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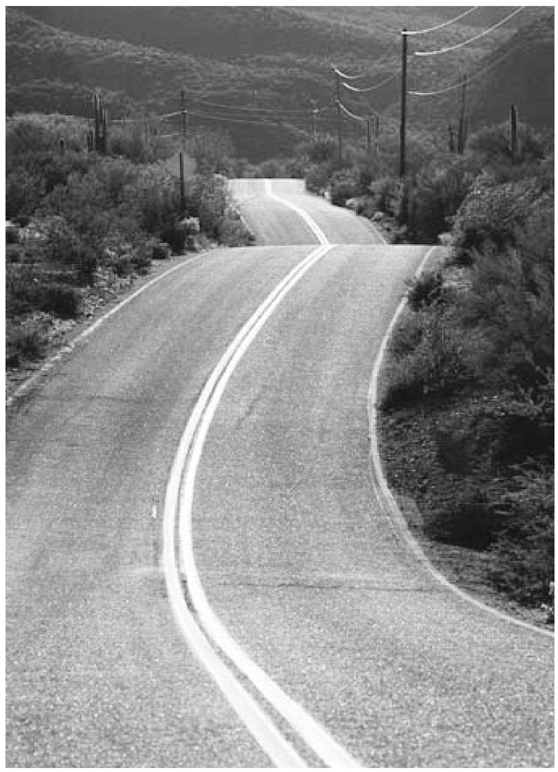
Gearing Up for Hydrogen



America's Road to Sustainable Transportation

James S. Cannon

March 1998

About the Author

James Cannon is an internationally recognized researcher, author, analyst, and speaker on energy development, environmental protection, and related public policy issues. Long associated with INFORM as a staff member and then senior consultant, he is the author of Spotlight on New York: A Decade of Progress in Alternative Transportation Fuels (1997), a summary and evaluation of New York State and New York City's progress toward sustainable transportation. His published works also include Harnessing Hydrogen: The Key to Sustainable Transportation (1995), a report illuminating the exciting potential of hydrogen as a clean, renewable fuel alternative for a non-polluting transportation system for the next century; Drive for Clean Air (1989), the highly influential study of natural gas and methanol as alternative vehicle fuels; and Paving the Way to Natural Gas Vehicles (1993), which identifies the actions necessary for the successful transition to natural gas. Mr. Cannon is currently continuing his research on the viability of non-polluting solar hydrogen-powered vehicles and the role natural gas can play as a clean-burning "bridge" fuel to solar hydrogen.

The author of two INFORM studies on acid rain, Controlling Acid Rain: A New View of Responsibility (1987) and Acid Rain and Energy: A Challenge for New Jersey (1984), Mr. Cannon also wrote two INFORM studies of coal conversion options in New York and New Jersey. In 1975 he was the coauthor of INFORM's A Clear View: Guide to Industrial Pollution Control and the 1976 report on alternative energy sources, Energy Futures: Industry and the New Technologies.

Mr. Cannon received an A.B. in chemistry from Princeton University and an M.S. in biochemistry from the University of Pennsylvania. Mr. Cannon is also President of Energy Futures Inc., an energy and environmental research organization in Boulder, CO, serving other nonprofit organizations, government agencies, and private industry clients since 1979.

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Gearing Up for Hydrogen:
America's Road to Sustainable Transportation

by James S. Cannon

In the wake of the accords hammered out at last year's summit on global climate change in Kyoto, there is great cause for alarm about where our present energy path is taking us. What is becoming ever clearer is that global climate change is inescapable without a significant decrease in the use of fossil fuels.

Much attention has focused on coal burning as a major source of carbon dioxide and on the need to reduce it, especially in coal-dependent China, if the world is ever to combat climate change successfully. The facts, however, suggest that the major problem lies much closer to home.

It is the United States, and not China, that generates the largest quantities of carbon emissions, by a score of 1.3 billion tons to 830 million tons per year, respectively. Thanks mainly to the 195 million motor vehicles now cruising America's roadways, oil burning in this country is largely responsible for a per capita carbon dioxide emission rate nearly nine times higher than China's. Oil burning in the United States accounts for 43 percent of the nation's carbon dioxide emissions, compared to just 35 percent from coal burning.

America will not succeed in effectively tackling such pressing problems as urban air quality, toxic pollution, energy security, and the national debt if it does not also address its dependence on oil as a vehicle fuel. Transforming our transportation system is key to solving many of these problems, while also providing a great opportunity to develop models of transportation for a world secure from the threat of global climate change.

