON

HYTHANE, AND ONE ON CNG

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Vehicle Ownership	Stapleton Airport No. 1-42	Stapleton Airport No. 1-43	Public Service Company No. 1-53
Test Fuel	Gasoline	Hythane-Hy5 ¹	CNG

EMISSIONS TESTING

TABLE 1

DENVER HYTHANE
PROJECT EMISSIONS
TESTING PLAN, PHASE II

LA-4		Gas	Gas	Gas
	Screening Test 100 Miles February, 1991 Vehicle Baseline Data		Converted Vehicle	Converted Vehicle
FTP				
A	Fuel Baseline Data 7,846-9,553 Miles February, 1992	Gas FTP (2) (THC) Aldehydes (2) BTEX (2) CH4 by GC (2)	Gas FTP (2) (THC) Aldehydes (2) BTEX (6) CH4 by GC (2)	Gas FTP (2) (THC) Aldehydes (2) BTEX (6) CH4 by GC (2)
B	FTP1 9,363-17,954 Miles March - July, 1992	Gas FTP (2) (THC) BTEX (1) CH4 by GC (1)	Hy5, CNG FTP (2) (THC) CH4 by GC (2)	Hy5, CNG FTP (2) (THC) Aldehydes (2) CH4 by GC (2)
C	FTP2 17,053-19,492 Miles October-November, 1992	Gas FTP (2) (THC) Aldehydes (2) BTEX (2) CH4 by GC (1)	Hy5, CNG FTP (2) (THC) Aldehydes (2) CH4 by GC (1)	Hy5, CNG FTP (2) (THC) Aldehydes (3) CH4 by GC (1)
D	FTP3 21,612-22,100 Miles January - March, 1993	Gas FTP (2) (THC) Aldehydes (2) BTEX (2) CH4 by GC (2)	Hy5, CNG FTP (4) (THC) Aldehydes (4) CH4 by GC (4)	Hy5, CNG FTP (4) (THC) Aldehydes (4) CH4 by GC (4)
HOT 505				
E	Adjusted Voltage 22,000+ Miles March, 1993			Hy5, CNG Only vehicle tested

Notes:

- Duplicate sampling performed on each test.
- Each test consists of four sections:
 - 1) Cold Start; 2) Cold Stabilized; 3) Hot Start; 4) Background (BTEX background was not 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.

Abbreviations: () = # of tests; FTP, Federal Test Procedure; THC, Total Hydrocarbons
BTEX, Benzene, Toluene, Ethyl Benzene, Xylenes; CH4, Methane; GC, Gas Chromatograph

completed in February 1991, may be found in Chapter 3, *Summary and Results*, under 3a.) The LA-4 test (named for the location where the test originated—Los Angeles) differs from an FTP test in that the vehicle engine is warm before the analyses begin; the time to complete the test is shorter, and accordingly, it is less expensive. The LA-4 is typically utilized as a screening test to determine whether significant resources and time should be expended for the more costly FTP testing.

While the shorter LA-4 is convenient and more cost effective as a screening tool, the FTP provides a more representative look at emissions by sampling tailpipe exhaust throughout three different drive cycles or stages. Stage 1, termed a Cold Start, occurs after the engine temperature of a vehicle has stabilized for a minimum of 12 hours and a maximum of 36 hours. During the next step of this stage, the vehicle is placed on a dynamometer and emissions are quantified as the vehicle is put through the paces of a computer-generated drive cycle which simulates a typical start-and-stop course through an urban neighborhood. This stage takes 505 seconds to complete.

Stage 2 is termed a Cold Stabilized Start and, as the name implies, is the most stable stage of the FTP testing. This stability is attributed to the fact that the engine is already warm which results in lower emissions. In this stage, the vehicle runs through a drive cycle on the dynamometer for 868 seconds, after which time the engine is turned off and a ten minute "Hot Soak" or resting phase is observed before beginning with Stage 3. The third "Hot Transient" testing stage utilizes a computer simulated drive cycle identical to Stage 1, but is performed on a warmed engine.

The vehicle baseline results from the LA-4 tests showed that all three vehicles operated within a normal and acceptable range. The project proceeded according to schedule with another battery of tests beginning in February, 1992. At this time, each of the three research vehicles had logged between 7,000 to 10,000 miles while operating on gasoline, and a fuel baseline was established by running the first set of FTP tests on all three vehicles.

This fuel baseline FTP test, which included analyses for carbon monoxide (CO), nitrogen oxides (NO_x), total hydrocarbons (THC), carbon dioxide (CO₂), and fuel economy (FE) was the first of four sets of analyses performed. The other testing included benzene, toluene, ethylbenzene, and ortho and para-xylenes (BTEX), along with methane and certain aldehydes*.

Once the difficulties surrounding the lab analyses were worked out, Stage A, the FTP baseline, was completed on February 14, 1992 (see Table 1, page 12). To recap Stage A, all three vehicles had been operating on gasoline for 7-10,000 miles, and four types of analyses were performed on each vehicle: FTP testing, aldehydes, BTEX, and methane. Duplicate testing for these parameters on each vehicle was also part of the testing protocol to assure reproducibility. This is a quality control process which enables accurate assessment of the results, and is one method of assuring precision in laboratory and instrument performance.

* **TECHNICAL NOTE:** The original work agreement developed between the City and the CDH lab stated that acetaldehyde, formaldehyde and acrolein would be the aldehydes analyzed, however, due to some difficulties encountered during the baseline analyses, the aldehyde list was changed. This decision was made when the first analytical chart depicting the aldehyde concentrations was reviewed and the accuracy of the results for acrolein were suspect. To understand the concerns of the lab analyst, a short explanation of the procedure used to measure aldehydes is reviewed.

Before a sample is injected into the instrument used for aldehyde analyses, a solvent is added to the sample for dilution and measurement purposes. The solvent used in this particular laboratory test is acetone which elutes at the same time as acrolein when analyzed by a high pressure liquid chromatograph (HPLC). This means that the peak on the instrument chart (the chromatogram) does not differentiate between the solvent and acrolein compounds, therefore, acrolein cannot be accurately quantified. Because of this problem, the aldehyde analysis included the original acetaldehyde and formaldehyde compounds, but benzaldehyde and propionaldehyde were substituted for the acrolein compound.

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Energy Task Force of the Urban Consortium**P**ROJECT MEETINGS WERE

HELD TO DISCUSS

INCONSISTENCIES,

RESULTING IN THE DESIGN

OF VARIOUS ENGINE AND

CONVERSION EQUIPMENT

MODIFICATIONS

These additional data points also offered valuable comparisons of emissions from different vehicles operating on either CNG or Hythane.

After the FTP baseline testing was completed, IMPCO conversion kits were installed on the Hythane (1-43) and the CNG (1-51) vehicles by HCI in the latter part of February and early part of March 1992. (An IMPCO kit consists of a carburetor, regulator, fuel control processors, and solenoid valves and allows a gasoline engine to operate on gaseous fuels). The gaseous fuel vehicles were also rendered incapable of operating on gasoline at this time, i.e. they were designated as dedicated fuel vehicles only.

FTP1 (Stage B) began in March of 1992 and was completed by July 1992. The FTP1 testing and methane analyses were conducted on all three vehicles operating on their respective fuels. In addition, the gasoline vehicle was tested for BTEX, and the CNG vehicle was tested for aldehydes. The Hythane and CNG vehicles were then FTP tested 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 any factors the vehicles may introduce. It should be noted that although the vehicles were dedicated to operate on only one fuel for testing purposes, the Hythane and CNG truck were temporarily reconfigured so they were once again capable of running on either alternative fuel—Hythane or CNG.

Although the original plan required methane and aldehyde analyses on all three vehicles during every round of testing, due to continuing analyses and sampling problems, vehicle operational difficulties, and technical errors, not all tests were performed. The participants did not feel that this decision would negatively affect the project integrity, nor alter conclusions drawn at the end of testing. BTEX analyses were limited to only the baseline test for the CNG and Hythane vehicles due to levels below the detection limit.

Complications were encountered during BTEX analyses and were due, in part, to instrument operational difficulties. The gas chromatograph used for BTEX measurements, was obtained "on loan" from the Stapleton International Airport laboratory. After considerable work and effort was expended by the Aurora Emissions Technical Center, it was determined in August 1992 (before FTP2 testing), that the gas chromatograph should be equipped with a new computer interface system for easier programming. The Tech Center also installed a capillary column (the column through which the sample travels as measurements of the sample concentration are made) to replace the packed column originally installed in the instrument. When measuring low levels of BTEX, the capillary column provides a higher degree of accuracy when compared to the packed column.

The methane procedure originally used also proved to be inadequate for the purpose of this research project, and alterations and changes to the EPA methodology were made. These changes provided a more accurate methane result used in the estimated NMHC calculation.

Because of some of the vehicle operational difficulties encountered throughout FTP1 testing (Stage B), the results—which were not repeatable—were not indicative of the actual emission values which could be obtained if the engines operating on their respective fuels were more tightly controlled. Several project meetings were held to discuss these inconsistencies. These meetings resulted in the design of various engine and conversion equipment modifications in the hopes of ultimately providing a better understanding of the true implications of a hydrogen additive in CNG. Additional discussion concerning these modifications may be found in Section 2d, *Modification of Engines and Conversion Kits*.

Throughout July and the first days of August 1992, HCI implemented the suggested engine modifications on the alternative fuel research vehicles 1-43 (Hythane) and 1-51 (CNG). On August 6, 1992, the Aurora Emission Technical Center conducted Hot-505 tests on 1-43 and 1-51, again comparing both fuels on each vehicle, to determine whether the modifications would provide repeatable, reliable data. (A Hot-505 test is similar to the FTP test, but lasts 505 seconds—approximately 8.5 minutes—rather than the full FTP drive cycle of approximately 31 minutes. It also costs much less than an FTP test, which was a major factor as the Tech Center had already provided more analyses than originally requested). The Hot-505's did show repeatable results, which gave an accurate indication of the net improvement resulting from the engine modifications.

The gasoline vehicle (at approximately 19,000 miles) received FTP2 testing in October and during the third week of November. Both the CNG and Hythane research vehicles had logged 17,000 miles and were also tested for the second FTP series at this time.

The third FTP test was completed on the gasoline vehicle in January 1993, at which time the other two vehicles still needed to accumulate approximately 2,000 miles each before the third FTP could be performed. It was estimated that 1-43 and 1-51 would log only about 1,000 miles per month, thus extending the project well into 1994 for completion of the fourth and final FTP test.

A reevaluation of the need to perform a fourth FTP test was made at this point in the program. Originally, the testing plan required that the two gaseous fueled vehicles be converted back to gasoline, and subsequent FTP testing be conducted to determine how the three engine/emission control systems aged. The project participants decided that the project should forego the three-vehicle gasoline test series, as simple observations and oil engine wear testing of each truck could provide information just as valuable.

In addition, the testing results had shown that although CO was reduced, NO_x was slightly increased when hydrogen was added to CNG. To determine the overall value of Hythane in lowering emissions, the CO-NO_x relationship needed further study. If there was a way to incorporate a slightly different approach in the testing program, a crucial understanding of how to use Hythane in future applications could more easily be developed.

In an attempt to clarify Hythane's potential, alterations to the project design were discussed, agreed upon, and a project extension was requested and granted. Changes to the project in March 1993 included eliminating the fourth FTP, conducting Hot-505 tests on the Hythane vehicle only, and incorporating minor engine adjustments. The results of the Hot-505 tests are discussed in Section 3a, *Emission Testing*. Throughout the months of April, May, June and July, the emissions data was compiled and analyzed in preparation for the final report.

2d. MODIFICATIONS OF ENGINES AND CONVERSION KITS

After the Phase I testing of the Chevy S-10 was completed, analysis of the FTP test results indicated that when a gaseous fuel such as Hythane is burned in an engine designed for gasoline, the message the oxygen sensor transmits to the catalyst can result in a miscalibration of the fuel-to-air ratio. Due to this miscalibration, the engine tends to run lean (a lower fuel-to-air ratio), resulting in higher NO_x measurements.

