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The Potential For Hydrogen As an Energy Source

GAO surveyed a portion of the literature on the status, progress, and problems surrounding the development and commercialization of hydrogen as an energy source.

Generally, hydrogen as a fuel is virtually inexhaustible, clean burning, convenient, versatile, and free from foreign control. But it does, however, have certain limitations in that it is practically nonexistent in its free state, and it must consume a primary energy source in its production. In fact, hydrogen consumes more energy in its production than is released by its use, resulting in a net energy loss. Therefore, hydrogen's potential for replacing fossil fuels seems unlikely until a renewable primary energy source, such as fusion, solar, or geothermal, can be used to produce hydrogen economically.

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PREFACE

For the next 25 to 50 years, the United States will be in a period of transition from dependence on oil and natural gas as a primary energy source to essentially inexhaustible forms of energy. Hydrogen, one of several potential inexhaustible energy resources, is being looked at from the standpoint of whether it can be of use in making such a transition. We surveyed the literature on the status, progress, and problems surrounding the development and commercialization of hydrogen as an energy source. We also interviewed experts in the field of hydrogen research and development, and discussed with experts in other disciplines the various aspects of efforts to promote the widespread use of hydrogen as a fuel source.

Hydrogen is clean burning, convenient, versatile, and free from foreign control. But hydrogen has limitations in that it is practically nonexistent in its free state and consumes more energy in its production than is released by its use, resulting in a net energy loss. Currently, the most prevalent energy sources used for producing hydrogen are coal, oil, and natural gas. However, increased conversion of these usable and exhaustible fossil fuels to hydrogen is highly unlikely because it is more economical to burn these fuels directly to obtain energy. Therefore, hydrogen cannot be considered as a replacement for fossil fuel sources such as oil or gas until renewable energy source alternatives such as nuclear fusion, and solar or geothermal energy can be developed to produce hydrogen economically.

The Department of Energy (DOE) recognizes these limitations and has small research and development efforts underway relating to hydrogen. DOE's funding for such efforts amounts to a little more than $29 million a year, most of which relates to DOE's programs in military applications, basic energy sciences, and coal gasification. Research in such areas as hydrogen storage, transmission, and utilization is funded on a low-keyed basis, and little funding is provided for research on end-use applications. If and when hydrogen becomes abundant, the necessary infrastructure changes, although costly, could be made in a timely and effective manner. Additionally, converting to major hydrogen usage, such as that envisioned under a hypothesized hydrogen economy, would not require any major scientific or technological breakthroughs but would, for the most part, require resolution of engineering problems such as those associated with production, transmission, storage, and use.

This study is being provided to those congressional committees that have an ongoing interest in energy. In addition, copies will be made available to interested persons on request.

We hope this overview of the potential for hydrogen as an energy source will help achieve a better understanding of the subject.

J. Dexter Peach
Director

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ABBREVIATIONS

DOE	Department of Energy
GAO	General Accounting Office
H	hydrogen
O	oxygen

THE POTENTIAL FOR HYDROGEN AS AN ENERGY SOURCE

INTRODUCTION

An ideal fuel for use in meeting the Nation's energy needs would be one that is virtually inexhaustible, clean burning, convenient, versatile, and free from foreign control. Hydrogen could be such a fuel, but it has limitations in that it is practically nonexistent in its free state and must be produced, consuming a primary energy source such as gas, oil, or coal in the process. On the other hand, with existing technology hydrogen can serve as a fuel for all conventional energy uses, including industrial applications; electric power generation; and residential, commercial, and transportation purposes.

In a hypothesized hydrogen economy in which hydrogen is consumed as a main source of energy and is produced by means of the most reliable technology, water is decomposed into its constituent elements of hydrogen (H) and oxygen (O) using a nondepletable energy source such as fusion or solar energy. The hydrogen produced is then transported through various means, including pipelines, and burned to provide heat energy for the needs of the economy. Since the burning of hydrogen involves combining it with oxygen, the hydrogen economy actually comprises a closed system in which (1) hydrogen and oxygen are separated from water, requiring the expenditure of energy, and (2) when needed, hydrogen is recombined with oxygen, forming water and in the process releasing useful energy. Unfortunately, however, the amount of energy derived from burning the hydrogen is less than the amount of energy that was consumed to produce it.

