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About the Cover:

Family vehicles in the U.S. consume enough fuel each year to cover a regulation-size football field to a depth of about 40 miles. FETC partners with industry and other organizations to develop and deploy ultra-clean, high-performance fuels, ensuring that we can continue to depend on our transportation-based economy to bolster our transportation-based lifestyle.

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Drink Your Car Exhaust?

At the National Hydrogen Association's 10th Annual U.S. Hydrogen Meeting and Exhibition held recently in Vienna, Virginia, high school students from Merit Academy in Santa Cruz County, California, made ice cream from an ice cream maker powered by a hydrogen fuel cell.

The students received DOE funds to build the hydrogen fuel cell as a class project. They took it to the conference, and became a big hit by passing out their product. Conference attendees enjoyed the ice cream and could also view—and drive—two hydrogen-powered cars.

Making ice cream with a hydrogen-driven device may seem trivial, but vehicle propulsion from hydrogen is not. It has global implications. Among the supporters for such an idea is DOE—and a number of government and private industry researchers. One of DOE's missions is to ensure that future generations have a clean environment. DOE's hydrogen strategic plan states: *Strategies involving the nation's energy supply are based on the need for energy and environmental security, and the ability to compete in the world market. . . Environmentally, the nation is being forced to react both to the need for cleaner urban air and to the potential effects of global climate change. . . The solution is a clean, sustainable, domestic energy supply. Hydrogen can be one of the answers.*

DOE and FETC have recognized that advanced energy concepts and a clean environment go hand-in-hand. As such, they have made a commitment to explore hydrogen's potential as a fuel for the future.

Why Hydrogen?

Hydrogen is being touted as the fuel of the future because it is a clean, environmentally friendly fuel. When hydrogen is used in a fuel cell, the cell emits no pollutants: only electricity, heat, and pure water are produced.

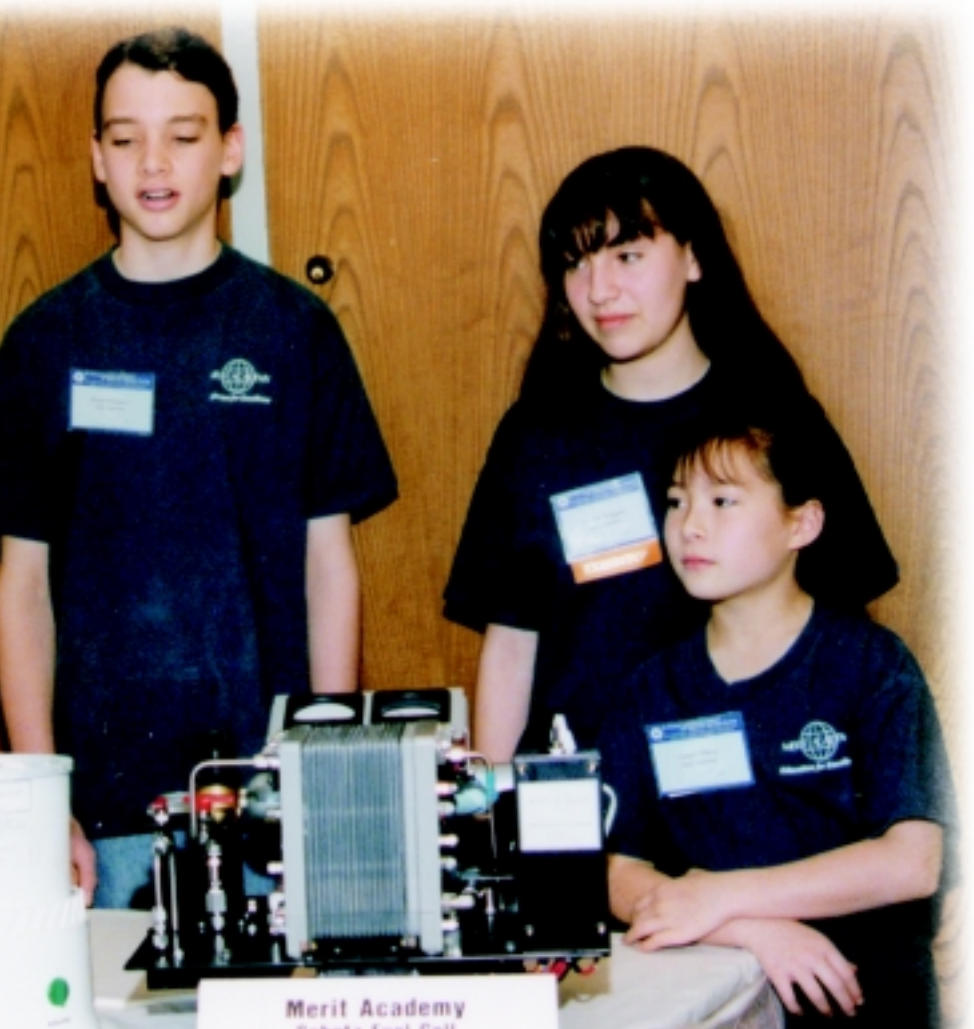
In a story reported in the *Los Angeles Times,* a DaimlerChrysler engineer showed off one of the company's hydrogen-driven cars, then took the passenger to the rear of the car where the engineer held a paper cup up to the exhaust, collected the liquid, and offered it to drink. The liquid was pure water.