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A "trial" feedback loop system was created to adjust this message so that a recalibrated fuel-to-air ratio would be recognized. This system, initially installed on the Phase I Chevy S-10 pickup, consists of an electronic feedback circuit which incorporates an oxygen sensor installed downstream of the catalyst to provide corrected voltage to the catalyst. The corrected voltage causes the engine to run at a richer fuel-to-air ratio and results in lower NO_x .

To explain the effect the fuel-to-air ratio has on the fluctuating relationship between CO and NO_x , some of the trade-offs between these two pollutants during fuel combustion must be understood. Tailpipe emission results show an inverse relationship in the proportion of CO to NO_x ; i.e. with lower CO emissions higher NO_x results, and lowering NO_x emissions indicate a higher CO concentration. Carbon monoxide emissions from Hythane are already considerably lower than gasoline (approximately 70% lower) and relatively lower than CNG alone (approximately 35-40% lower), so there is sufficient range for adjusting CO levels and still staying well below the ULEV emission standards. By adjusting the fuel-to-air ratio, CO emissions slightly increase and the desired decrease in NO_x results.

Because this "trial" feedback loop effectively improved NO_x emissions on the S-10, during the last two weeks of February 1992, the Hythane and CNG trucks were also equipped with feedback loop systems. The application of this system allowed the two alternative fuel trucks to run at optimal levels on their respective fuel, thus allowing a more equitable comparison of emissions with the gasoline truck.

During the installation and testing of the feedback loop on the research vehicles, there were considerable attempts to locate the "lambda window" (the optimal setting for the fuel-to-air ratio which would provide the lowest emission results for all emissions). During testing only, an additional oxygen sensor was placed upstream of the catalyst which indicated that the mixture was running rich, whereas the sensor downstream of the catalyst did not indicate a rich mixture. Considerable time was spent making adjustments and checking the fuel-to-air ratio, but the lambda window remained elusive. Although the narrow range of stoichiometric balance was not found, the resulting refinements decreased NO_x levels by operating the vehicles at a net rich mixture.

Several other problems plagued the project during this period. In late February 1992, the oxygen sensors began to "go to sleep" during the cold start tests. Before the oxygen sensor is "warmed", the signal it sends does not accurately represent the fuel-to-air ratio. This results in large CO emission increases during idling, at slow speeds, or light load conditions. The sensor in the CNG vehicle was replaced with a heated oxygen sensor and the problem was partially resolved. The other two trucks were retrofitted with heated sensors and duplicate FTP's were run with acceptable repeatability.

The next month, PSCo received a recall notice from the vehicle manufacturer for the throttle position sensor on the CNG research vehicle. The part was replaced and a check was made on the two vehicles operating at Stapleton International Airport for faulty sensors. It was determined that the gasoline and Hythane research vehicles were later production models and did not need to have the sensor replaced.

Several other small mechanical problems were resolved in March including a sticking hot air duct vent to the engine which caused problems with intake air temperatures. These temperature problems were solved by locking open the faulty duct. In addition, improperly operating solenoid valves in the IMPCO kit were replaced with AllenTM air solenoids and the installation of new air bleed orifices (0.070 inches) were also used in lieu of standard IMPCO orifices.

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

One of the most difficult problems to resolve involved the limited control technology provided by the conversion kits when attempts were made to operate two different gaseous fuels on the same kit. As noted in Section 3, *Emission Testing*, the Hythane vehicle was tested on both CNG and Hythane fuel, as was the CNG vehicle. In order to accomplish this, one IMPCO conversion kit was dedicated to run on Hythane and one to run on CNG by specifically tuning each kit to their respective gaseous fuel. During the first FTP test, the kits were then swapped between vehicles, dependent upon which fuel was being tested. It was anticipated that this process would compensate for the difference in fuels and prevent the need to retune the IMPCO conversion kits each time an FTP was run.

Although this method eliminated the need to retune each kit, the swapping process was quite lengthy and kept both vehicles from their designated duties while kits were removed, emissions were tested, kits were removed again, and finally reinstalled in the appropriate vehicle. It was also evident that the swapping process still did not provide strictly comparable test conditions, so a different approach was undertaken.

In April, after monitoring the FTP testing process with an IMPCO Fuel System Analyzer—a handheld diagnostic tool which shows when the engine is in closed loop control and when the system is operating in a lean or rich mode during acceleration or deceleration—the operational limitations of the conversion kit became even more apparent. The fuel control technology for the carburetor simply did not have sufficient range to operate both Hythane and CNG fuels at the same calibrated fuel-to-air ratio. If the kits were calibrated for Hythane, they would typically run rich when operating on CNG. The opposite was true when the kits were calibrated for CNG. Most of these difficulties were the result of weak vacuum signals in the airflow system the impact of which caused too much fuel and too little vacuum to effectively lean out the fuel mixture and, subsequently, higher CO emissions were recorded.

Several theories for the design of a more versatile system, which would provide a stronger vacuum signal to the final dome of the regulator, were contrived. Considerations were only given to solutions which would provide a simple mechanical means of increasing repeatability and providing more accurate data, but which would not markedly impact the project design.

The first suggestion as to use advanced technology equipment which was not available at the project inception. An IMPCO conversion kit—which has a double carburetor (#200) configuration—was recommended, as was the installation of a Lucas injector system. A third option included the purchase of an up-graded electronic system to provide greater precision and control of the air:fuel ratio.

None of these solutions proved fruitful, because the suggested replacement carburetor and upgraded electronic equipment were not State certified and would have required the submittal of paperwork for an additional waiver from the EPA for legal operation. Sufficient experience had already been gained in this area when a waiver (originally requested for the engine modifications required to properly install the conversion kit) had been granted. This was a time consuming effort, and there was no desire to repeat the process. It would also extend the completion date of the project beyond acceptable limits. Concerns about the time, expense, and complexity of changing the present conversion kit technology, and the realization that the “newest” available technology would always be just beyond our grasp, became the basis for forming a new plan in May of 1992.

If the IMPCO control system had an additional vacuum supply from the engine’s intake system, better regulation of the fuel and air mixture might result. In the original IMPCO fuel

ONE OF THE MOST DIFFICULT PROBLEMS TO RESOLVE INVOLVED THE LIMITED CONTROL TECHNOLOGY PROVIDED BY THE CONVERSION KITS WHEN ATTEMPTS WERE MADE TO OPERATE TWO DIFFERENT GASEOUS FUELS ON THE SAME KIT.

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control system (shown in Figure 1, below), the air flow through the IMPCO carburetor experiences a pressure drop during different cycles (acceleration or deceleration). This reduced pressure is applied to the top of the diaphragm in the final regulator via a solenoid valve. The valve is designed to open and close on a schedule that is set by the IMPCO fuel control computer maintaining the correct mixture. When the engine is decelerating or at idle, the vacuum signal is weak above the throttle. If the resulting signal causes insufficient vacuum to maintain control, the engine either runs rich and makes CO or runs lean and makes NO_x. Because of the small pressure drop through the carburetor at idle, the vacuum needed to lean out the mixture is not available.

The alterations made to the engine to supply an additional vacuum source are illustrated in Figure 2 on page 19. A relatively high vacuum source was available in the manifold during deceleration and idle. There were concerns that applying too much vacuum would lead to wild swings in the manifold pressure and an uncontrolled system would result, so a very low pressure one-way check valve was used to create a "small" leak. When the throttle was opened, a greater control vacuum developed below the carburetor and the one-way valve eventually opened, returning the control system to normal operation.

In July 1992—just before FTP2 testing began—HCI designed and retrofitted the CNG and Hythane vehicles with this system. The two vehicles were road tested and monitored with the IMPCO fuel system analyzer. The change did not prove satisfactory as the results were still variable and non-repeatable. Variations were noted particularly as the pressure in the supply fuel tank decreased to less than 1,000 psi.

Finally, after weeks of renewed research, an approach to supply the additional vacuum was developed in August. This new approach was based on the "Bernoulli Effect" (or the Kinetic Theory of Gases) which states that the pressure in an airstream falls as the rate of flow increases. To apply this concept to the conversion system in the research vehicles, it was necessary to determine where the smallest juncture in the air flow system was. The lowest air

FIGURE 1
IMPCO FUEL CONTROL

FIGURE 2

PROPOSED CHANGES

pressure was located at the most narrow segment of the air flow path, just above the venturi mixer. (See Figure 3, page 20).

The Hythane vehicle was reconfigured with additional vacuum supplied to this narrow segment, and a road test was performed using the portable fuel system analyzer to determine whether these changes improved the system. The results were consistent, repeatable and stayed within the monitoring range of the handheld analyzer.

Occasionally, during acceleration on a steep grade, the analyzer would not register due, in part, to the setting of the idle adjustment screw at a slightly lean ratio. This had the effect of "enriching" the fuel-to-air ratio during acceleration. Since acceleration is a lean mode cycle and typically produces high NO_x operation, the slight "enrichment" adjustment produced less NO_x , so no alterations to the idle adjustment screw were made.

Once the road test was complete, Hot-505 analyses were conducted on both gaseous fueled vehicles using both Hythane and CNG. The repeatability was good depicting tight engine control, and the supplemental vacuum modification was termed a success. The two vehicles could now be equitably compared on either fuel.

One additional issue concerned the range of the gaseous fuel supply tanks on the Hythane and CNG vehicles. A CNG storage tank filled to capacity (an averaged maximum amount of 2500 psig—pounds per square inch gauge) has an approximate 80 mile range. To limit the number of fuelings per day, an additional tank was added to the bed of both gaseous fuel vehicles to provide a 160 mile range.

2e. PERFORMANCE

Testing during Phase I and Phase II of the project to determine the performance capabilities of Hythane was conducted at two separate locations. The Phase I Chevy S-10 pick-up truck was

FIGURE 3

VENTURI VACUUM SOURCE

A BIT OF LEVITY WAS

EXPERIENCED AT THE
INCONGRUOUS SIGHT OF
THE S-10 VEHICLE IN
LINE BEHIND SEVERAL
HIGH PERFORMANCE
RACE CARS AWAITING
THE CHANCE TO DASH
DOWN THE STRIP

taken to the Bonneville Salt Flats during the week of August 18-24, 1991 and tested on Hythane and CNG. The vehicle produced a top speed of 84 mph on both Hythane and CNG. (A bit of levity was experienced at the incongruous sight of the S-10 vehicle in line behind several high performance race cars awaiting the chance to dash down the strip. It proved to be one of the more amusing experiences of the project).

Phase II performance testing at an abandoned airstrip in Ft. Collins, CO was conducted with the aid of Colorado State University (CSU) and project participants on April 20, 1992. The Hythane and CNG trucks were tested on both Hythane and CNG fuels (the odometer reading was approximately 10,000 miles for each vehicle) and the gasoline vehicle tested on gasoline (with an odometer reading of approximately 17,000). The phase I vehicle was also tested on gasoline, CNG, and Hythane fuels.

Two runs per vehicle per fuel were timed over a quarter-mile run. The results were anticipated, with the lighter weight S-10 vehicle clocking the fastest time and the CNG vehicle the slowest. CNG and Hythane fuels averaged approximately 55 miles per hour in 25.4 seconds, and gasoline clocked in at approximately 60 miles per hour in 22.8 seconds. (See Appendix C for a complete list of all timed results). The performance test indicated, overall, that the introduction of 15% hydrogen does not compromise the performance of CNG; a factor many fleet managers have a specific interest in because of required performance standards (e.g. police fleet vehicles).

2f. FUELING FACILITY

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

STAPLETON:

1. The use of Stapleton would simplify the permitting process (due to the fact that a CNG fueling station is presently operating on-site).
2. Stapleton is a more convenient location for the Hythane test vehicle which is owned by Stapleton.

AIR PRODUCTS:

1. The use of the Air Products' site eliminated the need to transport hydrogen to Stapleton as it could be dispensed to the Hythane vehicle on-site.
2. Air Products' personnel were familiar with safety and maintenance issues concerning hydrogen and other gases 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 design of the fueling station received considerable input by all project participants and the final engineering of this pilot facility proved successful. The heart of the fueling station is a Sulzer brand FuelMaker™ natural gas (NG) compressor which was originally designed for the residential market; specifications are listed in Appendix D. Other components of the facility include a ten cylinder storage cascade to provide for a fast fill system, a blender which mixes the two fuels 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 amount of hydrogen and natural gas entering the system 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 could alter the pressure of the blended fuel). The ten-cylinder cascade system is divided into three banks; two banks of three cylinders and one bank of four cylinders. Check valves located within the cascade system to insure that the pressure of each bank is independent and not linked to the other banks in the storage system, thereby allowing a three-stage "cascaded" fill process. The Hythane fuel is provided to the vehicle via a flexible hose connected to the cascade.