Thus, hydrogen cannot be considered a replacement for an energy source but instead is comparable to electricity, which is a secondary source of energy. Hydrogen, like electricity, represents a medium for storing, distributing, and using energy generated from other means.

In the future, however, hydrogen could become a major energy source in the event that (1) fossil fuels become too valuable or scarce to burn and (2) hydrogen could be produced economically from a renewable energy source such as nuclear fusion, and solar or geothermal power.

CURRENT PRODUCTION PROCESSES

Over 5 million tons of hydrogen are being produced annually, and production is expected to more than double within the next 10 years. Although there are various processes by which hydrogen can be produced, almost all of it is produced from natural gas and other highly hydrogenated hydrocarbons. A comparison of the various processes is shown in appendix I.

CURRENT AND POTENTIAL USES

Hydrogen is used principally as a feedstock in the production of fertilizers and as a raw material for refining crude oil. Presently, little if any hydrogen is being used as a fuel. However, given an abundance of supply, hydrogen has almost universal application as a fuel, ranging from generating electricity to powering automobiles and jet aircraft.

Gas utilities

For residential and commercial establishments, hydrogen can be used to replace natural gas used for:

--Space heating in conventional furnaces.

--Space cooling in absorption-type air conditioners.

--Various household and kitchen appliances.

--Hot water heating.

--The generation of high-quality, high-purity process steam.

In addition, hydrogen could be added to natural gas, thereby extending the life of that depletable resource.

Electric utilities

Electric energy demands vary on an hourly, daily, and monthly basis. Utilities try to use their most efficient powerplants most of the time and their lower efficiency powerplants only during high-demand periods. If a more efficient, cost-effective medium could be developed for storing electricity, utilities could increase the use of their most efficient plants by storing the excess power generated during low-demand periods for use during high-demand periods. This would help eliminate the need for using their less efficient powerplants. Hydrogen could serve as such a storage medium. It could be produced and stored by the utilities during low-demand periods and later burned during high-demand periods to generate electricity.

Transportation

Extensive tests have shown hydrogen to be an attractive transportation fuel; feasibility studies have indicated that it could be an excellent fuel for railroad, marine, aircraft, and automobile engines. Liquid, gaseous, or solid hydrogen could serve as such a fuel; however, its practical potential is limited by a number of factors which are discussed in the following section.

FACTORS AFFECTING EXPANDED USE

Given an inexhaustible energy supply for producing virtually unlimited quantities of hydrogen, a number of factors exist which could impede its expanded use as a fuel. These factors are discussed below.

Economic

Ultimately, the decision to use hydrogen as a fuel will depend on its cost, which is now two to five times that of oil or natural gas.

Because of its conversion cost, hydrogen cannot compete with fuels used to produce it. Presently, the least expensive source of hydrogen is natural gas. The next cheapest source of hydrogen would be energy produced from coal gasification; however, this source is limited because it is more economical to convert coal to synthetic natural gas and/or crude oil. However, since the cost of fossil fuels continues to increase, and given alternative economical methods to produce hydrogen from solar or fusion power, hydrogen could become a competitive fuel.

Storage

Hydrogen can be stored as a gas, liquid, or solid, the most common method being high compression gas storage in metal cylinders. These cylinders are heavy, awkward to handle, and when storing large quantities, very expensive. As an alternative, hydrogen gas could probably be stored under pressure in underground caverns and mines (as natural gas) and in depleted oil and gas fields. Experimental studies are planned by the Department of Energy for evaluating the possibility of underground storage, taking into consideration the extent to which leakage losses and contamination represent potentially serious problems.

Hydrogen stored in a liquefied form must be cooled to a very low temperature (-423^0 Fahreheit) and contained in well-insulated vessels requiring the latest techniques in cryogenic, or low-temperature engineering. The primary benefit of liquid storage is that liquid hydrogen is 700 times more dense and therefore requires less storage space than does hydrogen in its gaseous form; however, the conversion from gas to liquid is energy intensive, accounting for 30 percent of the energy stored in the liquid.

