

# **Hydrogen** and **Fuel Cells:** A Comprehensive Guide

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# Contents

List of Figures.....	xiv
List of Tables.....	xvi
Acknowledgments .....	xvii
<b>What's all the Excitement About?.....</b>	<b>1</b>
<b>1. Concept and Vision .....</b>	<b>3</b>
Hydrogen as an Energy Carrier .....	3
Production From Any Source.....	4
Hydrogen Complements Electricity .....	5
Taking the C Out of HCs .....	6
Storing Electricity From Renewable Sources.....	8
Handling and Producing Hydrogen.....	9
Power On Demand From Hydrogen Fuel Cells.....	10
Fuel cell markets .....	12
Fuel cell types .....	13
Micropower Makes Sense .....	14
Microgenerators .....	15
Receptive utilities at last? .....	16
Fuel Cell Cars Unveiled.....	17
Profiting From Your Engine .....	19

A Vision of an Energy Internet.....	20
References.....	22
<b>2. Drivers and Barriers.....</b>	<b>23</b>
<b>Our planet's health.....</b>	<b>26</b>
Potential effects of climate change.....	27
Evidence of global warming.....	28
Methane emissions.....	30
Government actions.....	31
Air pollution in the developing world.....	34
Efficiency as a route to pollution control.....	36
Profiting from air pollution control?.....	39
<b>The Global Oil Picture.....</b>	<b>40</b>
Oil consumption trends.....	41
How soon will we run out of oil?.....	43
Dependence on imports from the Middle East.....	46
Energy security and geopolitics.....	50
An opportunity for hydrogen.....	52
<b>Big Business Buys In—Automaker/Oil Producer Alliances.....</b>	<b>52</b>
<b>Changes in the Electric Power Industry.....</b>	<b>54</b>
Restructuring and competition.....	55
Demand for higher quality power.....	56
Meeting peak demand.....	58
Micropower's advantages to electric utilities.....	59
<b>Government Support For Hydrogen.....</b>	<b>61</b>
European Union.....	62

Japan .....	64
United States.....	66
U.S. state programs .....	69
Canada .....	71
Australia .....	71
China.....	72
Iceland .....	72
Norway .....	73
<b>Barriers and Challenges .....</b>	<b>74</b>
Distribution costs .....	74
Fuel cell technology and onboard hydrogen storage.....	75
Hydrogen production costs .....	76
Capturing carbon .....	77
Regulatory and institutional barriers.....	78
Risk of electric price increases .....	81
Safety .....	82
<b>Outlook For a Transition to a Hydrogen Economy.....</b>	<b>82</b>
<b>References.....</b>	<b>85</b>
<b>How would Hydrogen be Used? .....</b>	<b>89</b>
<b>3. Fundamentals and Background .....</b>	<b>91</b>
Our Supply of Hydrogen .....	91
Hydrogen's Properties.....	92
The Cleanest Fuel.....	94

<b>Producing Hydrogen</b> .....	95
Electrolysis.....	95
Reforming.....	97
Other processes .....	97
<b>Fuel Cell Technology</b> .....	98
Types of fuel cells .....	98
Fuel cell applications.....	103
<b>How Hydrogen Is Used Today</b> .....	104
<b>Hydrogen's Early History</b> .....	105
<b>Exploiting Hydrogen's Properties</b> .....	106
<b>Fuel Cells Enter the Picture</b> .....	108
<b>Hydrogen's Renaissance(s)</b> .....	110
<b>References</b> .....	115
<b>4. Applications and Markets</b> .....	117
<b>A Rapidly Growing Market</b> .....	118
<b>Oil Companies Enter the Hydrogen Market</b> .....	120
BP involved in automotive hydrogen .....	120
Shell's hydrogen program .....	121
ChevronTexaco teams with Hyundai, UTC.....	122
<b>Automotive Fuel Cell Market</b> .....	122
<b>Fuel Cell Vehicle Demonstrations</b> .....	124
Ford Focus fleet .....	126
Honda FCX cars.....	127
DaimlerChrysler cars, trucks, and buses.....	128