There is low pressure natural gas service to the site provided through preexisting underground lines as well as a hydrogen supply distributed through a manifold system. The hydrogen is pressurized at 50 psig (pounds per square inch gauge) in a seven-bottle hydrogen storage system, which is housed within the Air Products building. The natural gas enters the facility at approximately 20 psig. Both fuels are introduced to the Hythane fueling station, located outside the Air Products building and mixed at a measured volume containing 15% hydrogen and 85% CNG. It should be noted that this mixture can also be measured by energy content as 95% CNG and 5% hydrogen; sometimes called "Hy-5".

THE DESIGN OF THE FUELING
STATION RECEIVED
CONSIDERABLE INPUT BY
ALL PROJECT
PARTICIPANTS AND THE
FINAL ENGINEERING OF
THIS PILOT FACILITY
PROVED SUCCESSFUL.

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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 first became functional, the fuel mixture underwent laboratory analyses before the vehicle was fueled to confirm the composition was correct and the quality consistent. Thereafter, the fuel mixture underwent periodic laboratory analysis at Public Service Company (PSCO). The chart below illustrates the percentage of hydrogen in CNG calculated from the PSCO laboratory results.

FUELING STATION
BLENDING-PERCENTAGE
OF HYDROGEN TO CNG

The facility's storage system is designed to store fuel at a maximum pressure of 2900 psig. This results in a vehicle tank pressure of 2400 or less due to the fueling pressure drop. (Ambient temperature variations and the fueling schedule affect the total psig at any specific fueling time). A photograph of the portable fueling station is shown on page 24 and the fueling facility schematic is shown in Figure 4, on page 23.

2g. 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 and County of Denver (the City) 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 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.

FIGURE 4

HYTHANE FUELING
STATION SYSTEM
SCHEMATIC

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)

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 (the City) 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 that 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. Instead, the City and Air Products agreed to proceed with a bilateral letter of understanding and an agreement that the City would assist Air Products in obtaining a similar letter or arrangement from HCI.

2h. PERMITTING/SAFETY

The safety issues arising because of the use of pressurized containers for fuel storage required that permits be obtained for the fueling station. The Denver Fire Department's permitting guidelines for fuel storage tanks generally fall into two categories—location of the fueling tanks, and the installation of the tanks themselves. The basic requirements for each are discussed in Appendix E. These guidelines were met and consequently approved by the Denver Fire Department.

As the Hythane Project progressed, additional assistance and discussions with the Fire Department ensued. Several permitting and safety issues were reviewed and safety plans were formulated for the Denver Fire Department's approval. An explanation of these issues follows.

In January 1992, the Fire Department pressure tested the "portable" fueling station (specifically, the cascade system) at 4500 lbs. pressure for 30 minutes. Once the fueling station arrived at the permanent site (Air Products), and was connected to the natural gas and hydrogen lines, the Fire Department also pressure tested and approved these on-site source lines.

A provision for emergency situations was the next category of concern. An emergency number printed on a weather resistant placard was placed on the gate leading into the fueling station area. The number would connect the caller to a 24-hour line should an emergency with the fueling station or the research vehicle require immediate attention. The Fire Department approved the sign size, color, visibility and location.

In March, a tour of the fueling station and a question-answer session was arranged for all three shifts of the Fire Department. Information was exchanged, safety questions answered, and station and vehicle operations were reviewed to encourage familiarity with the fueling station.

The implementation of additional safety factors included: 1) the placement of fire extinguishers in each of the gaseous fuel vehicles and at the fueling station site; 2) proper vehicle labeling for the CNG and Hythane vehicles to fulfill the Department of Transportation requirements for gaseous fueled on-road vehicles; 3) a grounding strap which is connected to the vehicle bumper before fueling; 4) a sign, located on the inside of the fueling control box door, listing the basic steps required to fuel the Hythane truck; and 5) a training session for all applicable drivers regarding fuel characteristics and the safe operation of the vehicle and station.

Once safety issues and pressure testing were concluded, the management team addressed additional permitting requirements. HCI obtained the plumbing and electrical permits, in addition to preparing the site to comply with local standards. The site preparation included pouring the cement foundation for the fueling station to set on, and surrounding the fueling station site with a chain link fence. A diagram illustrating the safety features of the station can be found in Figure 5 on page 26.

The Denver Building Division was also contacted concerning the necessity of obtaining a building permit. This permit was not required for the fueling station, as it was considered to be a piece of equipment rather than a building.

Although the original hydrogen supply at the Air Products site was stored at sufficient pressure for operation of the fueling station, operational changes at the Air Products hydrogen storage plant required some reconfiguration of the hydrogen supply system. A manifold to increase the hydrogen supply volume was provided by Air Products in February 1992. No additional permitting was necessary for the manifold as it was to be kept in an enclosed building already approved for the storage of hydrogen fuel.

Driver's Training/Safety Manual

Air Products & Chemicals, Inc. (AP&C) agreed to locate the fueling station on their site if certain conditions dealing with the insurance liability issues were met. Part of their agreement involved the project team members coordinating a safety training program for the drivers. Therefore, a driver's safety training seminar was held on March 16, 1992 for drivers of the research vehicles. Frank Lynch of HCI, Mike Gutierrez of PSCo, and Dan Fields of AP&C lectured on important topics during the seminar.

HCI'S INSURANCE BROKER

SUBMITTED 16 INSURANCE

APPLICATIONS, AND

RECEIVED 16

DECLINATIONS

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To assure that the drivers and operations staff completely understood the safety issues surrounding gaseous fuels, a Driver's Training Manual which covered fueling, operational and safety procedures for alternatively fueled vehicles was created. A copy was kept in both the Hythane and CNG vehicles and at the Fueling Station. A copy of the manual may be found in Appendix F.

2i. FUELING STATION MODIFICATIONS

On March 9, 1993, the fueling station was officially and formally opened. A ribbon-cutting ceremony for the station was held on March 12, 1992 with Denver Mayor Wellington Webb officiating. Representatives of the five project participants were in attendance, in addition to local television stations, newspaper reporters and journalists for affiliated magazines and newsletters who provided coverage of the event.

The station functioned as expected, however, solutions for a few problems were refined in the ensuing months. In June of 1992, lower pressures encountered during the fueling process required some minor modifications to the fueling station. During fueling, the compressor intake pressure was falling below the lower limit, causing automatic shutdown. To alleviate this problem, a small pressure regulator was installed to the #1 bank of cylinders to feed additional gas to the compressor.

FIGURE 5

SAFETY FEATURES OF THE
HYTHANE FUELING SITE

During the third week of September, the FuelMaker compressor on the fueling station stopped working altogether. The owner's manual was reviewed and it was determined that, as a maintenance precaution, the rings and diaphragms on the compressor module needed to be changed after approximately 1,000 hours of operation. The required parts were ordered and Natural Fuels, a local natural gas supplier, replaced the module. The station was operable in about three weeks.

During the interim wait for the station parts, estimates of the correct ratio of hydrogen to CNG were made to refuel the Hythane research vehicle. This process involved filling the fuel tank on the Hythane truck with approximately 1,000 psi of CNG at a public CNG filling station. A transportable cylinder of hydrogen was placed in the bed of the truck and 500 psi of hydrogen was then transferred into the truck's fuel tank. The last step involved "topping off" the fuel tank with CNG. This provided approximately 2,400 psi of fuel at an estimated 15% hydrogen to 85% CNG ratio.

2j. VEHICLE FUEL USE, MAINTENANCE TRACKING, AND DRIVER SURVEY

Vehicle Fuel Use

To track the amount of fuel and motor oil used by each vehicle for the duration of the project, a logbook with standardized formatting was developed to record the date, mileage, and amount of fuel pumped at each fueling. Public Service Company recorded the data for the CNG test vehicle and Stapleton recorded the data for the gasoline and Hythane vehicles. From these data, calculations for the range of each vehicle and the cost per gallon of fuel was made for comparisons. The mileage range for the gasoline vehicle was approximately 21 miles per gallon; there was no appreciable mileage difference between the Hythane and CNG fuels which both averaged 18-19 miles per gallon.

A preliminary cost analysis was performed on Hythane based on current merchant liquid hydrogen pricing and using a 500 vehicle fleet operating on Hythane as the baseline. Using the Hythane formulation of 5% hydrogen and 95% CNG, measured by energy content, the estimated price of Hythane was about \$1.13 per gallon equivalent. (Hydrogen was estimated to cost \$5.00 per equivalent gallon and the CNG cost was approximately \$.69.) This was competitive with the cost of regular unleaded gasoline which averaged about \$1.13 per gallon at the time of the cost analysis. The \$5.00 cost per Hythane equivalent gallon does not include all capital and operating costs for the Hythane fueling station.

Oil Analyses

Maintenance intervals were scheduled at approximately 4, 8, 12, 16 and 20,000 miles, at which time a complete servicing was done. The services included oil and filter changes using 15w40 Pennzoil, air filter change, and chassis lubrication. Oil samples were taken at each oil change and oil wear tests were conducted for comparability studies. Results of the oil wear tests are included in Appendix G, and showed that the maintenance required for the gaseous fueled vehicles was less than for the gasoline powered vehicle.

Driver Survey

A driver survey was developed to obtain subjective, informative opinions concerning various vehicle/fuel operations. The ease of fueling, operation of an alternatively fueled vehicle and general impressions were some of the questions addressed. Concerns regarding driver/operator education, fueling procedures, and vehicle safety were also detailed.

A RIBBON-CUTTING

CEREMONY FOR THE
STATION WAS HELD ON
MARCH 12, 1992 WITH
DENVER MAYOR
WELLINGTON WEBB
OFFICIATING

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Once the drivers became familiar with the fueling protocol, only two complaints were voiced: 1) It took longer to drive to the fueling station site (as was mentioned earlier, it was not at the airport location); and 2) Fueling time was a bit longer than when fueling with gasoline. The drivers did not feel that performance, range or drivability of the alternatively fueled vehicles were noticeably compromised. A copy of the driver's survey may be found in Appendix H.

2k. HAZARD AND OPERABILITY PLAN

Before the fueling station was built, any potential hazards which could be associated with this new blended fuel were researched and addressed in a Hazard and Operability Study (HAZOP) developed by Air Products' project members and with technical advice from HCI. This study includes a procedural flow chart which is used to troubleshoot potential problems, determine the degree of hazard, and develop methods to mitigate problems. (The complete plan may be found in Appendix I).

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 have approximately seven times the range of CNG, the 85% concentration of CNG essentially dominated the flammability characteristics of Hythane.

Research also showed that the safety characteristics for natural gas compression by the FuelMaker™ compressor and the National Fire Protection Association safety requirements for fueling CNG vehicles could both be applied satisfactorily to 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.

One of the prime considerations of the HAZOP plan required differentiating between a minor problem and an emergency. To elucidate the primary hazards of the Hythane fueling station, the following comprise 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 were counteracted by the addition of the following features:

1. Leaks within the compressor were detected by the flammable gas detector head located in the vicinity of the outlet cooling air stream of the FuelMaker™ compressor. Leaks from any other equipment are minimized by detection in the earliest stages. This was accomplished by using a hand-held flammable gas detector which was passed by each mechanical joint and valve packing in the system on a periodic basis (approximately every three weeks). The Hythane mixture was odorized due to the 85% natural gas (NG), measured by volume, meeting the odor regulations for NG;
2. The NG feed was overpressure-protected by the gas company. The hydrogen feed was overpressure-protected by Air Products. The FuelMaker had an internal pressure switch to shut itself down and 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.