Transforming Our Vehicle Population

Fortunately, a potential solution to some of the world's most urgent environmental and energy problems lies in transportation options already near at hand. A variety of alternatively fueled vehicles commercially available today are cleaner and safer than gasoline or diesel vehicles, while using more abundant and domestically produced energy sources. One plentiful alternative fuel, natural gas, emits nearly 20 percent less carbon dioxide and other greenhouse gases than petroleum. Even better options are in the wings, the most important of which are vehicles powered by pollution-free hydrogen. A gradual transition through a variety of alternative fuels to a renewable-based, zero-polluting motor vehicle powered by hydrogen offers an exciting path to a sustainable future for transportation.

When INFORM began exploring the potential of various alternative transportation fuels in 1986, there were no hydrogen fuel cell cars on the world's roadways. A prototype fuel cell racing car was unveiled in 1991, and since then a number of demonstration fuel cell cars and buses have been built. Daimler-Benz, the German manufacturer of Mercedes, has built three generations of its NECAR (New Electric Car) fuel cell vehicle. The company's top management has publicly declared its belief that fuel cells will be the successor technology to the internal combustion engine, which Daimler-Benz first developed for automotive use more than a century ago. Daimler-Benz has been so bold as to proclaim it will begin mass-producing fuel cell cars by the year 2004 and will be building 150,000 per year by 2006.

In 1996, Toyota produced its first fuel cell car, called the RAV-4, and Mazda publicly displayed its first fuel cell vehicle in conjunction with the Kyoto climate change meeting in December 1997. In the United States, Chrysler, Ford, and General Motors have been developing fuel cell vehicle designs for several years, although none is in operation so far.

In 1997, Daimler-Benz, Ford, and Ballard Power Systems of Canada announced joint ventures of over $450 million for hydrogen fuel cell research to develop and commercialize the world's next generation of virtually pollution-free cars and buses. Today's prototypes are costly, and they need refining. But they are indisputably becoming a "real world" option.

These new vehicles powered by hydrogen fuel cells offer a glimpse of a radically different personal transportation future—a future powered by renewable and pollution-free energy resources. Along with other fuels and automotive technologies such as electric cars powered by batteries, hydrogen vehicles offer an alternative to our nearly total reliance on oil as a transportation fuel. As such, they provide a solution to the environmental and energy supply problems that, eventually, are sure to undermine the viability of today's conventional cars.

The Major Challenge to Hydrogen Development: Political Commitment

The chief challenges to the advancement of hydrogen vehicles in the United States are the need to develop stronger political leadership, a heightened national commitment to fundamental change, and adequate investment of public and private sector financial support.

A look at the Kyoto Protocol offers a case in point. Under this climate change agreement, the United States is committed to reducing greenhouse gas emissions by 7 percent below actual 1990 levels by the years 2008 to 2012. Despite endorsement of this agreement by President Clinton, the nation's current policies appear sadly insufficient to get the job done. In fact, several recent studies, including one by the government's own Energy Information Administration, predict that current policies and trends will lead to an increase in greenhouse gas emissions of between 33 and 40 percent above actual 1990 emissions, a far cry from a 7 percent turn in the opposite direction.

The opportunities for innovation and economic growth in hydrogen energy are largely untapped, and many nations are working to establish an early position in this fledgling field. Germany and Japan are leading the way in hydrogen vehicle technology. There is also growing interest in multinational projects, most of which are proceeding without the participation of the United States.

A substantial financial commitment to hydrogen research over the course of a decade in this country would likely lead to the development of a variety of vehicles fueled by hydrogen that perform as well or better than the gasoline vehicles of today, with a small fraction of the environmental impact, includ-ing a 65 to 95 percent drop in greenhouse gas emissions. This investment in hydrogen would not require "new" federal dollars; a reallocation of funds within our current national energy program (with its emphasis on nuclear and fossil fuels) could finance the move to sustainable transportation.

However, no major commitment of financial support is on the horizon. President Clinton has proposed a $6 billion incentive program over a five-year period to help boost technologies that reduce carbon dioxide emissions. These incentives include a $3,000 tax credit, beginning in the year 2000, for the purchase of a vehicle that gets twice the average fuel economy of today's gasoline cars and, beginning in 2003, a $4,000 credit for one that gets three times the fuel economy for its class. Such transportation incentives, however, are only one of seven major incentives that constitute the Clinton package. Indeed, $6 billion over five years is an insignificant figure, amounting to only $1.2 billion per year, of which perhaps only $300 million would go to transportation. By way of comparison, American consumers pay $300 million for gasoline every 17 hours.

It remains to be seen what roles various nations will play in providing new automotive fuels and technologies. It is clear, however, that the stakes are huge for the United States: in the balance hangs the quality of the environment and the competitiveness of the US automotive and energy industries in the global transportation marketplace of the twenty-first century.