Hydrogen can be stored as a solid through the use of metal hydrides. Metal hydrides are chemical compounds which form when pure hydrogen, under pressure, comes into contact with certain pure metal or metal alloy powders. When the hydrogen is needed for use, the hydrides can be made to decompose through either depressurization or heating process, thereby emitting pure hydrogen. Although hydrides can store up to twice as much hydrogen in the same volume required by liquid hydrogen tanks, hydrides contain very little hydrogen on a mass basis. For example, when hydrogen is stored in the form of a hydride consisting of iron-titanium material, only about 1 percent of the hydride's total weight represents recoverable hydrogen. Thus researchers are seeking inexpensive lighter alloys for eliminating the weight penalty problem.

Transmission

Hydrogen can be transported as a gas or a liquid. Small quantities of hydrogen gas are presently being shipped in high-pressure cylinders, and natural gas mixed with hydrogen is routinely transmitted through pipelines. Some studies have been made to determine the feasibility of shipping pure hydrogen through existing natural gas pipeline systems. Such studies have shown that pure hydrogen systems require higher horsepower compressors to push the hydrogen through the pipelines because hydrogen gas is significantly lighter than natural gas.

The studies also show that pure hydrogen tends to make some pipeline materials brittle. Researchers are attempting to find materials and inhibitors that will prevent this.

Although liquid hydrogen can be transmitted long distances through well-insulated pipelines, the cost of these pipelines amounts to about $100 per linear foot, or more than $500,000 per mile for a pipe 5 inches in diameter. Currently, large quantities of liquid hydrogen are shipped using insulated truck trailers and rail tank cars. If larger quantities are needed, ocean-going tankers and barges could be used.

Safety

Hydrogen is one of the most flammable and explosive fuels available and must be handled with appropriate safeguards. It can be safer than conventional fuels in some applications and more hazardous in others. For example, liquid hydrogen is more difficult to contain than gasoline; ambient gasoline vapors, however, are more difficult to contain than ambient hydrogen. Industry has proven that both fuels can be safely and easily contained in gaseous as well as liquid forms. Studies of future hydrogen applications revealed no major safety problems in the industrial and commercial markets, but some problems could surface in transportation and residential uses.

Commercialization

The large capital expenditures required to implement major hydrogen usage could impede future commercialization efforts. Because the majority of hydrogen systems will not be compatible with existing energy systems, a forceful industrial and governmental commitment to the hydrogen economy would probably be needed.

Hydrogen commercialization activities would probably begin in large single-purpose installations, producing and consuming their own hydrogen. Following this, hydrogen would probably be used in industries where large storage facilities could be located and widespread use would begin after distribution systems are established.

A conversion from existing fuels to gaseous and liquid hydrogen fuel would require massive and expensive changes in the existing infrastructure, for which one or more sectors of the economy would have to absorb the cost. This could be a serious drawback to the implementation of major hydrogen usage.

Potential barriers and incentives

As with any new emerging technology, socio-political, institutional, or other barriers could alter the expanded use of hydrogen. However, despite these barriers, there are a number of factors which favor development of hydrogen as a fuel.

Socio-political

The issue of safety and the public's perception of it is constantly raised whenever hydrogen systems are being considered. The public in general is unfamiliar with hydrogen, and the risks inherent in its large-scale use are relatively unknown. Contradictory claims only serve to confuse the public, and the large-scale, rapid introduction of a hydrogen economy could be construed as an unnecessary and premature exposure to unfamiliar risks. This could lead to public reluctance and opposition to accepting the change. Therefore, consideration must be given not only to the actual safety level but also to the public's perception of the risks involved. The following are other socio-political barriers to a hydrogen economy:

--Training of personnel in all facets of the system from production to consumption would be costly and time consuming.

--Conversion of home appliances and remetering can result in public resistance because of costs.

--Relocation of energy-intensive industries to achieve closer proximity to hydrogen production centers could create many economic and social consequences.

--Shifting emphasis on pollution problems of major urban areas from fuel use to fuel production could be resisted.

On the other hand, the following factors favor the development of hydrogen, irrespective of these barriers:

--Hydrogen as a clean burning fuel could be used in areas where air quality constraints limit the use of other combustibles because of pollution.

--Transmission of hydrogen through underground pipelines has aesthetic advantages over overhead electric lines.