THE DRIVERS DID NOT FEEL
THAT PERFORMANCE,
RANGE OR DRIVABILITY OF
THE ALTERNATIVELY
FUELED VEHICLES WERE
NOTICEABLY COMPROMISED

In the very remote chance that a vehicle storage tank still connected to the fueling station would over-pressurize, causing the gas to back-flow from the vehicle into the fueling station, a pressure safety valve and other check valves were located on the station for protection;

3. Vent lines from all vent valves and relief valves were taken to a single vent header pipe at a safe overhead location. The vent was directed straight upward and included both a weep hole and a manual drain to prevent freezing of accumulated (rain) water. The single vent header incorporated a very small nitrogen purge in order to keep air out of the vent pipe (since it contains a flammable gas while venting).

The only areas permitted to vent at the station were the standard fire fuse (melt-out) plugs in the top of each hydrogen storage cylinder. These vent only if the storage cylinders are exposed to fire;

4. Partial vacuums were prevented in order to eliminate air intrusion into the system. The FuelMaker was equipped with a built-in safety system to prevent this occurring should the pressure fall to 1.0 psig; and
5. The hydrogen analyzer and the flammable gas meter were placed within a warmed cabinet. A small nitrogen purge located in this cabinet insured that the instruments would not become ignition sources, should the analyzer leak. An asphyxiation warning sign was also placed on the cabinet door.

During the summer of 1991, HCI utilized both this HAZOP plan and additional 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.

2l. EPA

Personnel at the regional office of the (EPA) Environmental Protection Agency were contacted and weekly project summary updates were sent to apprise them of the project status. The EPA was also invited to attend any of the project meetings should they desire. In addition, Bill Myron at the Colorado Department of Health-Mobile Sources Section was kept abreast of all modifications and changes with the research vehicles.

2m. PUBLIC RELATIONS ACTIVITIES

As a tribute to the growing interest in Hythane as an alternative fuel, requests to attend several alternative fuel seminars to give presentations on the project as well as media coverage at exhibitions, conferences and trade shows were received. Locally, several week-long activities were planned to provide public education of Hythane and discuss the potential of clean-burning fuels. A brief list of the events attended locally and nationally follows.

Vehicle Exhibitions

1. May, 1992; "Clean Air Week" sponsored by the American Lung Association in Denver, Colorado. A brochure was developed explaining The Denver Hythane Project and can be found in Appendix J.

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2. September 1992; Global Environmental Day in Denver, Colorado.
3. May 1993; Alternative Fuels Seminar in Boulder, Colorado.
4. May 1993; Alternative Fuels Fair in Longmont, Colorado.
5. June 1993; Air and Waste Management Association Conference in Denver, Colorado.

Hythane Presentations and Papers

1. May 1992; Hydrogen Industry Council in Canada.
2. 1991, 1992, 1993; National Hydrogen Association.
3. October 1992; APWA Western Snow and Ice Removal Conference in Denver, Colorado.
4. November 1992; Red Rocks Community College in Lakewood, Colorado.
5. December 1992; Rocky Mountain Fleet Managers Association in Lakewood, Colorado.
6. June 1993; Alternative Fuels Conference in Madison, Wisconsin.
7. July 1993; South Coast Air Quality Management District in Diamond Bar, California.
8. September 1993; 5 Metanauto Conference in Bologna, Italy.
9. October 1993; Pollutec Conference in Paris, France.

THE INTEREST HAS GROWN
TO THE EXTENT THAT
SEVERAL HYTHANE
PROJECTS ACROSS THE
UNITED STATES HAVE
BEEN INITIATED

In July, 1992, a videotape detailing the Denver Hythane Project was also created by Bob Morris of Worldnet (a division of the US Information Agency out of Washington DC). Mr. Morris specializes in environmental issues and news events occurring in the United States. An interview with several Hythane project participants on the project design, purpose, and projected use of Hythane were explored.

The final tape was sent throughout the Worldnet television network (consisting of 125 countries) during the last part of 1992 and in early 1993. Phone calls have been received from Buenos Aires, Argentina and Europe due to the airing of the tape.

Nationally, private organizations and municipalities have contacted project members to obtain additional information on the progress of the report. The interest has grown to the extent that several Hythane projects across the United States have been initiated, along with international interest in countries such as Canada, Argentina, Italy and France.

TECHNICAL COMPARISON BETWEEN HYTHANE, CNG AND GASOLINE

Chapter 3

3a. EMISSIONS TESTING

Phase I

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

The second round of Phase I 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. In order to test this special catalyst, HCl was required to obtain a waiver from the state to satisfy the anti-tampering provisions as promulgated by the Environmental Protection Agency (EPA). (See Appendix K for a copy of the letter requesting the waiver).

The testing data in both cases was favorable, and substantiated the premise that some Hythane emission results were lower when compared to gasoline or CNG. It should be noted that a tuning error in the engine periodically caused slightly lean operation which resulted in data inconsistent with previous results obtained for carbon monoxide (CO) and nitrogen oxides (NO₂) during October and November of 1991. Table 3 on page 32 lists these test results.

Stages 1, 2 and 3 in Table 3 represent the three cycles which constitute the FTP test as described in Section 2C *Emission Testing* under *Testing Schedule Description*. The FTP composite is a weighted average of these three stages and is the number used when comparisons of emission results are made. Table 4 on page 33 lists the averaged emission results for gasoline, CNG, Hythane and pure hydrogen based on data compiled by HCl.

SUMMARY AND RESULTS

TECHNICAL COMPARISON BETWEEN HYTHANE, CNG AND GASOLINE FUELED VEHICLES:
Energy Task Force of the Urban Consortium**TABLE 3**HYTHANE FTP. EMISSION
RESULTS/PHASE I
(GRAMS/MILE)

TEST SITE/ DATE	THC	CO	NO _x
FTP COMPOSITE:			
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
STAGE 1			
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
STAGE 2			
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
STAGE 3			
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 10-91 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 O₂ 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.

	NMHC	CO	NO _x
GASOLINE	.59	14.1	2.2
CNG	0.01	2.96	0.9
HYTHANE TRUCK (CARB, 1991)	0.01	0.7	0.2
PURE HYDROGEN (GM, 1972)	<0.01	< 0.01	0.2

* units are expressed as grams per mile

The Phase I data effectively demonstrates that Hythane exceeds the present EPA light duty truck standards established for sea level and high altitude. Hythane emissions also meet or exceed the standards set for Transitional Low Emission Vehicles (TLEV), Low Emission Vehicles (LEV), and Ultra Low Emission Vehicles (ULEV) for NMHC, CO and NO_x (see Table 5 below). Standards for Inherently Low Emission Vehicles (ILEV) refer to evaporative emission testing standards which Hythane also meets. Although CNG alone lowers air pollutants, results from Phase I demonstrate that Hythane offers further improvement for CO and THC.

TABLE 4

EMISSION RESULTS* FOR
GASOLINE, CNG, HYTHANE
AND HYDROGEN

	NMHC	CO	NO _x
Sea Level			
Federal Light Truck	0.8	10.0	1.2
High Altitude			
Federal Light Truck	1.00	14.0	1.7
California "TLEV"	0.125	3.4	0.4
California "LEV"	0.075	3.4	0.2
California "ULEV"	0.040	1.7	0.2

* units are expressed as grams per mile

TABLE 5

CURRENT EMISSION
STANDARDS*

Phase II

During Phase II, steps were taken to insure that there were no outliers in the three research 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 the three vehicles once they had accumulated 100 miles operating on gasoline. The results indicates that the vehicles were within the normal range of emissions and all results met the federal standard requirements as Table 6 on page 34 shows.

Although the three research vehicles are considered heavy duty vehicles (weighing 8,500 lbs GVW or more), there were no federal standards nor were there chassis dynamometers available for heavy duty vehicles at the time of testing. Because of these factors, the light duty dynamometer at the Aurora Emissions Technical Center was used and the results were compared to light duty vehicle standards.

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TABLE 6

LA-4 EMISSION RESULTS
AT 100 MILES*

	THC	CO	NO _x
LIGHT DUTY TRUCK STANDARD	0.8	10.0	1.2
GASOLINE (42) 7-10-91	0.09	1.58	0.93
Duplicate 7-18-91	10.08	1.44	0.89
HYTHANE (43) 7-10-91	0.04	0.33	0.77
Duplicate 7-18-91	0.05	0.57	0.75
CNG (51) 7-17-91	0.38	0.52	0.66
Duplicate 7-17-91	0.04	0.39	0.87

*Vehicles operating on unleaded gasoline fuel.

Units are expressed as grams per mile.

Testing was performed at high altitude.

FTP and HOT-505 Testing

Once the baseline FTP testing was completed and conversion kits had been installed on the two gaseous fueled vehicles, three FTP's were conducted on each research vehicle. The vehicles had operated on their respective fuels for 1,000 to 2,000 miles, before the first FTP began. The difficulties in maintaining closed loop control and the resulting problems with obtaining repeatable data provided unacceptable results during FTP1. Although the results are included in this report, they do not contribute to the overall summary of Hythane emissions. The results of the first FTP test for all three vehicles are summarized in Table 7 on page 35.

The results from the second and third sets of FTP's are shown in Tables 8 and 9 respectively on pages 36. (A complete copy of the results from all three FTP's are found in Appendix L). These results were well received in that most of the problems involved with achieving a tightly maintained fuel dispensing system had been satisfactorily resolved, resulting in acceptable duplicate analyses repeatability.

As described in Section 3a, *Emissions Testing*, however, the ambiguity of the inverse relationship between the NO_x and CO emission results still did not clearly demonstrate the potential of Hythane as a clean burning fuel. The decision to run several Hot-505 tests on the Hythane vehicle provided valuable data demonstrating that for the same amount of NO_x emissions, Hythane could lower CO emissions by approximately 35% (see Table 10 on page 37). Although full FTP tests would have provided more complete data, it is anticipated that the Hot-505 results will provide encouragement for further research to unveil the inherent possibilities of Hythane.

3b. SUMMARY

A great deal of world-wide interest has been generated due to the innovative efforts and diversity of information provided by the Denver Hythane Project. The research has contributed not only relevant emission data, but has also addressed the operational difficulties encountered when an engine is retrofitted for alternative gaseous fuels. Pertinent field observations concerning performance, driveability, safety issues and public acceptance of Hythane have also enhanced the importance of this study.

TABLE 7

FTP 1

The dedication and involvement of the five participants has been one of the largest contributions to the success of Hythane research. Each participant willingly gave whatever was needed to assure the success of the project. All of the participants displayed enthusiasm and teamwork throughout the two years of research, despite numerous technical and logistical problems which required additional effort, imposed operational difficulties on the participants, added financial costs, and extended the completion schedule.

A summary of the difficulties encountered in the comparison of emission results between Hythane and CNG testing are as follows:

1. The NO_x results varied by a factor of two among the three supposedly identical new vehicles;
2. The original equipment manufactured (OEM) oxygen sensors were not sufficient in providing the control required for accurate assessment of the fuels. This was due to two factors: the sensors were not heated, and they were located too far from the engine to remain active throughout an entire FTP test;
3. There was insufficient control in the standard IMPCO conversion kits. This made it exceedingly difficult to test both natural gas and Hythane under the same calibration adjustments; and
4. As a pioneering project, protocol and scheduling had to be constantly monitored and changed to accommodate the knowledge acquired as the project progressed. This limited the quantity of tests performed in the original plan.