The Transition to New Sources of Renewable Energy

The world is in the middle of the second major energy transition in human history. The first transition occurred when fossil fuels—coal, oil, and natural gas—replaced renewable food and wood resources as the major sources of energy used in human activity. This shift to fossil fuels made possible a massive increase in energy use during the past 150 years, which has contributed to the high standard of living enjoyed by the industrialized world.

The second energy transition (now in progress) is marked by a transition to cleaner fossil fuels containing less carbon and more hydrogen, and by a shift to renewable resources that human beings previously were unable to harness.

Moving Toward Hydrogen: More Powerful, Cleaner Fuels

FUEL TYPE	Percentage Hydrogen	Energy Content (Btu per lb)	Particulates (lbs per million Btu)	Carbon Dioxide (lbs per million Btu)
Dry wood	5	6,900	5.22	775
Coal	50	10,000	5.00	240
Oil	67	19,000	0.18	162
Natural gas	80	22,500	<0.01	117
Hydrogen	100	61,000	0.00	0

INFORM calculations based on energy content and conversion data from US Energy and Information Administration, *Annual Energy Review 1993*; I. Ali and M. Basit, "Significance of Hydrogen Content in Fuel Combustion," *International Journal of Hydrogen Energy*, December 1993; and US EPA, *Compilation of Air Pollutant Emission Factors*, 1993.

Transportation: Severe Energy and Environmental Problems

The transportation sector is where the world's energy and environmental problems are particularly severe. Automotive exhaust emissions are the largest single source of air pollution in the world today, especially in urban areas. In the United States, about half of all air pollution regulated under federal law and 31 percent of the carbon dioxide emissions implicated in global warming come from the transportation sector. The vast majority of the 195 million cars, buses, and trucks in the United States (and of the 520 million on the road worldwide) burn gasoline or diesel fuel, both of which are refined from oil, the most limited and rapidly depleting fossil fuel.

Hydrogen: Virtually Limitless, Virtually Pollution-Free

Hydrogen accounts for more than 80 percent of all the matter in the universe. Most of this buoyant gas that occurs naturally escapes the earth's atmosphere into space; the rest is bound up in chemical compounds. Industry produces hydrogen for a variety of purposes, usually by obtaining it from fossil fuels, the source of more than 99 percent of the hydrogen produced worldwide. Virtually all of this hydrogen is used in the chemical industry as a feedstock; a small portion is used in hydrogen fuel cells that have helped power the US space program for decades.

The fossil fuel from which hydrogen can today be produced most cleanly and efficiently is natural gas. Splitting away four atoms of hydrogen from the single atom of carbon in a molecule of natural gas is much easier than refining gasoline down to its basics. Hydrogen can also be produced using renewable energy resources as part of a sustainable transportation system. For example, solar energy can be used to split the water molecule, releasing hydrogen. Thus produced, pure hydrogen can be burned in an internal combustion engine to power conventional automobiles. Or hydrogen, in a fuel cell, can power an electric vehicle. Either way, using hydrogen releases water vapor as its only by-product. This vapor can serve again as the source of additional hydrogen production, thereby completing a cycle that can be continued indefinitely.

Natural Gas: A Bridge to Hydrogen

The technology for producing and harnessing hydrogen is available today. But establishing a hydrogen-based transportation system would likely take a few decades. Natural gas, a fossil fuel that offers substantial advantages over oil-derived fuels, could facilitate the transition to hydrogen fuel. It also has a role to play in fueling electric hybrid engines, an advanced transportation option attracting increasing attention because of its near-term potential to improve overall vehicle performance.

As documented in INFORM's publications *Drive for Clean Air* and *Paving the Way to Natural Gas Vehicles*, natural gas offers greater energy security compared with gasoline and several other transportation fuels because there are abundant natural gas reserves in the United States, Canada, and Mexico. In terms of environmental performance, natural gas vehicles dramatically reduce air pollution: up to 95 percent less carbon monoxide and toxic air pollution, 80 percent fewer hydrocarbon emissions, and 30 percent fewer nitrogen oxides than gasoline. Natural gas vehicles also emit significantly less carbon dioxide than oil-burning vehicles.

Natural gas already powers about 750,000 vehicles worldwide (70,000 in the United States). As automotive fuels, natural gas and hydrogen are linked in several ways:

- Natural gas and hydrogen can both be burned in internal combustion engines.

- Hydrogen can be added to natural gas to make it burn more cleanly.

- Both fuels have similar automotive storage and refueling system technologies.

- Most manufactured hydrogen is currently extracted from natural gas.

