Hydrogen and Fuel Cells:
A Comprehensive Guide

Rebecca L. Busby

PennWell®

Contents

List of Figures

List of Tables

What's all the Excitement About?

Imagine an unlimited supply of pollution-free power. That's the ultimate reason for excitement about hydrogen. Right now, it's only a theoretical promise. How we might actually get there is the subject of this book.

Hydrogen's main attraction to energy engineers is that it can be produced from water or from any hydrocarbon fuel, or even from energy sources of the future that we can't envision yet. Like electricity, hydrogen carries energy that is produced from other sources and delivers it in the form of power and heat. Compared to electricity, however, hydrogen is easier to store—a vital distinction.

The feature of hydrogen that excites environmental scientists is that it creates no harmful emissions when used in an electrochemical fuel cell to generate power. The only by-product is water. In the future, all of our energy needs could be met by hydrogen that is produced from renewable sources like wind power and solar energy.

The transition toward a hydrogen economy is already under way. Over the past century or so, we've switched from wood fuel to coal, then to oil, and now to natural gas, which is gradually taking oil's place as our most popular fossil fuel. This shift reflects a slow reduction in the amount of carbon contained in the fuel and an increase in its hydrogen content. The ultimate next step is to eliminate carbon altogether and use pure hydrogen.

Hydrogen fuel cells are already being tested in vehicles and used commercially in micropower plants, which generate electricity where it's needed instead of transmitting it over long distances. In a future hydrogen economy, fuel cells would power most of our vehicles, and micropower plants would proliferate, complementing our supply of electricity from the utility grid by providing extra power during periods of peak demand.

1. Concept and Vision

Hydrogen is not a source of energy like oil or natural gas—instead, production of hydrogen consumes energy. That's because hydrogen atoms are almost always bonded with other elements into compounds like water or hydrocarbon fuels, which require energy to break apart.

However, because hydrogen is found in so many different fuels and compounds, it can be produced from any energy source—and it can be obtained from one of our planet's most common substances, water.

The concept of a hydrogen economy envisions a future where all of our energy needs will be met by hydrogen that is produced from renewable sources like wind power and solar energy. Our economy would be based on an unlimited supply of pollution-free power. This vision is not just around the corner, but a transition is gathering steam, and hydrogen certainly has a part to play in the world's energy mix within the foreseeable future.

Hydrogen as an Energy Carrier

Rather than being an energy source, hydrogen is usually considered an energy carrier—a way to transport and store energy that is produced from other sources. Similarly, electrons serve as an energy carrier today in the form of electric power.

Also, renewable resources like wind turbines and solar energy are sources of micropower. As we have seen, however, they need a way to store their electrical output in order to become more practical. In this case, hydrogen would be the product of the renewable generator rather than its fuel.

Other micropower technologies being developed include engines and turbines modified to run on hydrogen or hydrogen/natural gas blends. Some hydrogen vehicles use internal-combustion engines (see chapter 4).

Receptive utilities at last?

Electric utilities traditionally have resisted the encroachment of micropower on their turf, but several factors have recently combined to stage a turnaround in utility attitudes—soaring electricity consumption during peak hours, gradual deregulation of electric industries worldwide, market pressure from eager competitors, and good old-fashioned customer demand for more reliable, higher quality power.

Also, the cost of building new transmission lines and electricity distribution systems has escalated, along with public opposition to such projects. This has frustrated utilities that desperately need more capacity to deliver power to their customers. And new technologies are affording utilities better control over unpredictable amounts of electricity streaming in and out of their grid from external sources like fuel cells and other micropower units. These factors are discussed in more detail in chapter 2.

Micropower and large natural gas-fueled turbines are expected to provide nearly 62% of new generating capacity in the United States through 2025.[13] According to the Electric Power Research Institute's former president Kurt Yeager, "Our society is changing more broadly and more rapidly than at any time since Edison's day. The current power infrastructure is as incompatible with the future as horse trails were to automobiles."[14]

The renaissance in micropower is very promising to many industry observers. Vijay Vaitheeswaran says, "If micropower really takes off, then there is every reason for optimism about our planet's future. Let the revolution roll!"[15]

2

Drivers and Barriers

Just a few years ago, American automakers could hardly give away an all-electric car, despite generous tax credits. California had forced manufacturers to offer zero-emission vehicles, but customers roundly rejected them.

Yet today, people are eager to join months-long waiting lists to buy hybrid gasoline-electric vehicles, and automakers are tacking several thousand dollars onto their prices. In this case, government policy didn't work to mandate a market for an environmentally beneficial product—instead, technology advances and customer demand created it.

Several interrelated forces are driving the world's industrial nations toward a hydrogen economy that could use fuel cells for much of its electricity, from multi-megawatt plants down to home generators and car engines. Eventually our supplies of hydrogen could be provided by renewable, pollution-free sources. What are the most important forces driving us toward this vision, and what are the chances that hydrogen energy systems will become a reality?