The team members effectively overcame these difficulties and the conclusions provide valuable information for further testing of Hythane. The effectiveness of Hythane as an alternative transportation fuel is summarized on page 38:

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TABLE 8

FTP 2

TABLE 9

FTP 3

TABLE 10

CNG-HY5 COMPARISON AT
EQUAL SENSOR VOLTAGE
SHOWING THE USUAL CO
DECREASE AT THE
EXPENSE OF A NO_x
INCREASE

COMPARISON BETWEEN
HYS AND CNG. THE
HYDROGEN ADDITIVE
DOES NOT SIMPLY MOVE
THE EMISSIONS ALONG A
SLIDING SCALE OF CO VS.
NO_x

THE DEDICATION AND
INVOLVEMENT OF THE
FIVE PARTICIPANTS HAS
BEEN ONE OF THE
LARGEST CONTRIBUTIONS
TO THE SUCCESS OF
HYTHANE RESEARCH

1. The emission results demonstrated that the major difference between Hythane and CNG is Hythane's potential to deliver clean CO emissions at the expense of a small increase in NO_x when the fuel is at a stoichiometric equivalence ratio. It should be noted, however, that a portion of the observed exhaust emission levels of Hythane could be due to differences in the chemical composition of the fuel, a change in the fuel metering characteristics due to the changes in the physical properties of the fuel or, a combination of both.
2. Within the adjustment range of the fuel mixture available with heated zirconia oxygen sensors, the inverse relationship between NO_x and CO allows a richer fuel mixture to make less NO_x and more CO with either Hythane or natural gas. The study also pointed out that varying the oxygen sensor setpoint voltage resulted in different CO vs NO_x trends for natural gas and Hythane.
3. The last portion of Hot-505 testing conducted during the study provided an understanding of this "trade-off" between CO and NO_x. By increasing CO emissions from Hythane—through the enrichment of the fuel-to-air equivalence ratio—NO_x is lowered to the same level as that encountered with CNG. It is still possible to get less CO emissions with Hythane than natural gas at this enriched fuel-to-air ratio.
4. The beneficial emission effects of hydrogen added to natural gas were proportionately greater than the energy input from hydrogen (5 BTU's out of 100 BTU's),
5. When compared to gasoline, the use of CNG or Hythane resulted in significant reductions in the emissions of unburned hydrocarbons, (THC vs NMHC), CO, and CO₂.
6. As expected, benzene, ethylbenzene, toluene, ortho-xylene and para-xylene emissions were not detectable in exhaust when using CNG or Hythane.
7. Total aldehydes, formaldehyde and acetaldehyde emissions were lower when using CNG or Hythane fuels when compared to gasoline. Only very small quantities of propionaldehyde were present when using the gaseous fuels and no benzaldehyde was detected when using gaseous fuels.
8. It has been demonstrated that with an effective training program and adherence to required safety regulations, a vehicle can safely operate on a blended gaseous fuel such as Hythane.

3c. HIGHLIGHTS AND LESSONS LEARNED

1. **Liability.** 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. **Costs.** 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.** 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. **Waivers.** 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. **Conversions.** 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 demonstrated 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 to their mutual benefit. 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 fleet managers 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, in 1991 Denver was selected as one of 12 international cities to participate in the 10-year Urban CO₂ Reduction Project with the International Council on Local Environmental Initiatives (ICLEI) under the auspices of the United Nations. Since CO₂ 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 in 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 North America and overseas. 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 included formalizing a collaborative relationship with the National Renewable Energy Laboratory (NREL) so that a standardized data protocol could be developed. Although these efforts did not establish a Hythane/CNG Commercialization Plan, the interest of various agencies continues, and through their cooperative efforts and continued interest in Hythane, a plan may yet be developed.

Issues related to the incorporation of Hythane into the CNG infrastructure fueling network was 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 was another parameter which was to be assessed. Denver had proposed to sponsor a Hythane Seminar to ascertain any biases toward the fuel in terms of safety and acceptability. Preparation for the seminar would have begun during the spring of 1992, at the time when the FTP results did not represent acceptable repeatability and operational problems with the conversion kits were abundant. There were concerns over how many seminar attendants would attend a conference on a fuel which, to date, had displayed ambiguous test results. After several discussions with PTI, it was determined that a report summarizing the compendium of Hythane projects currently conducted throughout North America would be of more advantage than the seminar.

In February and March of 1992, interviews with five different organizations located in Montreal and Ontario, Canada, Miami and Orlando, Florida, and Phoenix, Arizona concerning Hythane projects underway or in the preliminary stages of development were investigated. A comprehensive report outlining the details of these trips is available upon request.

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.

Appendices

APPENDIX A SPECIALIZATIONS ON GM TRUCKS AND CONVERSION KIT

VEHICLE INFORMATION:

	Hythane Vehicle VEHICLE NO. 1	CNG Vehicle VEHICLE NO. 2	(Information Only) Gasoline Vehicle VEHICLE NO. 3
MAKE	Chevrolet	Chevrolet	Chevrolet
MODEL	Pickup truck 3/4 ton 4x4	same	same
YEAR	1991	same	same
VIN	1GCGK24K6ME200129	1GCGK24K4ME127245	1GCGK24K2ME201990
LICENSE #	Denver 3819	690-AA4-PU	Denver 3818
VEHICLE I.D. #	W-1-43	15-151	W-1-42
ENGINE DISPL.	5.7 Liter	same	same
# OF CYLINDERS	V-8	same	same
FUEL SYS. TYPE (ORIG.)	Throttle Body Fuel Injection	same	same
CONVERSION DATE	February 1992	February 1992	N/A

APPENDIX 1-A

SPECIFICATIONS ON
THREE RESEARCH
VEHICLES

APPENDIX 1-B

SPECIFICATIONS ON
CONVERSION KITS

DATE OF ORDER 11/7/91		DATE REQUIRED ASAP		SHIP VIA UPS		F.O.B	
ORDER VIA PHONE		QUOTATION NO.		TERMS		X FOR RESALE	
Phone/ Faxed PO/ Mailed PO		verbal - Rube		Net 30		FOR USE	
QUANTITY							
	Ordered	Received	PLEASE SUPPLY ITEMS LISTED BELOW				
1	2		FB-300 AM-50-2 Carburetors				55.3 110.7
2	2		PEV-1 3.7 - 6" H ₂ O Column Springs				0.4 0.8
3	2		S2-109 2.7-3.85" Extra Springs				2.9 5.9
4	2		Fuel Lock -off Solenoid Valves VFF 30-2				31.0 62.1
5	2		AFCP - 1 Fuel Control Processors				187.5 375.0
6	2		PEV- 1 Regulators				58.3 116.6
7	4		G-121 Solenoid Valves				18.1 72.5
8	2		A1-16-1 Adaptors				11.8 23.6
9	2		AA-2-49 Filler				11.4 22.9

APPENDIX B

PHASE II

GASOLINE POWERED
VEHICLE - EMISSION TEST
DATES AND ODOMETER
READINGS

VEHICLE: 1-42 (GASOLINE-POWERED)
BASELINE DATA: INDOLINE FUEL
FTP 1,2 & 3: INDOLINE FUEL

DATE	TEST	ODOMETER
02/05/92	BASELINE	9,535
02/06/92	DUPLICATE	9,553
07/22/92	FTP 1	17,942
07/23/92	DUPLICATE	17,954
10/20/92	FTP 2	19,481
10/21/92	DUPLICATE	19,492
01/21/93	FTP 3	22,046
01/22/93	DUPLICATE	22,058

PHASE II

HYTHANE POWERED
VEHICLES - EMISSION
TEST DATES AND
ODOMETER READINGS

VEHICLE: 1-43 (HYTHANE-POWERED)
BASELINE DATA: INDOLINE FUEL
FTP 1,2 & 3: HYTHANE & CNG FUEL

DATE	TEST	FUEL	ODOMETER
02/07/92	BASELINE	INDOLINE	7,846
02/11/92	DUPLICATE		7,865
03/26/92	FTP 1	HY-5	9,363
03/27/92	DUPLICATE		9,375
04/02/92	FTP 1	CNG	9,410
04/03/92	DUPLICATE		9,421
11/23/92	FTP 2	HY-5	17,053
11/24/92	DUPLICATE		17,065
11/25/92	FTP 2	CNG	17,109
12/01/92	DUPLICATE		17,127
02/19/93	FTP 3	HY-5	21,576
02/23/93	DUPLICATE		21,595
02/24/93	FTP-3	CNG	21,612
02/25/93	DUPLICATE		21,633
02/26/93	DUPLICATE		21,644

PHASE II

CNG POWERED VEHICLE -
EMISSION TEST DATES
AND ODOMETER
READINGS

VEHICLE: BASELINE DATA: FTP 1,2 & 3:		1-51 (CNG-POWERED) INDOLENE FUEL HYTHANE & CNG FUEL	
DATE	TEST	FUEL	ODOMETER
02/13/92	BASELINE	INDOLENE	8,231
02/14/92	DUPLICATE		8,250
03/25/92	FTP 1	CNG	9,934
03/26/92	DUPLICATE		9,957
04/03/92	FTP 1	HY-5	10,024
04/08/92	DUPLICATE		10,043
11/25/92	FTP 2	CNG	17,707
12/02/92	DUPLICATE		17,919
12/03/92	DUPLICATE		17,932
12/04/92	FTP 2	HY-5	17,951
12/08/92	DUPLICATE		17,963
12/09/92	DUPLICATE		17,975
03/02/93	FTP 3	CNG	22,050
03/03/93	DUPLICATE		22,062
03/04/93	FTP 3	HY-5	22,089
03/05/93	DUPLICATE		22,100

TECHNICAL COMPARISON BETWEEN HYTHANE, CNG AND GASOLINE FUELED VEHICLES:
 Energy Task Force of the Urban Consortium

APPENDIX C
PERFORMANCE TESTING

VEHICLE/ DRIVER/ FUEL	DIRECTION	1/4 MI E.T. SEC	1/4 MI MPH	MAX G	@ SEC
#151/	N	25.16	54.6		
HENNESY/ NG	S	25.33	55.8		
HENNESY/ NG	N	25.97	53.4		
HENNESY/ NG	S	25.73	55.4	0.289	1.6
AVERAGE/ NG		25.55	54.8	0.289	1.6
VEHICLE/ DRIVER/ FUEL	DIRECTION	1/4 MI E.T. SEC.	1/4 MI MPH	MAX G	@ SEC
#151/					
HENNESY/ HY5	N	25.68	53.8	0.305	1.8
HENNESY/ HY5	S	25.67	55.1	0.300	1.1
HENNESY/ HY5	N	25.77	52.7	0.310	1.7
HENNESY/ HY5	S	25.61	55.3	0.304	1.7
AVERAGE/ HY5		25.68	54.2	0.305	1.6
W-1-43/					
MARTINEZ/ HY5	N	24.58	55.6	0.357	2.0
MARTINEZ/ HY5	S	24.77	56.5	0.329	1.2
MARTINEZ/ HY5	S	25.21	56.3	0.296	1.7
MARTINEZ/ HY5	N	25.37	54.1	0.316	1.7
AVERAGE/ HY5		24.98	55.6	0.325	1.7
W-1-43/					
MARTINEZ/ NG	N	24.97	55.4	0.323	1.9
MARTINEZ/ NG	S	24.71	56.8	0.339	1.9
MARTINEZ/ NG	S	25.62	53.5	0.333	2.0
MARTINEZ/ NG	N	25.86	54.4	0.299	1.8
AVERAGE/ NG		25.29	55.0	0.324	1.9

VEHICLE/ DRIVER/ FUEL	DIRECTION	1/4 MI E.T. SEC	1/4 MI MPH	MAX G	@ SEC
W-1-42					
HENRY/ GAS	S	22.86	60.3	0.418	1.5
HENRY/ GAS	N	22.88	59.7	0.413	2.3
HENRY/ GAS	S	23.06	59.7	0.415	1.4
HENRY/ GAS	N	22.68	60.6	0.420	2.4
AVERAGE/ GAS		22.87	60.1	0.417	1.9
VEHICLE/ DRIVER/ FUEL	DIRECTION	1/4 MI E.T. SEC.	1/4 MI MPH	MAX G	@ SEC
S-10					
LYNCH/ NG	N	23.24	56.3	0.544	0.9
LYNCH/ NG	S	23.65	57.6	0.512	1.8
LYNCH/ NG	N	23.32	57.7	0.535	0.8
LYNCH/ NG	S	23.19	59.5	0.534	2.0
AVERAGE/ NG		23.35	57.8	0.531	1.4
S-10					
LYNCH/ HY5	N	23.39	56.0	0.567	1.0
LYNCH/ HY5	S	23.38	58.2	0.540	1.8
AVERAGE/ HY5		23.39	57.1	0.554	1.4
S-10					
LYNCH/ GAS	N	22.06	58.7	0.574	2.2
LYNCH/ GAS	S	21.38	63.2	0.586	2.0
AVERAGE/ GAS		21.72	61.0	0.580	2.1

APPENDIX D FUELMAKER SPECIFICATIONS

FuelMaker natural gas vehicle refueling appliance, Model C3

Gas	Inlet pressure	
	• minimum	1.7 kPa (7in. 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	700mmL 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)

TECHNICAL COMPARISON BETWEEN HYTHANE, CNG AND GASOLINE FUELED VEHICLES:
Energy Task Force of the Urban Consortium

APPENDIX E
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.

