



## contents

ix	FOREWORD
xi	INTRODUCTION
2	ONE The Way Forward
18	TWO Where We've Been, Where We Are . . .
30	THREE Today's Fossil Energy Beast
48	FOUR The Back End of the Beast
70	FIVE The Emerging Picture
98	SIX Nature's Way
110	SEVEN The Matter of Safety
126	EIGHT Making Hydrogen
150	NINE Putting Hydrogen to Work
164	TEN Hydrogen in Space
190	ELEVEN Hydrogen at Home, at Work, at Play
204	TWELVE Driving on Hydrogen
230	THIRTEEN Bypassing the "Chicken and Egg"
248	FOURTEEN Flying Hydrogen
264	FIFTEEN Riding the Rails
276	SIXTEEN On the Waterways
288	SEVENTEEN The Internet of Energy
298	EIGHTEEN Misconceptions
308	NINETEEN Making It Happen
326	TWENTY An Empowering Vision
344	SUGGESTED READING
346	RECOMMENDED WEB SITES
347	BIBLIOGRAPHY
362	INDEX

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***Geoffrey B. Holland***

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***James J. Provenzano***

## foreword

When we look at the world and see its many challenges, the need for a new kind of energy economy is at the top of the list. For more than a century, oil has been central to the way we live. It has brought us unprecedented personal freedom and economic prosperity. But now the good that came to society from fossilized energy has been overshadowed by the devastating pollution generated by its use. This pollution compromises public health, seriously damages our environment, threatens economic and political stability, and is the major cause of global warming.

In addition, there is another concern that accompanies our dependence on oil. Only so much remains available and reasonably recoverable. We have already consumed about half of all the oil that has ever existed, most of that in the past thirty years. Every day, it becomes more difficult to find new discoveries. Very simply, we are fast approaching the end of the fossil energy road.

Energy is essential to any society, but a twenty-first-century economy needs twenty-first-century energy sources and technologies. In the administration of Governor Arnold Schwarzenegger, where I served as the secretary of California's Environmental Protection Agency, we made clean, renewable energy a priority. Wind, solar, geothermal, biomass, and energy from ocean waves and river currents are all clean sources of energy that can be harnessed to make electricity.

The question becomes how do we make renewable sources of electricity storable for use when and where it is needed? Batteries are part of the answer. The new battery technologies are very impressive. They will play an important part in the future energy marketplace, but they are unlikely ever to match the energy storage potential and convenience of gasoline.

That's where hydrogen comes into the picture. Any energy source that can be made into electricity can also make hydrogen. That is the key to a clean, sustainable energy future.

California's electric utilities are now mandated by law to get at least 20 percent of the energy they deliver to their customers from renewable sources by 2010. Our state has committed 3.2 billion dollars in incentives to the Million Solar Roofs Initiative to install 3,000 megawatts of solar generation on homes, schools, farms, businesses, and municipal buildings before 2020. By 2020 the Global Warming Solutions Act will have reduced global warming emissions in California back to their 1990 levels, driving even more demand for clean energy.

A big change is also coming with motor vehicles. Hydrogen-powered vehicles are already being demonstrated by most of the world's automakers. The California Fuel Cell Partnership was created with the world's major automakers to test their newest fuel-cell auto technologies, and we created the California Hydrogen Highways Initiative to deliver

hydrogen fueling stations every twenty miles along all of the interstates and major state highways in California.

The world is entering *The Hydrogen Age*. That is a very good thing. It will mean cleaner skies. It will address global warming in the most effective way possible. It will eliminate our dependence on foreign oil and end the political conflict driven by our oil addiction. These are all things we can celebrate. The really great news is this exciting energy transition will not be a drag on the economy. On the contrary, it will stimulate unprecedented economic opportunity. Millions of good jobs will be created over the years it will take to fully implement this bold, clean energy vision. We *need* to do it now, and we *can* do it now.

This book by Geoffrey Holland and James Provenzano offers a compelling and comprehensive view of the issues related to the monumental energy transition that is now underway. It was written for the layperson who wants to be informed. It could not have come at a better time.