- Gas blends containing up to 20 percent hydrogen could be distributed through existing natural gas pipelines, and the construction of new pipelines to carry hydrogen could benefit from existing "rights of way" for natural gas distribution.

Because of this overlap, investing in refining and expanding the infrastructure for natural gas vehicles could also lay the groundwork for the use of hydrogen.

The Essential Move to a Sustainable Transportation System

The first "revolution" in personal transportation occurred at the turn of the last century, with the development of the automobile. Today's electric vehicles, including those powered by fuel cells, represent a second transportation revolution. Alternative fuels—those not derived from oil—have already made inroads in the transportation energy market. In the twenty-first century, these could become the norm for the world's passenger vehicles. There are five interconnected reasons for making this shift:

1. Environment: Pollution from vehicles is creating an atmosphere that is increasingly damaging to the environment, from the ground to the stratosphere.

2. Health: More than 50,000 people may die prematurely each year from exposure to the fine particulates emitted primarily by trucks, buses, power plants, and factories.

3. Economics: The costs of producing oil continue to increase, as deeper wells are drilled farther

and farther from markets and in harsh climates. Similarly, regulatory costs related to oil use are increasing, such as those associated with measures to prevent supertanker oil spills.

4. Energy security: The military and political costs of maintaining energy security in international markets are becoming untenable. Oil dependence was a motivating force in the Persian Gulf war, which involved 400,000 American soldiers and expenditures of more than $50 billion.

5. Supply: World oil supplies are finite.

Hydrogen: A Carrier for Renewable Energy Resources

While this country continues to pursue the short-term gains in air quality made possible by reformulated gasoline, it must not abandon its aggressive search for renewable energy resources. But if these renewable resources are to power vehicles, they must first be transformed into a clean, movable form—an "energy carrier." Hydrogen produced from water, using energy from solar resources, may be the optimum energy carrier.

Tapping the sunshine falling on just 5 percent of the world's desert regions would supply enough energy to meet the world's total energy demand. Five forms of solar energy could be used for hydrogen production:

1. Solar thermal power: Using the heat from direct sunlight

2. Photovoltaic cells: Converting sunlight to electricity via photosensitive chemicals

3. Wind power: Tapping wind energy to turn electricity-generating windmills

4. Hydropower: Tapping the energy of falling water, the most widely used renewable energy resource today

5. Biomass: Extracting hydrogen from plant material or burning plant matter to release energy

Three Pathways for Hydrogen Use in Vehicles

Hydrogen has been demonstrated as a viable automotive fuel in three technological modes: internal combustion engines connected mechanically to conventional vehicles; fuel cells that produce electricity to power electric vehicles; and hybrids that involve combinations of engines or fuel cells with electrical storage systems, such as batteries.

Both natural gas and hydrogen are versatile. Natural gas can be burned directly in the engine of today's cars; it is also a major fuel for electrical generation and is currently the source of most hydrogen production. Hydrogen is capable of powering both internal combustion engines and electric motors; it can generate electricity and can be produced directly from renewable resources. (Note: Candidates for use in transportation energy systems also include other nuclear fuels for fission and fusion reactors and other fuels and energy carriers, such as propane, methanol, and ethanol. However, cost, environmental, or supply factors make all of these less viable short-term options.)

Using Hydrogen in Internal Combustion Engines

- Conventional combustion engines require modification, not major redesigning, to burn hydrogen. The proven, commercially available technology to use natural gas in combustion engines is similar to the technology needed to use hydrogen.

- Burning hydrogen releases less pollution than burning any fossil fuel. Hydrogen combustion releases no carbon monoxide, hydrocarbons, particulate pollution, or carbon dioxide. The most significant environmental challenge associated with hydrogen combustion is the emission of nitrogen oxides, formed when heat from combustion causes nitrogen and oxygen in the air to fuse. These emissions are very low, however—less than 10 percent of those from a gasoline engine operating with pollution control equipment, and they could be further reduced with such equipment installed.

- Demonstration projects have shown that a natural gas blend containing 5 percent hydrogen reduces air pollution from natural gas vehicles by 50 percent and provides a practical way to introduce hydrogen as an automotive fuel.

Using Hydrogen in Fuel Cells

- Hydrogen and oxygen merge in a fuel cell, forming water and releasing energy as electricity. Because there is no combustion to generate the high temperatures that lead to the formation of nitrogen oxides, fuel cell-powered electric vehicles offer the cleanest way of using hydrogen: they are zero-emission vehicles.

- Fuel cells are two to three times as energy efficient as combustion engines. An internal combustion engine loses more than 80 percent of the energy it generates, mainly as waste heat. When a hydrogen fuel cell is used, the energy loss is 40 to 60 percent, so the energy percentage delivered as movement is much greater.