TECHNICAL COMPARISON BETWEEN HYTHANE, CNG AND GASOLINE FUELED VEHICLES:
Energy Task Force of the Urban Consortium

APPENDIX F
DRIVER'S SAFETY TRAINING MANUAL

F-1. HYTHANE™ STATION OPERATION & SAFETY GUIDELINES

Hythane™ is a compressed fuel gas mixture containing hydrogen and natural gas. Both hydrogen and natural gas are flammable. The mixture to be used in the Denver Hythane™ Project contains 5% hydrogen, when measured by energy content, and 15% hydrogen when measured by volume. The combustion properties of Hythane™ are dominated by natural gas but some differences exist. Hythane™ is stored at the fueling station at pressures up to 3000 psi. Highly compressed flammable gases require special handling procedures which will be discussed in this manual.

**FOR QUESTIONS
CONCERNING THIS
TRAINING MANUAL
CONTACT:**

DEBORAH KIELIAN,
PROGRAM MANAGER
CITY AND COUNTY
OF DENVER
ENVIRONMENTAL
PROTECTION DIVISION
605 BANNOCK STREET
DENVER, CO 80204

(303) 436-7305

Necessary equipment:

1. The Hythane™ Truck, Stapleton Airport truck #W-1-43
2. The key to unlock the Hythane™ fueling station gate.
Note: the Air Products office next to the fueling station has a spare key to this lock if you misplace yours.
3. Wear gloves when fueling the truck, frost bite can occur from the snap coupling and "Fill/Vent" valve.

F-2. FUELING INSTRUCTIONS

1. Enter the driveway at the north end of 5285 Joliet: stay to the left and park at the west end of the driveway opposite the fueling station gate.
2. Place the gear selector in PARK, turn off the engine and set the parking brake.

SMOKING AND OPEN FLAMES ARE PROHIBITED IN THIS AREA

3. Unlock the gate and enter the fueling station. If there is snow on the ground, please use the snow shovel, located on the northwest corner of the enclosure, to clear a path from the gate to the fueling equipment. There is a broom for clearing snow away from the fueling equipment. The compressor needs access to cooling air so please clear snow from around the compressor.
4. Just inside the gate is a grounding cable attached to a stake. Connect the clamp on the end of the grounding cable to the fuel line just under the truck door. Make sure there is a metal-metal connection.
5. Two fuel tanks are located in the truck bed with one fueling connector fitting them. Remove the protective cover from the fueling fitting. Wipe any moisture or debris from the fitting with a rag.

TECHNICAL COMPARISON BETWEEN HYTHANE, CNG AND GASOLINE FUELED VEHICLES:
Energy Task Force of the Urban Consortium

6. Remove the fueling connector from the receptacle and release the hose from its retaining hoop. If there is snow, moisture or dirt on the fueling connector, please wipe it clean with a rag before using.

7. **MAKE SURE THE "FILL/VENT" VALVE LOCATED ON THE END OF THE HOSE IS IN THE "VENT" POSITION.** Take the hose to the truck and connect it to the fueling fitting.

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605 BANNOCK STREET
DENVER, CO 80204

(303) 436-7305

8. Switch the "Fill/Vent" valve to the "Fill:" position.

9. Return to the fueling equipment and open the door on the control cabinet. You will see three pressure gauges labeled "1", "2", and "3". The valves just below these gauges are to be operated in sequence during the fueling operation.
10. Open valve #1. You will hear the rush of gas into the truck. When the flow slows down, a check valve will begin to 'buzz' indicating that the transfer for the first phase is complete. Close valve #1.

VALVE #1

TECHNICAL COMPARISON BETWEEN HYTHANE, CNG AND GASOLINE FUELED VEHICLES:
Energy Task Force of the Urban Consortium

11. Repeat step 10 for valve #2. Open valve #2 and wait, as in step 10, for the buzz.
Close valve #2.

VALVE #2

12. Repeat step 10 for valve #3. Open valve #3 and wait, as in step 10, for the buzz.
Close valve #3.

VALVE #3

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CITY AND COUNTY
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605 BANNOCK STREET
DENVER, CO 80204

(303) 436-7305

13. Get the key to the Fuelmaker™ which is inside the control cabinet.

14. Open the Fuelmaker™ door and press the start button. After the Fuelmaker™ starts, close the Fuelmaker™ door and return the key to the control cabinet. Close the cabinet door. This will begin the SLOW process of refilling the Hythane™ storage bottles in the fueling station.

TECHNICAL COMPARISON BETWEEN HYTHANE, CNG AND GASOLINE FUELED VEHICLES:
Energy Task Force of the Urban Consortium

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15. Go to the truck and switch the "Fill/Vent" to "Vent". Remove the fueling connector and return the hose to the fueling station and place the connector to the holding receptacle. Place the hose in its retaining hoop to protect from wind damage.

16. Remove the grounding cable from the truck and put it back inside the fueling station enclosure. Lock the gate and carefully back out of the driveway. Watch out for standing pipe near the street.

F-3. EMERGENCY PROCEDURES

FIRE

Hydrogen burns in air with a pale blue, almost invisible flame. Therefore you may not be able to see a hydrogen fire, especially during daylight hours. If you suspect a hydrogen fire, look for heat convection and test the area by waving the straw broom (located near the fire extinguisher), in front of you as you walk in. Should the broom catch fire, follow the steps 1 through 5 outlined below.

Natural Gas burns in air with a bright flame. Once hydrogen has been mixed with natural gas, the resulting flame will glow brightly, similar to a natural gas fire.

If you suspect a gas or hydrogen fire, do the following:

1. DO NOT USE A FIRE EXTINGUISHER ON A GAS OR HYDROGEN FIRE!!
2. Turn off both gas valves if possible. (If not possible, continue to steps 3 through 5). These valves are located to the left (east) of the fueling station, are red in color and are labeled "Master Shutoff". The two valves feed natural gas and hydrogen to the fueling station and shutting them off will stop the flow of the gases to the

Fueling Station. If you can close these valves, the fire will burn itself out. (NOTE: If the fire is fueled by Hythane in the storage cylinders, the fire may take a long time to burn itself out.)

3. Turn off the electrical power at one of the two "Emergency shut-off" buttons by pressing the button. Pressing this button will sound a local alarm. These buttons are also red in color and one is located on the outside fence next to the entry gate. The other is located on the fueling equipment to the left of the control cabinet. If you accidentally press one of these buttons, you can reset it by pulling it back out.

**ELECTRICAL
EMERGENCY SHUT-OFF**

Should you be unable to get to the gas valves at the fueling station to shut them off, go inside the Air Products building to the hydrogen manifold located against the north wall and turn off the valve operating the hydrogen tanks. There is no additional natural gas shut off point.

4. There is a phone located inside the Air Products building at the inner office.
Call the local Fire Department : 373-8527
and /or Air Products and Chemicals: 329-9353
5. A fire extinguisher is located on the west fence inside the fueling station enclosure. This may be used to prevent a gas fire from spreading to other materials but should not used to extinguish the fire itself.

Do not spray the fire extinguisher on the source of either gas flame. It is acceptable to spray the extinguisher on surrounding areas (fence, building wall, or parts of the fueling station that are not close to the source of the flame).

6. If the Air Products building is locked, drivers should use the truck radio to turn in the fire alarm. (NOTE: There is NO conveniently close street fire alarm).

TECHNICAL COMPARISON BETWEEN HYTHANE, CNG AND GASOLINE FUELED VEHICLES: Energy Task Force of the Urban Consortium

FOR QUESTIONS CONCERNING THIS TRAINING MANUAL CONTACT:

DEBORAH KIELIAN,
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CITY AND COUNTY
OF DENVER
ENVIRONMENTAL
PROTECTION DIVISION
605 BANNOCK STREET
DENVER, CO 80204

(303) 436-7305

GAS LEAKS

Hydrogen is an odorless gas. Methane, the primary ingredient of natural gas, is also odorless. Natural gas contains an odorant, so should a leak occur, it can be detected by its unpleasant "rotten egg" smell. When these two gases are mixed to form Hythane, they have the characteristic 'smell' of natural gas.

There are two flammable gas detectors at the fueling station. One is located near the fueling equipment and the other behind the fence to the west of the fueling station. If either of these detectors sense a gas leak, they will activate an alarm.

For gas leaks (if you smell a leak or hear the alarm):

1. Press the **RED "Emergency shutoff" button** located next to the gate on the outside fueling station fence or to the left of the fueling equipment control panel.
2. Clear the area.
3. Warn any Air Products employees who may be working at the adjacent plant.
4. Call **HYDROGEN CONSULTANTS INC: 791-7972**

ELECTRICAL PROBLEMS

The FuelMaker™ is connected to 208 volts alternating current (208 V AC). If you suspect an electrical problem:

1. Press the **RED "Emergency shutoff" button** located next to the gate on the outside fueling station fence or to the left of the fueling equipment control panel.
2. Clear the area.
3. Warn any Air Products employees who may be working at the adjacent plant.
4. Call **HYDROGEN CONSULTANTS INC: 791-7972.**

ASPHYXIATION

Breathing high concentrations of hydrogen, natural gas, Hythane or nitrogen gases can result in suffocation due to lack of oxygen. Because the fueling station is located outdoors, the risk of asphyxiation is small. However, the control box on the front (north) of the fueling station or the control box to the west of the fence (located outside the fueling station enclosure) could accumulate concentrations of gases should a leak develop. Therefore **DON'T STICK YOUR HEAD IN THE CONTROL BOX.**

PNEUMATIC HAZARD

Hythane™ is stored at the fueling station at pressures up to 3000 psi. Therefore if you notice any loose, worn, leaking or damaged components in the plumbing lines, clear the area and alert Hydrogen Consultants Inc. at 791-7972.

FROST BITE

Certain components in the fueling equipment may become extremely cold during the fueling operation. This includes the snap coupling and the "Fill/Vent" valve that connects to the truck. Therefore wear gloves when filling the truck.

APPENDIX G OIL WEAR TESTS

PETROLABS INC.
4495 So. Santa Fe Dr.
Englewood, CO 80110

303-781-01
FAX 303-781-11
800-355-1-

CUSTOMER NAME : CITY AND COUNTY OF DENVER
ST ADDRESS : 4500 WABASH
CITY, ST, ZIP : DENVER, CO 80216
ATTN :
WORKSITE : STAPLETON AIRPORT FLEET MAINT
PHONE :

CUSTOMER # : 1104G11002
UNIT # : W-1-43
MAKE & MOD : HYTHANE
COMPONENT : ENGINE
FUEL TYPE : HYTHANE
OIL VI/MFG : 15W-40

SAMPLE INFORMATION						PHYSICAL DATA						
TEST NUMBER	SAMPLE NUMBER	SAMPLE DATE	REPORT DATE	MILES SINCE NEW OIL	MILES SINCE OIL CHANGE	OIL ADDED	VIC	SAE	WATER % VOLUME	SOOT % VOLUME	MLC % VOLUME	GLYC %
1	2024	09/17/92	09/18/92	14250	4250		17.4	50	0	1.2	0	NE
2	2875	12/15/92	12/16/92	17416	725		13.6	40	0	0.4	0	NE
3	3985	02/16/93	02/17/93	4118			16.4	40	0.1	0	0	NE
SPECTROCHEMICAL ANALYSIS IN PARTS PER MILLION BY WEIGHT												
TEST NUMBER	IRON	STEEL	COPPER	ALUMINUM	COBALT	LEAD	PHOSPHORUS	SILICON	SODIUM	ANTHR	WATERS	GLYCERIN
1	74	74	3	5	25	50	25	14	0	99 X	0	0
2	49	20	3	8	35	0	32	32	0	22	0	0
3	78	38	28	8	20	70	58	78	0	8	0	8
ADDITIONAL PHYSICAL TESTS												
TEST NUMBER	WATER	SOOT	MLC	GLYC	PHOSPHORUS	CHLORINE	ZINC					
1	496	0	25	0	2058	2381	2356					
2	149	51	0	0	985	2311	1193					
3	375	180	75	0	1150	2925	1625					

TEST #3 EVERYTHING LOOKS GOOD AT THIS TIME.