Although our dependence on oil imported from the Middle East is often cited as a reason to develop alternative energy, environmental concerns are just as crucial, given the mounting evidence of global warming. As an added propellant, energy markets have become less constrained by regulation, especially in America and Europe, allowing greater opportunities for entrepreneurs. And technological innovation is unleashing a wave of improvements in the cost and convenience of energy services and products.

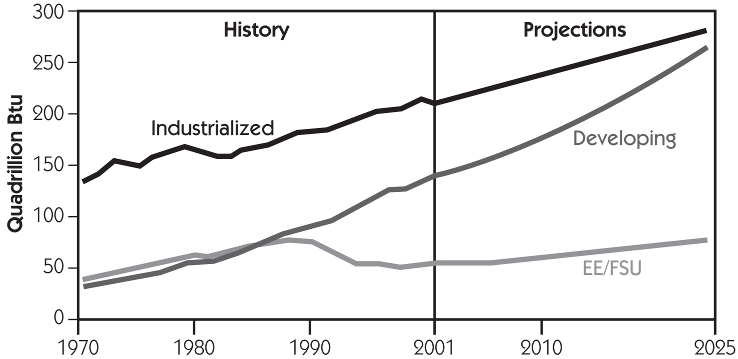

Fig. 2–6. Energy use in developing nations. Strong economic growth in China, Asia, and other developing regions will greatly increase their demand for energy. Artwork courtesy of EIA.

Developing countries run the risk of getting just as hooked on oil as their rich counterparts. And when oil prices spike, their economies suffer and their debt burdens mount. Hunting for new oil reserves is obviously worthwhile, but conservation and efficiency measures are needed in industrial and developing nations alike.

How soon will we run out of oil?

As in the global warming debate, scientific experts argue heatedly about when the world's oil production will peak and ultimately be depleted. Some analysts think we've already produced as much oil as we're ever going to, while others project the peak in the 2030s, 2040s, or beyond.

A series of articles by *Oil & Gas Journal* in 2003 and 2004 examined this issue in depth. Oil industry experts fall into the imminent peak group, which contends that the world is now at or near its maximum oil production levels, One of Europe's most visible programs is called Clean Urban Transport for Europe (CUTE), which is demonstrating 30 hydrogen fuel cell-powered public buses, three in each of ten cities (see chapter 4). European business leaders have also created the HyNet group, which is working on the Hydrogen Energy Roadmap for Europe. Participants include BP and Shell, BMW, industrial gas supplier Linde, and several utilities. The group provides input to the EU's research programs.

Japan

Japan's lack of oil and natural gas resources has forced it to take an aggressive stance on energy research. As early as 1974, Japan started Project Sunshine, which included a hydrogen budget reportedly in excess of $3 billion through 2000. In the early 1990s, Japan's hydrogen research morphed into a 30-year plan with funding of another $2 billion.

Like other industrial nations, Japan wants to reduce air pollution and improve energy efficiency. But another important goal of its hydrogen research is to create new industries and jobs, because Japan's economy has been languishing since the early 1990s.

All along, Japan's industry has been a global leader in developing fuel cell technology. Japanese utilities are mainly receptive to micropower, and Japan, with some of the world's biggest automakers in its corporate ranks, has also led implementation of hydrogen fuel cells in vehicles and development of fueling infrastructure (Fig. 2–15).

Hydrogen production from coal or even from natural gas might not gain broad public acceptance without development of carbon sequestration techniques, said the NRC report. This technical challenge will benefit from knowledge gained in sequestering CO_2 from other operations such as power generation, ammonia synthesis, and oil and gas production (see chapter 5).

Already, some of the world's energy giants are working with governments on CO_2 capture, and some environmentalists have decided to keep an open mind on the subject. As Vaitheeswaran concludes, "Sequestration could well act as a stepping-stone to a renewable-based hydrogen economy."[71]

Regulatory and institutional barriers

Many of the economic factors discussed so far could affect the market for hydrogen in stationary micropower applications, but not as drastically as in transportation. Fuel cell costs would have to fall, and their lifetimes would have to be extended for widespread use in stationary markets. But hydrogen for micropower plants would almost certainly be produced onsite, eliminating transport and distribution costs, and hydrogen storage tanks would not have to be as lightweight as on vehicles.

Instead, most of the risks and barriers affecting stationary micropower are regulatory and institutional—that is, they involve utilities' pricing and operational practices and local governments' rules about reliability, safety, cost, and environmental quality.

Interconnection requirements. Historically, the biggest obstacle to micropower has been connecting units with the utility grid. Most customers require interconnection for emergency power (standby or backup power), supplemental electricity, and in some cases for marketing or wheeling microgenerated power. The key to the ultimate market success of small micropower systems is the ability to safely, reliably, and economically connect to the utility grid.