- Various technological hurdles must be overcome before fuel cells can compete effectively, in terms of overall performance and cost, with internal combustion engines in automotive applications. Fuel cell demonstration projects now under way around the world will likely yield improved solutions to these technical challenges.

Hydrogen Electric Hybrids

By combining onboard engines or fuel cells that generate power with electrical systems that store power, electric hybrids may offer greater market potential than vehicles powered solely by single systems. In the United States, a hybrid electric bus powered by hydrogen has been running in Georgia since the 1996 Summer Olympics. Demonstrations of hybrid technology indicate that these vehicles may be lighter, smaller, more versatile, and offer better performance than vehicles running solely on hydrogen engines, fuel cells, or batteries.

A Comparison of Fuel Cells and Batteries

Fuel cells and batteries offer alternative ways of delivering electricity to an electric vehicle. Batteries store electricity, previously generated by an outside source, in the form of chemical energy. Fuel cells actually generate electricity on board the vehicle.

The electric motor, controller, and many of the other components of electric battery-powered vehicles are identical to the systems used in hydrogen fuel cell vehicles. However, hydrogen offers certain advantages over batteries. For example, refueling with hydrogen is quicker than recharging batteries, and most hydrogen storage systems are much lighter and smaller than batteries.

Hydrogen Vehicles Over the Years

Until recently, nearly all of the hydrogen-powered vehicles in use have run on modified internal combustion engines. The earliest testing of hydrogen in internal combustion engines dates back to the late nineteenth century. In Germany before World War II, more than a thousand vehicles were modified to run on hydrogen.

In the aftermath of the 1973 oil embargo, dozens of prototype internal combustion vehicles were built in the United States, Europe, and Japan to run on hydrogen. These hydrogen programs continue, with many automakers testing hydrogen vehicles. Fuel cell and electric hybrid vehicles are a much more recent phenomenon: the first modern-day fuel cell demonstration vehicle took to the road in 1991.

Options for Producing, Distributing, and Storing Hydrogen

Aside from the propulsion system itself, there are other factors affecting the commercialization of hydrogen vehicles, the most important being fuel production, distribution to refueling stations, and storage on board the vehicle.

Producing Hydrogen

Most hydrogen produced today is made from natural gas in a process known as steam reforming. Because this is the cheapest and most firmly established method of producing hydrogen, it is likely to predominate until production technologies based on renewable energy resources become commercially wide-spread. All of the methods of producing hydrogen from renewable resources face technical and economic hurdles that must be overcome if hydrogen is to fuel a sustainable transportation economy.

Nonetheless, within a decade, applied research could allow each of the following methods to play a vital role in producing commercial quantities of hydrogen. The first two methods listed below use technology that is already highly developed, while the last three are still in the early stages of development.

- Using electricity from renewable resources, such as hydropower, to split the water molecule through electrolysis
- Converting organic matter into hydrogen through the gasification processes of partial oxidation, pyrolysis, and steam reforming
- Using sunlight to heat catalysts that trigger the splitting of water into hydrogen and oxygen
- Collecting hydrogen generated as a waste product by some strains of algae and bacteria
- Heating water to more than 5,600 degrees Fahrenheit to break the molecular bonds and make it decompose into its component parts

Distributing Hydrogen

Once produced, hydrogen must be transported to markets. Today's hydrogen distribution system is extremely limited: there are only 450 miles of hydrogen pipeline in the United States, compared with 200,000 miles of oil pipeline and 1.3 million miles of natural gas pipeline.

Nonetheless, hydrogen pipeline distribution is a firmly established technology. The key obstacle to making the fuel widely available is the scale of expansion needed to serve transportation markets.

Another option is to liquefy hydrogen for distribution via barges, tankers, and rail cars. This is how liquefied hydrogen is delivered to its main customer, the space program.

Storing Hydrogen

Storing hydrogen on board a vehicle raises three critical issues: the weight of the fuel storage system, the system's volume, and the speed or ease of refueling the vehicle. These limitations can be minimized if hydrogen is used in fuel cells, whose inherently high efficiency reduces the amount of fuel a vehicle must carry. In contrast, the greater amount of fuel needed to power a hydrogen internal combustion engine vehicle makes these vehicles somewhat less practical.

The Natural Gas–Hydrogen Continuum

The technology and infrastructure to produce, store, and distribute natural gas overlap significantly with those needed for hydrogen. For this reason, the current and expanded use of natural gas as a vehicle fuel should ease the entry of hydrogen into the US energy market.