--A hydrogen economy would help promote the Nation's goal of energy independence, which has widespread public support.

Institutional

If there is a large-scale commitment to hydrogen, regulatory conflicts between the Federal and State Governments will probably surface. They would most likely involve such issues as occupational safety and health, construction regulations, licensing and professional requirements of workers, and accident liability. Greater Federal involvement in these areas is likely to be resisted and, in the absence of a clear resolution, lead to problems. The following are factors which might hamper hydrogen development:

--Regulation of utilities (siting, rate structures, capital investments) could involve similar Federal/State regulatory conflicts.

--Use of hydrogen for residential or commercial purposes could require revision of building codes.

--Hydrogen presently lacks a significant lobby which could delay implementation of an attractive energy system.

The impact of these barriers on the future development of hydrogen would, of course, have to be weighed in light of factors favoring its development, such as the following:

--The desirability of having a flexible energy system with multiple sources is preferred over reliance on a few systems.

--Hydrogen can be produced under existing technological systems, so that many of the potential regulatory disputes could well be resolved prior to large-scale hydrogen implementation. For example, if nuclear power is to be used to produce hydrogen, siting controversies could be resolved through the existing regulatory mechanisms.

FEDERALLY FUNDED RESEARCH AND DEVELOPMENT

Federally funded hydrogen research and development is being carried out in various areas. Funds provided for hydrogen research and development by the DOE divisions in conjunction with their respective research areas totaled over $29 million in fiscal year 1977, as shown on the next page.

Research area	Amount
	(millions)
Coal gasification	$ 9.4
Basic energy sciences	7.2
Military applications	6.7
Energy storage systems	4.5
Laser fusion	0.6
Solar energy	0.4
Transportation energy conservation	0.2
Environmental control technology	0.1
Total	$29.1

Most of the funds are being used on coal gasification, basic energy sciences, and military application programs, with very little going to research efforts relating to hydrogen storage, transmission, and utilization. DOE is placing much greater emphasis on programs for developing inexhaustible energy sources 1/ with hydrogen end-use applications research being funded on a low-keyed basis. If and when it becomes apparent that hydrogen can eventually be produced in abundance through the use of inexhaustible sources, DOE would still have sufficient time for reordering its priorities if a decision were made to develop hydrogen for widespread energy use. Although the infrastructure changes necessary to take advantage of this abundant fuel would be massive, costly, and disruptive, the conversion to an economy in which hydrogen is considered a major energy source would not require any major scientific or technological breakthroughs. Such conversion would, for the most part, require resolution of the various engineering problems such as those associated with production, transmission, storage, and use.

1/DOE is spending hundreds of millions of dollars on nuclear fusion, and solar and geothermal research programs.

COMPARISON OF HYDROGEN PRODUCTION ALTERNATIVES 1/

Process	Advantage	Disadvantage
Reformation of methane	Presently the cheapest method.	Scant long-term potential as a source because of limitations on methane supply; is already meeting gaseous fuel needs.
Coal gasification	Cheapest and most secure near-term alternative methane reformation; abundant coal reserves in the United States.	Ultimate limitation is exhaustion of the coal resource; requires large plant size. 2/
Electrolysis of water	Proven reliable technology; small unit plant size; well suited to all terrestrial solar energy collection approaches; oxygen coproduct; easily separated for possible use and economic credit; improvement in efficiency quite likely; can produce hydrogen at high (cont.)	High cost, lower net energy efficiency; possible resource limitation on catalyst. The need for a non-fossil fuel energy source.

1/Source: A February 1976 Stanford Research Institute Study entitled "The Hydrogen Economy A Preliminary Technology Assessment."

2/Coal can also be converted to synthetic natural gas or a liquefied fuel which can be used with very little or no change in the existing infrastructure. This would tend to preclude the gasification of coal to hydrogen for use as a gaseous or liquid fuel.

Process	Advantage	Disadvantage
	pressures thereby eliminating the need for costly compression to pipeline pressures.	
Thermochemical decomposition	Potentially most efficient nonfossil processes; not tied to fossil fuel resources possibly compatible with high temperature, focused solar collectors.	Not a proven technology; materials problem in containment; complex large unit plant size expected; expected release of potentially harmful chemicals.

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