Hydrogen is plentiful, making up about three-fourths of all the matter in the universe. One way of making hydrogen is from water. What could be easier: separate water into two gases—hydrogen and oxygen—burn the hydrogen as a fuel, and it rejoins oxygen to re-form water. Water is the most plentiful source of hydrogen, but a lot of energy at great cost is required to pry the hydrogen free. Renewable energy sources, such as solar, could supply this energy, making hydrogen production pollution-free.

Nearly all of the hydrogen currently produced comes from fossil fuels. And that, in part, is the problem. Although hydrogen as a fuel itself does not create pollutants, the extraction of hydrogen from fossil fuels does. Fossil fuels—whether for transportation, electric generation, or other uses—emit carbon dioxide (CO_2), a major factor associated with global climate change. Given the growing concern over global climate change that results from the emission of CO_2 and other greenhouse gases, DOE is spearheading efforts to reduce the amount of CO_2 emitted to the atmosphere. Hydrogen production from fossil fuels can be coupled with sequestration—another way of making hydrogen production pollution-free.

A number of obstacles stand in the way to increased use of hydrogen fuels. As a transportation fuel, hydrogen requires large storage containers aboard vehicles. In addition, hydrogen is costly to compress and ship from the source of production. In the DaimlerChrysler vehicle mentioned earlier, storage and compression are still big problems. Even though it can be a more efficient fuel than gasoline, hydrogen's low density—even when compressed—requires a storage tank about four times as big as a standard gas tank. In larger vehicles—such as hydrogen-driven buses like those in operation in Augusta, Georgia, and Vancouver, British Columbia, Canada—engineers can use space in the roof or passenger compartment for the tank.

A formidable obstacle to the public acceptance of hydrogen is what scientists call the "Hindenburg Syndrome," a reference to the hydrogen-filled airship that burned in New Jersey in 1937, killing 37 people. (See the note on the Hindenburg disaster on page 34.) Such incidents have left a negative impression among many potential consumers, prompting concerted efforts by hydrogen producers to demonstrate the safety of the gas. In hydrogen's defense, the founder of the National Renewable Energy Lab's



hydrogen program, Bill Hoagland, told the *Los Angeles Times* that fossil fuels, such as gasoline, also explode, but studies show that hydrogen is safer because it is nontoxic and dissipates rapidly because of its lightness.

Industry, DOE, and other government agencies are taking steps to promote the safety of hydrogen. Also, national and international codes and standards continue to be developed to maintain safety during production, distribution, and use. Safety measures include the development of safe storage systems and hydrogen leak-detection systems.