In theory, natural gas could be transported via pipeline in a blend containing up to 20 percent hydrogen, offering a cleaner fuel without the need to modify natural gas pipelines. Modifying the same pipelines to carry pure hydrogen, however, would require a number of potential problems to be addressed, such as embrittlement of some steels used in the pipelines and fittings tight enough to prevent natural gas but not hydrogen from escaping. Nonetheless, the experience gained by transporters of liquefied natural gas would be an asset as the market for shipping liquefied hydrogen grows.

There are many connections between the systems that use natural gas and those that use hydrogen in vehicles. For example:

- The weight and volume of the hydrogen fuel storage systems needed in fuel cell-powered vehicles are comparable to the weight and volume of the systems used successfully in natural gas vehicles.

- The materials and systems used to refuel natural gas vehicles are analogous to those used to refuel hydrogen-powered vehicles. For hydrogen–natural gas mixtures, they are the same as for natural gas.

- “Fast-fill” compressed-gas refueling technology can be adapted from natural gas systems and used to fill hydrogen fuel cell vehicles, offering a refueling time of about 5 minutes, which is comparable to gasoline refueling today.

- Natural gas and hydrogen both offer greater energy density in liquefied form than in gaseous form, reducing the space requirements for fuel storage by half when compared with compressed gas.

Hydrogen Development in the United States

Interest in hydrogen as a fuel has grown dramatically in the United States since 1990. The federal research and development program for hydrogen technologies, although still minuscule (at approximately $15 million per year) compared with other energy development efforts, has increased nearly 15 times since the beginning of the decade. At the same time, promising state, local, and private entrepreneurial hydrogen development efforts are under way.

Federal Hydrogen Programs: Limited Budgets, Fragmented Leadership

Despite the increase in hydrogen-related activities in the United States, the total effort by the federal government is still too small to spur sufficient private sector involvement in hydrogen technology or to catalyze a move toward a sustainable transportation system based on hydrogen. Annual federal spending on petroleum research is still about 60 times greater than the national hydrogen budget. Hydrogen spending also pales in comparison with government investments in other innovative transportation technologies.

The multidimensional nature of transportation energy issues requires strong leadership to ensure that all federal programs are moving in concert toward a common goal. The space program enjoyed such leadership, coordination, and national commitment. To date, these are lacking with regard to sustainable transportation in general and hydrogen vehicle development in particular.

A redirection of funding priorities could stimulate a competitive environment for the commercial development of the new hydrogen-based transportation technologies. At the same time, a greater focus on hydrogen vehicles could improve the United States’ position in the fast-changing international automotive and energy markets.

While the US vehicle market is nearly saturated, with one vehicle per 1.3 people, fast-growing China has one vehicle per 115 people. Since 1986, the number of motor vehicles in China has jumped 700 percent, compared to 13 percent in the United States. Because the Chinese and other developing countries have little or no existing economic investment in the conventional automotive infrastructure and must build from the ground up, they have an incentive to look to cleaner alternative fuels and engine technologies. Thus, they can avoid the problems associated with oil use. Alternatively, they can choose to follow the oil-based model of the industrialized world, with predictable consequences: the increased threat of global climate change and urban air pollution, as well as increased tension and conflict over shrinking oil supplies.

Hydrogen Development Worldwide: Will the United States Compete?

Except for space travel applications, world leadership in hydrogen research has never been centered in the United States. Today, Japan and Germany are better poised than the United States to capitalize on the nascent market opportunities for hydrogen-powered vehicles. Both Germany and Japan have made a national commitment to developing hydrogen as an alternative to oil dependence. Major automakers in both countries are playing a significant role in hydrogen development.

There are many hydrogen development efforts under way in other countries, including Belgium, Canada, Ireland, Italy, Norway, and Saudi Arabia. Canada makes and consumes more hydrogen per capita than any other nation, and its program is oriented toward serving world energy markets with hydrogen produced from its vast natural gas and hydropower resource base. The City of Vancouver is about to put three hydrogen fuel cell buses into operation. Canada, Norway, and Saudi Arabia are each participating in multinational projects that aim to link hydrogen energy-producing regions with countries that have high levels of energy consumption.

Around the globe, interest in hydrogen fuel is growing rapidly, and so is competition to develop the technologies needed to make its widespread use a reality. The actions that US policymakers and business leaders take now will determine what role the United States will play in the hydrogen energy systems of the future.