TECHNICAL COMPARISON BETWEEN HYTHANE, CNG AND GASOLINE FUELED VEHICLES:
Energy Task Force of the Urban Consortium

APPENDIX H
ALTERNATIVE FUELS DEMONSTRATION PROGRAM DRIVER SURVEY

Thank you for your participation in this alternative fuels project. Your assistance in this demonstration is essential. Please fill out the form EVERY FRIDAY AT THE END OF YOUR SHIFT. Please rate your vehicle's performance against what you would have considered normal for a gasoline engine. If have any questions, call Mike Merino at 893-6243.

Vehicle License # _____	Odometer Reading _____	Date _____					
Approximate time required to fill up: _____ Minutes							
<table border="0"> <tr> <td></td> <td>MUCH WORSE THAN GASOLINE</td> <td>SLIGHTLY WORSE THAN GASOLINE</td> <td>SLIGHTLY BETTER THAN GASOLINE</td> <td>MUCH BETTER THAN GASOLINE</td> </tr> </table>				MUCH WORSE THAN GASOLINE	SLIGHTLY WORSE THAN GASOLINE	SLIGHTLY BETTER THAN GASOLINE	MUCH BETTER THAN GASOLINE
	MUCH WORSE THAN GASOLINE	SLIGHTLY WORSE THAN GASOLINE	SLIGHTLY BETTER THAN GASOLINE	MUCH BETTER THAN GASOLINE			

Cold Operation

How did your vehicle start when the engine was cold? (Example: excessive cranking needed?) [] [] [] [] []

How did your vehicle run when engine was still cold? (Example: hesitation, stall, rough idle, acceleration.) [] [] [] [] []

Warm Operation

How did your vehicle start when the engine was warm? (Example: excessive cranking needed?) [] [] [] [] []

How did your vehicle run when the engine was warm? (Example: hesitation, stall, vapor lock and acceleration.) [] [] [] [] []

Driver Evaluation

In your opinion, how did your vehicle perform this week? [] [] [] [] []

Was there any difference in engine pinging or knocking? [] [] [] [] []

During the past week were there any experiences which in your judgment cause you to believe that this car's performance was effected by the fuel used? YES NO
[] []

Explain: _____

Can you suggest any Improvements

1. filling technique _____
2. other _____

General Comments

Again, thank you for your participation in this project.

WELLINGTON E. WESS
Mayor

CITY AND COUNTY OF DENVER

DEPARTMENT OF PUBLIC WORKS
STAPLETON INTERNATIONAL AIRPORT

AIRPORT MAINTENANCE OFFICE
STAPLETON INTERNATIONAL AIRPORT
ROOM T-3284
DENVER, COLORADO 80207
PHONE: (303) 270-1800

RESULTS OF FINAL SURVEY FROM DRIVERS

COLD OPERATION

1. Starting the engine while cold was rated slightly worse than gasoline.
2. Running the vehicle while cold was rated slightly worse than gasoline.

WARM OPERATION

1. Starting the engine while warm was rated equivalent to gasoline.
2. Running the vehicle while warm was rated equivalent to gasoline.

DRIVER EVALUATION

1. Drivers opinion of overall performance was that vehicle operated equivalent to a gasoline vehicle.
2. Drivers opinion on engine pinging or knocking was slightly worse than gasoline.
3. There was no indication by vehicle's performance that it was due to different fuel usage.

IMPROVEMENTS

1. Vehicle needed greater fuel capacity as far as filling techniques.

GENERAL COMMENTS

With greater fuel capacity and decreased fill time, this would be a fine vehicle. I enjoyed driving this vehicle and hope to see more of them.

TECHNICAL COMPARISON BETWEEN HYTHANE, CNG AND GASOLINE FUELED VEHICLES: Energy Task Force of the Urban Consortium

APPENDIX I HAZARD AND OPERABILITY STUDY

BY: AIR PRODUCTS AND CHEMICALS, INC., ALLENTOWN, PA
J.G. Hansel, Sr. Engineering Assoc., Eng. Safety Dept.
G.W. Mattern, Mgr. of Safety, Industrial Gas Division

with contributions from:
HYDROGEN CONSULTANTS, INC., LITTLETON, CO
F.E. Lynch, President HCI

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% H₂ content.

Early in the hazard review it was determined that the 5% H₂ in 95% NG would not differ significantly from NG in leak or flammability characteristics. Although the ignition energy of H₂ is only about 1/17th that of NG, and the flammability limits of H₂ 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 which are normally associated with the use of hydrogen equipment.

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 H₂ enter the system at the left side of figure regulated in the range of 20 to 25 psig. Regulated N₂ is also available for purging, as shown. The NG and H₂ 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) intrusion 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 H₂ 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 N₂ 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.

* 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 N₂ 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 H₂ 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 N₂ 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 N₂ 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.

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Hythane Comparison

TECHNICAL COMPARISON BETWEEN HYTHANE, CNG AND GASOLINE FUELED VEHICLES: Energy Task Force of the Urban Consortium

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.

<u>What-If</u>	<u>Hazard/Consequence</u>	<u>Mitigating Means</u>
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 <u>large scale</u> 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.

<u>What-If</u>	<u>Hazard/Consequence</u>	<u>Mitigating Means</u>
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).

<u>What-If</u>	<u>Hazard/Consequence</u>	<u>Mitigating Means</u>
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).

TECHNICAL COMPARISON BETWEEN HYTHANE, CNG AND GASOLINE FUELED VEHICLES: Energy Task Force of the Urban Consortium

STAINLESS STEEL HYTHANE VENT SYSTEM ON HYTHANE FUELING STATION DENVER COLORADO

TECHNICAL COMPARISON BETWEEN HYTHANE, CNG AND GASOLINE FUELED VEHICLES: Energy Task Force of the Urban Consortium

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 H₂/NG blend ratio.
4. Temperature-compensated dry test meter for NG.
5. Temperature-compensated dry test meter for H₂.
6. Parallel flow heat exchanger equalizes NG & H₂ temperatures.
7. Pair of solenoid valves for on-off switching of NG & H₂ flows.
8. Choke orifices regulate the blend ratio and flow (also see 3 above).
9. H₂ % 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.

APPENDIX J
HYTHANE BROCHURE *City and County of Denver**Colorado Department of Health**Air Products and Chemicals, Inc.**Hydrogen Consultants, Inc.**Public Service Company of Colorado*

Rocky Mountain News File, March 13, 1992

SCIENCE & ENVIRONMENT

George Douglas, Assistant City Editor ■ 892-2743

Clean-burning hythane debuts**High hopes rest on mix of hydrogen and natural gas as means to reduce metro vehicle emissions**By Bill Scanlon
News Environmental Writer

Hythane — a blend of natural gas and hydrogen — entered Denver's clean-fuel sweepstakes Thursday with the opening of a demonstration station at East 53rd Avenue and Joliet Street in Aurora.

Sponsored by the Denver Department of Health and Hospitals and other agencies, the pilot project will monitor air emissions from a hythane-powered truck and compare it to similar 1991 Chevrolet pickup trucks powered by natural gas and gasoline.

The Colorado Department of Health will sample and test the vehicle emissions.

Metro Denver drivers roll up 34 million miles a day, and seemingly nothing — neither rush-hour bumper-to-bumper traffic nor the stubborn brown cloud — can persuade them to opt for the bus or a car-pool.

Ninety percent of the cars on Interstate 25 during rush hours carry just the driver, state officials say.

So, cleaner fuels that emit less carbon monoxide and fewer hydrocarbons per mile have to be part of the solution, say policymakers.

Propane and natural gas have toe-holds here, with several filling stations throughout the metro area offering the alternative fuels.

Gov. Roy Romer backs pending legislation that would require 3,000 fleet vehicles to be open to

ing on the cleaner fuels by the turn of the century.

Now comes hydrogen, which carries the promise of being the cleanest of all. Right now, the hythane mixture is 85% natural gas.

A vehicle that has had the \$3,000 conversion to accept natural gas probably can accept the hythane as well, using the same safety precautions.

Frank Lynch, president of Hydrogen Consultants, said the addition of hydrogen poses only slight differences in combustibility from pure natural gas.

Bill Hoogland, manager of the Department of Energy's hydrogen-generation program at the National Renewable Energy Laboratory in Golden, sees great promise in hythane.

"We see it as an important first step to hydrogen," said Hoogland.

"Ultimately, we see hydrogen fueling electric vehicles with advanced fuel-cell technology. That's a few years away."

But more research is needed, Hoogland said, and Congress slashed funding for hydrogen research from \$2.5 million to \$1.4 million last year.

Soon, the fuel that is No. 1 on the periodic table could be No. 1 in the hearts of metro-area drivers.

Mayor Wellington Webb attended ribbon-cutting ceremonies Thursday at the event, co-sponsored by Hydrogen Consultants of Littleton.

"Hythane holds the potential to reduce the most potent pollutants emitted by gasoline-fueled automobiles," said Webb.

Widespread use of cleaner fuels is the key to Denver attaining national ambient air quality standards by mid decade, he said.

TECHNICAL COMPARISON BETWEEN HYTHANE, CNG AND GASOLINE FUELED VEHICLES:
Energy Task Force of the Urban Consortium

APPENDIX K
ANTI-TAMPERING PROVISIONS WAIVER

WELLINGTON E. WEBB
Mayor

CITY AND COUNTY OF DENVER

DEPARTMENT OF HEALTH AND HOSPITALS
ENVIRONMENTAL HEALTH SERVICE

635 BANNOCK STREET
DENVER, COLORADO 80204-450
(303) 693-7003

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

**APPENDIX L
EMISSIONS RESULTS**

**FOR RAW DATA
PERTAINING TO THE EMISSION RESULTS CONTACT:**

DEBORAH KIELIAN, PROGRAM MANAGER
CITY AND COUNTY OF DENVER
ENVIRONMENTAL PROTECTION DIVISION
605 BANNOCK STREET
DENVER, CO 80204
(303) 436-7305

SUSTAINABLE COMMUNITIES

AUSTIN, TX - Sustainable Systems Rating Program

The city of Austin, long a pioneer in sustainable research planning and practice, developed a sustainability rating system that can be used as a marketing tool to encourage high levels of resource conservation, appropriate usage, and economic development through residential building.

91-302. \$15.00

PTI - How to Save Thousands - Even Millions of Dollars Through Energy Efficiency (Video)

Looking for ways to save energy and money? This Urban Consortium Energy Task Force Video shows several cost-conscious and earth-minded methods to do so. Examples include how Phoenix saved \$32 million through retrofitting and how New York City built a natural-gas-powered fleet to comply with the Clean Air Act.

92-402 FREE!

SAN JOSE, SAN FRANCISCO, CA, & PORTLAND, OR - Sustainable Energy for Local Governments

With scarce resources and environmental concerns mounting, how can local governments move toward a sustainable system? This practical workbook identifies key components of sustainable energy.

Call Conservation and Renewable Energy Inquiry and Referral Services (CAREIRS) at 1-800/523-2929 for a copy.

SEATTLE, WA - Coordination of Energy and Air Quality

Learn how Seattle City Light (SCL) worked with industry to reduce air pollution emissions with positive economic effect. The study conducted during 1991 and 1992 resulted in a working relationship between two agencies (Seattle City Light and the Puget Sound Air Pollution Control Agency) with the same objective - to improve air quality and reduce energy consumption. Read about some of the difficulties encountered and lessons learned by SCL in accomplishing energy conservation among residential and commercial customers.

92-318. \$20.00

TUCSON, AZ - Tucson Solar Village—Project Management

The City of Tucson's 820-acre Solar Village project seeks to provide a sustainable community for up to six thousand residents, using solar energy to reduce energy needs by 75%, water conservation methods to reduce usage by 65% per capita, and recycling programs to reduce landfill solid waste.