National Hydrogen Program

DOE established a national hydrogen program to address these issues and to explore the potential of hydrogen as the fuel of the future. The program's mission is to research the production, storage, and use of hydrogen as a cost-effective energy source for utility, building, and transportation applications. DOE has developed a strategy that includes a 20-year mission statement: *In the next 20 years, concerns about global climate change and energy security will create the platform for the penetration of hydrogen into several niche markets. Ultimately, hydrogen and electricity will come from sustainable renewable energy resources, but fossil fuels will be a significant transitional resource during this period. The growth of fuel cell technology will provide a base for the establishment of the hydrogen option into both the transportation and electricity supply markets.*

FETC is implementing the hydrogen program effort for the DOE offices of Fossil Energy, and Energy Efficiency and Renewable Energy (EE).

As part of the collaborative effort, FETC signed a Memorandum of Agreement (MOA) with EE and other DOE offices to conduct hydrogen research. FETC's hydrogen Program Manager Harold Chambers notes, "FETC will focus on the production of the gas by conducting research and development on fossil fuels and the related infrastructure."

FETC will conduct hydrogen research in three separate agreement areas: evaluation of hydrogen production from western coal, advanced fuels, and development of a ceramic membrane to produce hydrogen. Since fossil fuels will serve as the source of hydrogen until further work is done to generate hydrogen from renewable sources, FETC's effort on the MOA is important. As Chambers explains, "This work associated with the MOA is needed to serve as a transition bridge from today's fossil-fuels energy economy to a hydrogen economy based fundamentally on renewable resources."

FETC scientists are working on a process called membrane separation to help move hydrogen into the marketplace. Although the demand for hydrogen is expected to rise over the years, low-cost abundant sources, such as coal gasification and off-gas streams, pose a problem because the

hydrogen is usually mixed with other gases. To solve the problem, FETC scientists are developing membranes as an economical and efficient way to "filter" the gases and recover hydrogen.

Hydrogen can be used to generate electricity and in highway vehicles. And the potential exists for its use in airplanes, boats, and locomotives. For anyone keyed into NASA's space shuttle program, the awe-inspiring power comes from the liquid hydrogen used as the propulsion fuel in the main rocket launcher. Internationally, Europe and Japan are considering the use of hydrogen-fueled aircraft. As U.S. researchers lower the production cost of hydrogen, it also becomes more attractive to overseas markets.

Hydrogen: A Transportation and Utility Fuel

DOE's Hydrogen Program addresses long-term markets in both the utility and transportation sectors where high-efficiency energy systems, such as fuel cells, will be developed. Fuel cells will be the major focus. The expected increase in fuel cell use serves as a major driving force in the development of hydrogen technology. The automotive industry alone is investing about $1 billion to develop a fuel cell for an electric vehicle. As an example, DaimlerChrysler and Ford have already invested over $750 million to cut fuel cell powerplant costs, an investment aimed at having fuel-cell-driven vehicles on the highway by 2004. General Motors has committed itself to the same time frame.

In the utility industry, GPU International, Inc. formed a joint venture with Ballard Power to produce 250-kilowatt (kW) size fuel cells by the year 2002. Detroit Edison and Mechanical Technology, Inc. formed PLUG Power to produce 3 to 5kW residential fuel cells by the same year.

Although FETC is not directly involved in DOE's initiative to develop a vehicle fuel cell, we have taken an active role in developing industrial fuel cell technology, supporting the development of three types of fuel cells for power generation. The first type, phosphoric acid fuel cells, has been installed in at least 70 sites around the country. A molten carbonate fuel cell, which has been tested at full-scale demonstration plants, offers high fuel-to-electricity efficiency. The third fuel cell, solid oxide, has been tested as part of 11 systems in the U.S. and Japan, displaying up to 70 percent efficiency in a combined-cycle power system.

Most market-entry fuel cell plants use natural gas as their source of hydrogen, but fuel cells are fuel-flexible. Other useable fuels include coal gas, methanol, landfill gas, or any others containing hydrocarbons.

Fuel Cells in Vehicle and Power Operation

Since many cities in the U.S. have been classified as air quality non-attainment areas largely because of vehicle emissions, the push is on to develop alternatively fueled vehicles that produce little or no emissions. California, for example, has mandated that 10 percent of all new vehicles be zero-emission vehicles by the year 2003.