Six Steps to Building Market Opportunities for Clean Hydrogen Fuel

The movement in the United States toward hydrogen vehicles faces huge obstacles to success, not the least of which is the intense opposition from the automotive and oil industries. Yet our transportation sector is where society's environmental, energy, and economic problems are most severe, where the rationale for changing the status quo is most compelling, and where opportunities to develop consumer support are greatest. The question facing our national leaders is not whether the United States can afford to lead in the transportation revolution, but *whether it can afford not to*. Building a broader market for hydrogen-fueled vehicles will require the following: *

1. **Building widespread public understanding of the tremendous adverse environmental, health, energy, and economic consequences of remaining dependent on oil and combustion engine automobiles, and of the exciting potential of the alternatives**

   Public education that exposes the problems of our continued reliance on oil and conventional vehicles, and the near-term feasibility of hydrogen, is critical to accelerating arrival of the sustainable transportation era.

2. **Developing market pull from consumers through public and private demonstrations of alternative trans-portation fuels and**

zero-emission vehicles that can help expand the demand for these vehicles by innovators, early adopters, and green consumers

Highly visible demonstrations, such as urban bus projects, are important to illustrate the advantages and viability of sustainable transportation.

3. **Significantly expanding government efforts to promote the use of alternative transportation fuels**

Sustainable transportation advocates need to have a more forceful presence in government programs to address oil dependence and automotive air pollution.

4. **Funding broader government and private sector research, development, and demonstration of sustainable transportation systems using renewable resources to produce hydrogen that powers fuel cell vehicles**

The budget of the National Hydrogen Program is an inadequate two-tenths of one percent of the Department of Energy's budget. Much more research is needed on direct hydrogen production from renewable resources, on techniques to increase the power density of fuel cells, and on fuel cell storage approaches with lower weight and volume requirements.

5. **Promoting more rapid commercial adoption of two key technologies that will enable us to make the transition to hydrogen fuel cells**

Use of two transitional technologies is critical to triggering changes and establishing some of the necessary components of sustainable transportation systems. Increased fuel demand from natural gas vehicles will promote expansion of the fueling infrastructure needed to deliver a gaseous rather than a liquid fuel. Increased use of electric vehicles powered today by batteries will promote improved electric propulsion systems that can, in the years ahead, be powered by fuel cells.

6. **Integrating sustainable transportation fuels and propulsion technologies among other strategies in the improved and expanded mass transit systems that the United States will need**

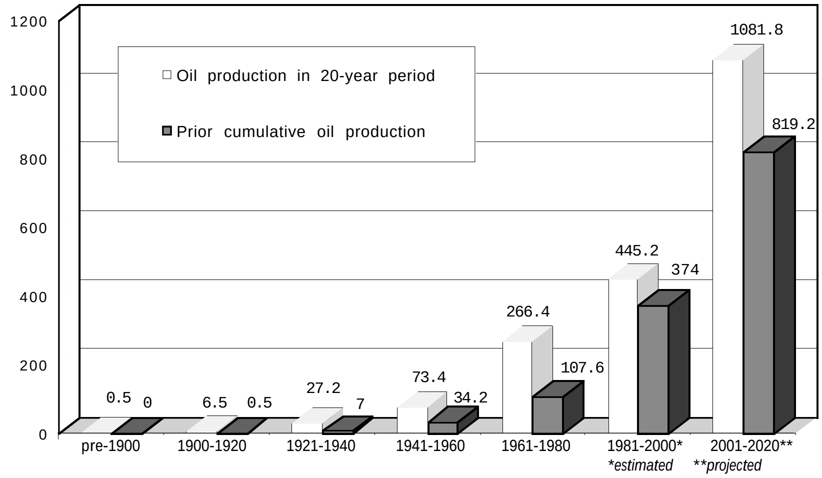
Transportation is a multidimensional problem that defies single-action solutions. Zero-pollution vehicles will not solve our transportation problems without a reduction in vehicle miles traveled and without innovative land use planning that reduces our dependence on the automobile. Efforts that bring the entire transportation reform community together are critical to developing a sustainable transportation system in the twenty-first century.

* The "six steps" were first published in "Clean Hydrogen Transportation: A Market Opportunity for Renewable Energy," by James S. Cannon, an April 1997 Issue Brief from the University of Maryland at College Park's Renewable Energy Policy Project (REPP). Readers can obtain this publication free of charge from REPP at (202) 293-2833.