Ballard's automotive fuel cell research .....	131
Toyota SUV, Prius.....	131
Other fuel cell vehicles.....	133
BMW sticks with engines.....	135
<b>Europe's CUTE Bus Program .....</b>	<b>136</b>
<b>Japan's Hydrogen Fuel Cell Program .....</b>	<b>137</b>
<b>Iceland's Ectos Project .....</b>	<b>138</b>
<b>California Fuel Cell Vehicle Programs .....</b>	<b>139</b>
The California Hydrogen Highway.....	139
California Fuel Cell Partnership.....	140
SunLine bus demonstration .....	141
<b>U.S. FreedomCAR Program .....</b>	<b>141</b>
<b>Hydrogen Fueling At Home.....</b>	<b>145</b>
Honda/Plug Power.....	145
Shell/Stuart Energy.....	146
First hydrogen/electricity station.....	147
<b>Utilities Involved in Hydrogen Micropower, Vehicles.....</b>	<b>147</b>
Hydrogen Technology Park .....	148
Tech Town microgrid.....	148
Canada's hydrogen village.....	149
Hawaii's plans.....	149
<b>Fuel Cell Micropower Technologies .....</b>	<b>149</b>
United Technologies phosphoric acid power plants.....	150
Siemens/Westinghouse solid oxide fuel cells .....	151
FuelCell Energy stationary products.....	152

Automotive fuel cells in an industrial application.....	153
Other micropower developments.....	154
<b>PEM Fuel Cells in Micropower Applications .....</b>	<b>155</b>
Residential and commercial micropower.....	155
Uninterruptible power supply applications .....	156
Plug Power's stationary applications.....	157
Japanese developers planning small fuel cell systems.....	157
<b>Microturbines in Stationary Applications .....</b>	<b>158</b>
Integrating fuel cells with microturbines.....	159
Microturbines in energy systems with fuel cells.....	160
<b>Fuel Cell Boats, Trains, and Planes .....</b>	<b>160</b>
Locomotive being developed.....	161
The sky's the limit? .....	161
<b>Portable Applications For Fuel Cells.....</b>	<b>162</b>
Competing with batteries .....	163
Early market entries .....	164
Personal power .....	164
Solid oxide portable fuel cells.....	165
Fuel cell shopping online.....	166
<b>Consumer Demand .....</b>	<b>166</b>
<b>References.....</b>	<b>168</b>
<b>How would a Hydrogen Economy work? .....</b>	<b>171</b>
<b>5. Production and Supply .....</b>	<b>173</b>

<b>Overview of Production Methods</b> .....	174
Units of measurement.....	175
Challenges and outlook.....	176
<b>Reforming Natural Gas and Liquids</b> .....	177
Barriers and research needs .....	180
Hydrogen production economics .....	181
Carbon emissions.....	181
Vehicle emissions .....	182
<b>Carbon Capture and Storage</b> .....	183
Sequestration technologies .....	183
Government/industry programs .....	187
Environmental concerns.....	187
<b>Producing Hydrogen From Coal</b> .....	188
Coal gasification potential.....	188
Hydrogen production economics .....	190
<b>Biomass and Waste Feedstocks</b> .....	191
Carbon emissions.....	192
Hydrogen production economics .....	192
<b>Electrolysis of Water</b> .....	193
Available systems.....	194
Hydrogen production economics .....	196
Integrating electrolysis with renewables.....	197
<b>Nuclear Power</b> .....	198
Industry status .....	198
Hydrogen production economics .....	199
Technologies being developed.....	200

<b>Hydrogen From Solar Power</b> .....	201
Hydrogen production economics .....	202
Solar water-splitting .....	203
Photolytic processes .....	203
Photobiological processes .....	204
<b>Wind-Powered Hydrogen Production</b> .....	206
Norway's wind-to-hydrogen project .....	206
Outlook .....	208
Hydrogen production economics .....	208
<b>Other Renewables</b> .....	209
<b>Long-Term Hydrogen Supplies</b> .....	211
<b>References</b> .....	213
<b>6. Storage and Safety</b> .....	215
<b>Hydrogen Storage Today</b> .....	216
Compressed gas tanks .....	216
Liquefied gas tanks .....	217
<b>Advanced Storage Technologies</b> .....	218
Metal hydrides .....	219
Chemical hydrides .....	221
Carbon materials .....	223
<b>Barriers and Challenges</b> .....	224
<b>Government/Industry Funding</b> .....	225
<b>Hydrogen Safety</b> .....	228
Comparison with other fuels .....	228
Leak detection .....	230
Safety practices, codes, and standards .....	231