One of the success stories associated with environmentally benign, fuel-cell-driven hydrogen vehicles is in Augusta, Georgia. There, a 33-foot, 230-horsepower hydrogen bus operates on a daily passenger route. DOE sponsored the development of the vehicle at its nearby Savannah River facility in South Carolina.

One of the primary uses for fuel cells will be in powerplants. Natural gas or cleaned coal gas is converted to a hydrogen-rich gas by a fuel reformer. The hydrogen-rich fuel gas and air then flow over an anode and a cathode that are separated by an electrolyte. This produces a continuous supply of electricity and, in the process, does not emit sulfur, nitrogen compounds, or solid waste.

DOE's support of hydrogen as a fuel of the future is consistent with our Nation's strategic goals for energy security, environmental security, and competition in the international marketplace. In addition, worldwide concerns about global climate change and impending federal and state air quality regulations serve as driving forces to find clean, alternative fuels and power systems.

Hydrogen, compared with natural gas, has the dual advantage of reducing both particulate and greenhouse gas emissions. Recognizing that advantage, industry and government have moved forward to develop hydrogen production systems and fuel cells. DOE projects that hydrogen use will increase rapidly in both the transportation and electric generation sectors as technologies are developed to reduce the costs of distribution, production, and storage.

Perhaps one day in the not too distant future we will collect our car exhaust as our traveling water supply. Now that's a clean fuel!

Hydrogen Exonerated in Hindenburg Disaster reads the headline of the Spring 1997 issue of the *Hydrogen Newsletter*, a publication of the National Hydrogen Association. Research by a retired NASA engineer confirmed that the fabric skin of the zeppelin, not the hydrogen filling, was to blame for the Hindenburg explosion. Yes, hydrogen fueled the fire. But the cause was the extreme flammabiliy of the fabric covering, coupled with the highly charged atmosphere from continuing electrical storms, and the unorthodox "high-landing" used (landing lines were dropped from the airship, in effect making a conduit for a ground-to-cloud electrical path).

The foundation for DOE's Hydrogen Program was laid in 1990 when Congress passed the Matsunaga Hydrogen Research, Development, and Demonstration Act. The act mandated that DOE develop those technologies necessary to implement the use of hydrogen energy. The Hydrogen Future Act of 1996 authorized DOE to spend over $164 million between 1996 and 2001 to research, develop, and demonstrate hydrogen production, storage, transport, and use.