91-304. \$12.00

TUCSON, AZ - Local Government Involvement in Long Term Resources Planning for Community Energy Services

Tucson has also developed a program to coordinate government research, utility, and business energy saving efforts. Results show that by taking a state-wide perspective on resource planning, additional savings and environmental benefits can be achieved through conservation and demand management.

91-313. \$20.00

ALSO AVAILABLE:

ST. LOUIS, MO - A Case Study in the Pursuit of Urban Energy Efficiency
89-315. \$15.00

ECONOMIC DEVELOPMENT

CHICAGO, IL - Implementation of Alternative Technologies through the Assessment of Energy Markets
89-301. \$14.00

MEMPHIS, TN - Economic Development through Energy Technology Transfer: Strategies for Local Governments
87-312. \$15.00

PTI - The Hidden Link: Energy and Economic Development Phase II: Marketing and Financing Strategies for Community Energy Projects
87-310. \$15.00

SAN FRANCISCO, CA - Energy Planning for Economic Development
88-309. \$18.00

BUDGETS AND PURCHASING

SEATTLE, WA - Integrating Energy Efficiency into Municipal Purchasing Decisions: Computerizing Procurement Choices
88-319. \$15.00

BUILDINGS

AUSTIN, TX - Sustainable Building Sourcebook

Building professionals obtain guidance through this technical support document for Austin's Green Builder Program, aimed at changing conventional building practices.

92-311. \$18.00

MONTGOMERY COUNTY, MD - Energy Efficient Building design: A Transfer Guide for Local Governments

A proven "how to" guide for local governments and the private sector on the implementation of energy efficient construction programs.

91-317. \$7.50

SAN FRANCISCO, CA - Energy Management Action Plan

The City/County of San Francisco has developed a methodology for local government energy

ABOUT THESE PUBLICATIONS

These publications were produced through research conducted by the Urban Consortium Energy Task Force (UCETF) of Public

Technology, Inc. Many of the research projects were funded through a grant from the U.S. Department of Energy.

The task force was established to address critical energy needs of urban America. The UCETF acts as a laboratory to develop and test solutions and share the resulting products or management approaches with the wider audience of both large and small local governments, states, and local authorities around the world.

UCETF membership includes elected officials, management, and technical professionals from urban cities and counties. It links through the Urban Consortium and PTI to national organizations, such as the National Association of State Energy Officials (NASEO), the National League of Cities, the National Association of Counties, and the International City/County Management Association to ensure the widespread exchange of information and technology.

For more information about the Urban Consortium Energy Task Force (UCETF) or these guidebooks, contact Jack Werner, PTI Business Director, at 202/626-2421.

offices to use in designing Energy Management Action Plans (EMAP). The guide walks readers through the process of creating an EMAP: identifying barriers; researching a setting for the project; and generating ideas to remove specific barriers. Help create more effective facilities in your jurisdiction via a holistic methodology.

92-310. \$20.00

ALSO AVAILABLE:

MEMPHIS, TN - Upgrade Energy Building Standards and Develop Rating System for Existing Low-Income Housing
92-306 \$20.00

NEW ORLEANS, LA - *Low- and Moderate-Income Residential Energy Conservation*
89-321. \$15.00

SAN JOSE, CA - *Energy Master Planning: Innovative Design and Energy Analysis for New Commercial Construction*
92-311. \$18.00

ST. LOUIS, MO - *Reducing Electricity Demand through Energy-Related Efficient Construction*
89-306. \$15.00

WASHINGTON, DC - *Energy Efficiency in Public Housing*
90-314. \$15.00

COOLING AND HEATING

CHICAGO, IL - *Central Station DHC (District Heating/Cooling) Feasibility*

This report explains how district energy systems can reduce the high cost associated with electricity prices for multi-use real estate.

90-304. \$18.00

PHOENIX, AZ - *HVAC Equipment Replacement for Best Size and Efficiency: A Technology Transfer Report*

This ready-to-use guide will help local governments with technical and economic evaluations for equipment replacement.

88-306. \$15.00

ALSO AVAILABLE:

PHOENIX, AZ - *Thermal Energy Storage: An Application Guide for Local Governments*
87-302. \$20.00

PHOENIX, AZ - *Cogeneration and Cooling in Small Scale Applications*
88-305. \$15.00

PHOENIX, AZ - *Impact of Urban Heat Island on Cooling and Environment*
91-323. \$5.00

PORTLAND, OR - *Energy Savings from Operation and Maintenance Training for Apartment Boiler Heating Systems*
91-320. \$18.00

SAN JOSE, CA - *Energy Efficient Urban Cooling Technologies: Proceedings*
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LIGHTING

KANSAS CITY, MO - *Modernization of Lighting in Municipal Auditorium*

Learn how lighting effectiveness can be improved while also decreasing cost and maintenance.

89-304. \$15.00

ALSO AVAILABLE:

NEW YORK, NY - *Marketing Energy Efficiency Programs to Commercial and Industrial Firms: Lighting Incentives and Rebates*
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DEMAND-SIDE MANAGEMENT

SAN JOSE, CA - *Negotiating a Demand-Side Bid*

Remove the mystery from the energy conservation-bidding process. Get general background

information on demand-side bidding information; learn advantages and disadvantages of participation; and, discover alternative and "ideal" scenarios for bidding. In addition, preview potential pitfalls and lessons learned from a municipal jurisdiction that has already been through the process and offers its transferable model for your benefit.

92-322. \$12.00

ALSO AVAILABLE:

PTI URBAN CONSORTIUM ENERGY TASK FORCE - Video: *Variable Frequency Drives: SAVING ENERGY!* Also, ask for PTI's other free videos, entitled the Urban Consortium Energy Task Force, and Cleaner Fueled Vehicles.
92-401. FREE

SMALL BUSINESSES

NEW ORLEANS, LA - *Reducing Impact of Energy Costs on Small Businesses*
88-312. \$15.00

UTILITY MANAGEMENT

PTI - *Electric Utility Franchise Conference Proceedings*

Details from the first conference of its kind includes research results, negotiating experiences, technological advancements, and regulatory changes.

89-307. \$20.00

ALSO AVAILABLE:

CHICAGO, IL - *A Municipal Guide to Least Cost Utility Planning*
90-323. \$18.00

CHICAGO, IL - *The Electric Utility Franchise Expiration and Renewal Process*
87-322. \$15.00

KANSAS CITY, MO - *Use of Cogeneration System to Control Electrical Demand*
90-305. \$15.00

HOUSTON, TX - *Electric Utility Franchise Guide*
87-311. \$20.00

WATER DISTRIBUTION

DETROIT, MI - *Energy Optimization of Water Distribution System*

Looking to cut your water transmission costs? An energy optimization project, such as that developed by Detroit, may help your jurisdiction cut one of its highest expenditures. Development of a computer program used to develop energy strategies and planning guidelines helped Detroit minimize power consumption and improve pumping efficiency at its pumping facilities. A guidebook identifying the transferable methodology used to develop the computer program will assist you in developing an energy optimization program for your municipality.

92-301. \$7.50

ALSO AVAILABLE

DETROIT, MI - *Computer Assisted Control for Municipal Water Distribution*
87-313. \$20.00

ENVIRONMENTAL MANAGEMENT

HAZARDOUS WASTE

ALBUQUERQUE, NM - *Hazardous Waste as an Energy Manager's Issue*
88-317. \$15.00

HENNEPIN COUNTY, MN - *Household Batteries: Evaluation of Collection Methods*
89-309. \$7.50

PTI - *Communicating with the Public about Environmental Risks*
89-314. \$13.00

SEATTLE, WA - *Evaluating Program Effectiveness of Household Hazardous Waste Collection*
90-330. \$15.00

SEATTLE, WA - *Evaluation and Comparison of Selected Household Hazardous Materials*
89-313. \$15.00

RECYCLING

MEMPHIS, TN - *Recycling and Composting Demonstration Projects for the Memphis Area*
91-332. \$25.00

MONTGOMERY COUNTY, MD - *Yardwaste Recycling Study: A Pilot Study for Composting Yard Waste with Existing Leaf Composting Program*
89-311. \$15.00

NEW ORLEANS, LA - *Waste Tire Recycling by Pyrolysis*
90-328. \$20.00

SAN DIEGO, CA - *Multifamily Recycling Programs: Program Data and Implementation Guidelines*
91-334. \$20.00

SOLID WASTE

DADE COUNTY, FL - *Maximization of Revenues for Power Sales from a Solid Waste Resources Recovery Facility*
Learn how to maximize electricity revenues from recourse recovery plants through Metro-Dade County's contract with Florida Power & Light Company to sell excess energy produced by burning municipal solid waste.

91-303. \$20.00

ALSO AVAILABLE

HOUSTON, TX - *Solid Waste Integrated Cost Analysis Model (Parts I and II)*
90-306. \$15.00; 91-331. \$15.00

MEMPHIS, TN - *Sludge Storage Lagoon Biogas Recovery (Phases I and II)*
89-310. \$15.00; 90-327. \$10.00

HYDRAULIC WASTE

DETROIT, MI - *Hydraulic Waste Energy Recovery: A Technical Report*
90-331. \$15.00

DETROIT, MI - *Hydraulic Waste Energy Recovery: A Technical Report - Phase II*
91-311. \$15.00

HOUSTON, TX - *Wastewater Treatment Process Energy Optimization*
89-303. \$13.00

TRANSPORTATION

ALBUQUERQUE, NM - *Alternative Vehicle Fuels in Municipal Duty: A Demonstration Project*

Examination of the comparative benefits of CNG, electricity, oxygenated fuels and gasoline as primary fuels for automobiles, with emphasis on environmental impact and fleet integration.
90-316 \$15.00

DENVER, CO - *Technical Comparison Between Hythane, CNG and Gasoline Fueled Vehicles*

A study demonstrating performance of Compressed Natural Gas (CNG) as compared to Hythane, a mixture of CNG and Hydrogen. Hythane was shown to have the potential to meet California's Ultra-Low Emissions Vehicle (ULEV) standard, a criterion currently met only by electric vehicles.
91-324. \$12.00

CONEG - *Refueling Alternatives Fuel Vehicles: Lessons Learned from the Marketplace*

A study supported by DOE, public officials and energy companies has been conducted by the Coalition of Northeast Governors (CONEG) Policy Research Center, Inc. The findings conclude that information and refueling are two critical needs if fleet managers are to operate alternative fuel vehicles. The study surveyed fleet operators in Northeast states. This report provides useful quantitative information for decision makers to make preliminary assessments of potential market demand for the development of refueling infrastructure to serve alternative fuel vehicles.

Copies of the report are available from CONEG at (202)624-8450 for \$50 for the two volume set, \$20 for Volume I and \$40 for Volume II.

HOUSTON, TX - *Compressed Natural Gas Fueled Vehicles: The Houston Experience*

A feasibility study with additional focus on refueling infrastructure.

90-320 \$22.00

LONG BEACH, CA - *NGV Fleet Fueling Station Business Plan*

Promote compressed natural gas vehicle use in your municipality's fleet. In this report, based on the City of Long Beach's experience, market barriers as well as an econometric model for the implementation of a CNG infrastructure are addressed. This transferable model may help your municipality effectively address issues associated with the implementation of such an infrastructure.

93-310. \$18.00

NEW YORK, NY - *Alternative Transportation Fuels: Financing Issues*

This study examines methods of financing alternative fuel vehicles which do not include government subsidies. Learn how high costs can be spread among a number of parties in the private sector.

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SAN DIEGO, CA - *California Clean Air Act - A Compliance Strategy*

The full cost of acquiring and operating a fleet of low emission vehicles is cited in San Diego's compliance strategy report. Learn from this jurisdiction's experience how to create a well-planned approach to changing over to a low emission fleet with minimal municipal service interruption, and improve air quality in your region.

92-330. \$20.00

PTI UCETF - *Cleaner Fueled Vehicles (Video)*

Uncertain fuel costs and environmental pressure make alternative fuel fleets increasingly important. Decide which Cleaner Fueled Vehicle is right for your city or county.

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DETROIT, MI - *Analysis of Operational, Institutional and International Limitations for Alternative Fuel Vehicles and Technologies*
90-311 \$18.00

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