Appendix

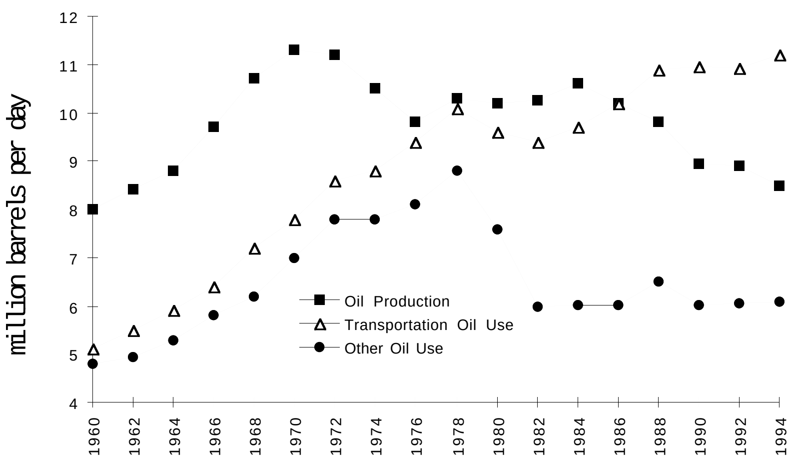
History of World Oil Use

During every 20-year period this century, the world has consumed more oil than had been consumed in all previous history. By the year 2000, total world oil use since its discovery in 1859 will exceed 800 billion barrels. Oil use during just the 20 years from 2001 to 2020 is likely to reach more than 1 trillion barrels, exceeding all the oil consumed during the 20th century and surpassing all oil reserves known to exist in the world today.



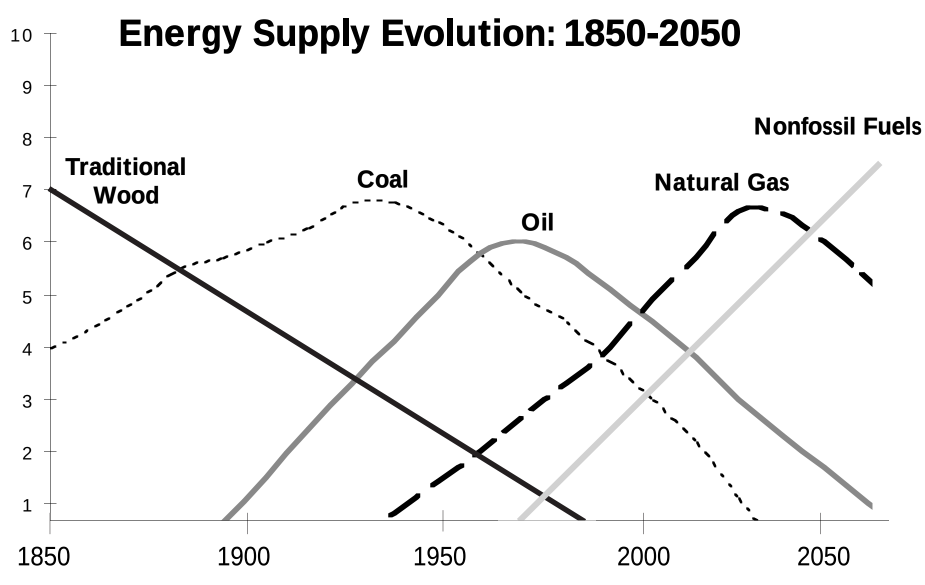
Source: INFORM calculations based on data from D. Yergin, *The Prize*; and United States Energy Information Administration, *International Energy Annual 1992*.

US Oil Production and Use in Transportation



Until alternative fuels come into widespread use for transportation, as they have in other energy sectors, the United States will have no choice but to continue relying on imported oil to meet its transportation energy demand. Other sectors have met the challenge of reducing reliance on oil: oil use in non-transportation applications including residential, commercial, and industrial uses and electrical generation dropped precipitously in the late 1970s and has remained level since then, due mainly to increased energy efficiency and use of alternative fuels. Although oil use in transportation dropped slightly, its upward climb was renewed in the early 1980s.

Progression in the use of energy resources shows that the world has been moving toward fuels that provide more power per unit of weight and that release less pollution when burned. By the early part of this century, coal had displaced wood-burning as the world's primary source of power; today, coal use has declined to 23 percent and oil accounts for the largest portion, 36 percent, of world energy use. Use of cleaner burning natural gas is on the rise, having sprung from nothing to a fifth of world energy use in this century.



Source: Adapted from the work of Caesar Marchetti, Austrian International Institute of Applied Systems Analysis, late 1970s

Publications and Membership

Publications

The following publication will be of interest to those seeking a more detailed examination of the ideas discussed in this article:

Harnessing Hydrogen: The Key to Sustainable Transportation, James S. Cannon (1995, 360 pp., $30).

Related publications from INFORM include:

Spotlight on New York: A Decade of Progress in Alternative Transportation Fuels, James S. Cannon (1995, 28 pp., $20).

Reformulated Gasoline: Cleaner Air on the Road to Nowhere. James S. Cannon (1994, 14pp., $5).

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