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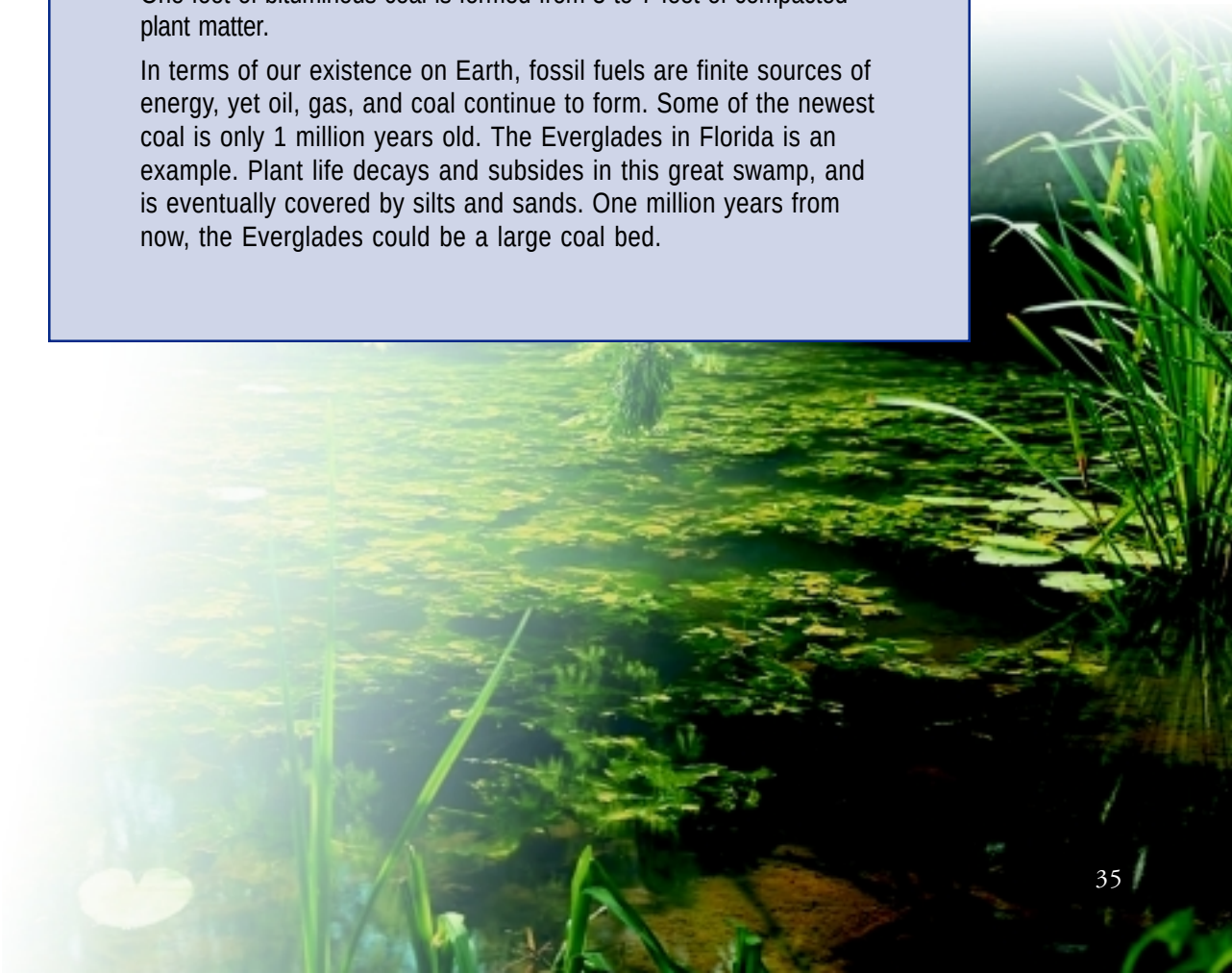
How Fossil Fuels Are Formed

Earth's fossil fuels were created millions of years ago. Natural gas and oil formed from plant and animal remains that accumulated at the bottom of ancient lakes and oceans, and then were buried by sediment (sand, mud) before they decayed. Layers of compacted sediments with organic material in them continued to accumulate. Over time, the weight of these layers created pressure and heat, which changed the sediment to layers of rock and the organic material into gas and oil trapped in the rock layers.

Natural gas is found in reservoirs with oil, in reservoirs by itself, or associated with coal. Methane gas is a by-product of the coal-forming process and is often a problem in coal mining. At greater depths (and therefore greater pressures and higher temperatures), oil is transformed to gas, so the deepest reservoirs are only natural gas.

Most of our coal was formed about 300 million years ago, when Earth was covered by steamy swamps. As the plant matter died, it sank to the bottom of the swampy areas, eventually forming a dense, soggy material called peat. Over time, the swampy areas drained. Coal was formed when the peat was squeezed by accumulating layers of compacted sediments, which subjected the peat to increasingly deeper burial and increasingly higher pressures and temperatures.

The greater the heat and pressure, the higher the rank of the coal formed. Anthracite is the hardest, highest ranking, and cleanest burning coal, followed by bituminous and then subbituminous coal. One foot of bituminous coal is formed from 3 to 7 feet of compacted plant matter.

In terms of our existence on Earth, fossil fuels are finite sources of energy, yet oil, gas, and coal continue to form. Some of the newest coal is only 1 million years old. The Everglades in Florida is an example. Plant life decays and subsides in this great swamp, and is eventually covered by silts and sands. One million years from now, the Everglades could be a large coal bed.