Barriers and challenges .....	233
The <i>Hindenburg</i> myth and other misperceptions .....	234
<b>References</b> .....	<b>235</b>
<b>7. Transportation and Distribution</b> .....	<b>237</b>
<b>Problems of Hydrogen Transport</b> .....	<b>238</b>
Road shipment .....	238
Hydrogen pipelines .....	240
Transportation economics .....	242
Outlook .....	243
<b>Fueling Station Infrastructure</b> .....	<b>244</b>
Infrastructure cost estimates .....	246
Fueling station equipment .....	247
Outlook .....	252
<b>References</b> .....	<b>253</b>
<b>Appendix A. Fuel cell light duty vehicles</b> .....	<b>255</b>
<b>Appendix B. Fuel cell buses</b> .....	<b>265</b>
<b>Appendix C. Worldwide hydrogen fueling stations</b> .....	<b>271</b>
<b>Appendix D. Worldwide fuel cell installations</b> .....	<b>281</b>
<b>Appendix E. Hydrogen cost calculations</b> .....	<b>341</b>
<b>Appendix F. Gaseous hydrogen safety</b> .....	<b>359</b>
<b>Appendix G. Liquid hydrogen safety</b> .....	<b>379</b>
<b>Glossary and Conversion Factors</b> .....	<b>395</b>
<b>Bibliography</b> .....	<b>415</b>
<b>Index</b> .....	<b>427</b>

# List of Figures

Fig. 1–1. Trend toward lower carbon fuels.....	7
Fig. 1–2. NEG Micon wind turbine .....	9
Fig. 1–3. Hydrogen economy concept .....	11
Fig. 1–4. Residential fuel cell.....	15
Fig. 1–5. GM HydroGen3.....	18
Fig. 1–6. BP hydrogen fueling station .....	18
Fig. 2–1. Global CO <sub>2</sub> emissions by region .....	34
Fig. 2–2. U.S. CO <sub>2</sub> emissions. ....	37
Fig. 2–3. U.S. electric power sector CO <sub>2</sub> emissions. ....	37
Fig. 2–4. U.S. energy use. ....	41
Fig. 2–5. Global oil consumers. ....	42
Fig. 2–6. Energy use in developing nations.....	43
Fig. 2–7. Future world oil production. ....	44
Fig. 2–8. Peak oil delay .....	45
Fig. 2–9. Conventional oil production forecasts .....	45
Fig. 2–10. Persian Gulf oil reserves.....	46
Fig. 2–11. Oil production outlook.....	48
Fig. 2–12. U.S. oil imports.....	49
Fig. 2–13. Natural gas resources. ....	49
Fig. 2–14. U.S. natural gas imports. ....	50
Fig. 2–15. Japan’s fuel cell vehicle developments .....	65
Fig. 2–16. Japan’s fuel cell vehicle goals .....	66
Fig. 3–1. Solar power facility in California .....	96
Fig. 3–2. PEM fuel cell schematic .....	99
Fig. 3–3. Early fuel cell .....	108
Fig. 3–4. Space craft fuel cell.....	109
Fig. 4–1. GM HydroGen3 in marathon.....	124
Fig. 4–2. GM Sequel concept car .....	125
Fig. 4–3. Ford Focus fuel cell sedan .....	126
Fig. 4–4. Honda fuel cell car .....	127

Fig. 4–5. Hydrogen-powered delivery vehicles .....	129
Fig. 4–6. DaimlerChrysler fuel cell cars.....	130
Fig. 4–7. Honda scooter .....	134
Fig. 4–8. CUTE hydrogen fuel cell bus. ....	136
Fig. 4–9. Iceland’s hydrogen fueling station .....	139
Fig. 4–10. California’s hydrogen and fuel cell facilities .....	140
Fig. 4–11. Honda/Plug Power Home Energy Station .....	145
Fig. 4–12. Stuart Energy Station.....	146
Fig. 4–13. Siemens/Westinghouse solid oxide fuel cell .....	152
Fig. 4–14. Japanese residential fuel cell. ....	155
Fig. 4–15. Capstone/Direct FuelCell hybrid system. ....	159
Fig. 4–16. E-plane prototype. ....	162
Fig. 4–17. Ballard AirGen portable fuel cell generator.....	165
Fig. 5–1. Steam reforming process .....	178
Fig. 5–2. Autothermal reformer .....	179
Fig. 5–3. Sleipner field.....	184
Fig. 5–4. U.S. CO <sub>2</sub> injection sites.....	185
Fig. 5–5. U.S. deep salt formations.....	186
Fig. 5–6. Gasification of coal and other hydrogen feedstocks.....	189
Fig. 5–7. Biomass crop of willow trees.....	191
Fig. 5–8. Electrolyzer at Hamburg hydrogen fueling station.. ..	195
Fig. 5–9. Algae for biological hydrogen production. ....	205
Fig. 5–10. Norway’s wind power-hydrogen project .....	207
Fig. 6–1. Metal hydride storage process.....	209
Fig. 6–2. Rack-mounted hydrogen cylinders.....	220
Fig. 6–3. Borohydride storage process .....	222
Fig. 6–4. Carbon nanotube research.....	223
Fig. 7–1. Hydrogen plant at California refineries. ....	239
Fig. 7–2. Munich airport hydrogen fueling station. ....	249
Fig. 7–3. Las Vegas hydrogen fueling station.....	251

# List of Tables

Table 2–1. European Union CO <sub>2</sub> emissions targets. ....	32
Table 2–2. Middle East share of production. ....	47
Table 2–3. Outage costs for selected commercial customers. ....	58
Table 2–4. European energy market restructuring. ....	63
Table 3–1. Fuel cell technologies. ....	102
Table 3–2. Recent history of hydrogen and fuel cell R&D. ....	111
Table 4–1. Demonstration and development of hydrogen vehicles. ....	142
Table 4–2. Demonstration and development of hydrogen fueling stations. ....	144
Table 5–1. Hydrogen costs for central steam methane reforming. ....	182
Table 5–2. Hydrogen costs for central coal gasification plant. ....	190
Table 5–3. Available electrolyzers for hydrogen fueling station applications. ..	195
Table 5–4. Nuclear hydrogen production options. ....	200
Table 5–5. Wind-powered hydrogen costs. ....	209
Table 5–6. Hydrogen production from U.S. domestic resources. ....	212
Table 6–1. Hydrogen Storage Grand Challenge. ....	226
Table 6–2. Properties of hydrogen and other fuels. ....	229
Table 6–3. Safety record of fuels and electricity. ....	230
Table 7–1. Pipeline construction costs. ....	242

# 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 pro-

duced 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.





# 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.<sup>13</sup> 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."<sup>14</sup>

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!"<sup>15</sup>



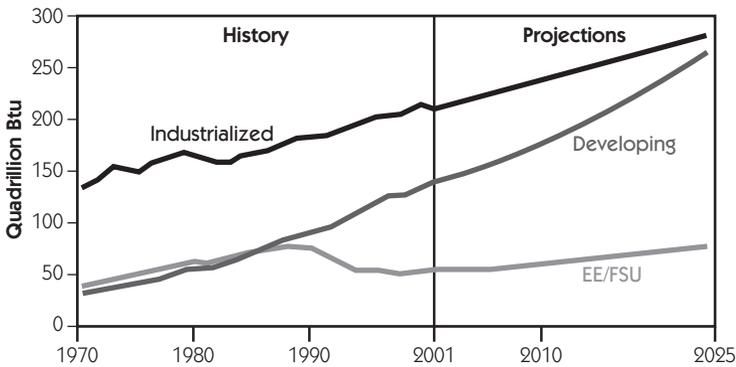
## Drivers and Barriers

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<sub>2</sub> 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<sub>2</sub> 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."<sup>71</sup>

## 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.