**Terry Tamminen**

**Director of the Climate Program, New America Foundation  
Former Secretary of CalEPA, 2003-2006**

## introduction

Euros, rupees, and dollars notwithstanding, *energy* truly is the universal currency on planet Earth. Since the earliest days of mankind, energy has shaped human relationships, defined and advanced cultures, created great wealth and prosperity, and has been the instigator of wars. Beyond food, water, and shelter, energy is the most basic of all human needs. At one time we took the availability of cheap energy for granted. Not anymore. For more than a century the world has depended on oil for the biggest share of its energy needs. But we are now in an era where the supply of oil can no longer keep up with demand. The age of low-cost petroleum energy is over. The world is sorely in need of a better answer. We not only need to meet the energy demands of a world that keeps asking *more* from our finite planet but we are also in desperate need of energy resources that will address air pollution, greenhouse gas emissions, environmental damage, and the continuous price fluctuations that plague our economies and all of us personally.

Many energy alternatives are being touted. The scramble is on to see which ones will rise above the rest. Each possibility comes with its own set of strengths and weaknesses. Very likely and, fortunately, the coming era will not be hugely dependent on a single energy source as it is today with oil. In some places there is lots of wind that can be used to generate electricity. In other places, direct sunlight will be the answer. Energy captured from the Earth in those places where it is available, such as geothermal, wave, and tidal power, can be harnessed to serve humankind ably. In each of these cases, energy is harvested in the form of electricity, which converts to useful work very efficiently. The problem with electricity as an *energy carrier* is that it is not easily stored for use when and how we need it.

Liquid fuels like gasoline have worked well for society because of the convenience and flexibility of their on-demand use capability. So, if the common product of the renewable energy sources that will power the future is electricity, there must be a way to store that electricity cleanly and efficiently in a form that makes it easily convertible to work whenever and wherever there is a need.

Fortunately, nature has provided an answer that seems almost too good to be true. Elegant in its simplicity, that answer is a gaseous substance called hydrogen. First among the chemical elements, a hydrogen atom consists of a nucleus and one electron. It is the most common substance in the universe. As an energy carrier, it offers the promise of virtually unlimited access to affordable, locally produced, zero-emission energy.

The age of hydrogen is close at hand. A few decades from now, perhaps by the middle of the twenty-first century, hydrogen likely will have replaced oil as the world's primary on-demand energy currency. That prospect carries with it great hope for the entire human family. In a hydrogen-powered world, bloody conflict driven by the geopolitical distribution of energy will fade and disappear. Gone will be the thick, polluted air hanging over

many of the world's urban centers. Gone will be the respiratory diseases and other illnesses linked to combustion-based air pollution. Gone will be the primary cause of global atmospheric warming and climate change.

Energy truly is planet Earth's grand elixir. In the award-winning movie *Quest for Fire*, the lean existence of a clan of cave dwellers revolves around their primary energy source . . . fire. They value it above all else. Though they have not learned how to make fire, they have evolved crude ways to harness it and to preserve it for use on demand. They revere their flame as something sacred. They nurture it and protect it against violent marauders who wish to possess it. The big turning point comes when the scruffy clan's fire is accidentally extinguished. A sense of dread grips the entire group. They risk their future sending three of their strongest on a perilous quest to find a source to rekindle the sacred flame. Ever since the time of the cave dweller the quest for energy has been crucial in shaping who we are, where and how well we live, and how we get along among ourselves and with others.

Since fire was first harnessed by man, we have burned carbon-based materials—living organisms such as plants and trees and the organic remnants of once living organisms—as fuel to do *work*. The organic remnants taken from under the ground are also known as fossil fuels. In the nineteenth century, human culture was transformed dramatically when coal, which is a highly concentrated form of fossil fuel energy, powered the Industrial Revolution. That triggered a massive migration from rural areas to the steel mills and heavy industry jobs in the cities. During the early years of the twentieth century, the discovery of petroleum oil triggered another major human advance. The availability of this liquid fossil energy in the form of gasoline gave the developed world unprecedented mobility and freedom as automobiles replaced horses as the primary form of personal transportation.

From coal, to gasoline, and more recently natural gas, the ready availability of low-cost, carbon-based fossil fuel energy has triggered opportunity, advancement, and massive cultural change. For the most part, that has been good news. The bad news is fossil fuels are a finite resource. In the case of oil, we have already used about half of all the liquid petroleum that has ever existed. Locked deep below the Earth's surface, what remains is being consumed ever more rapidly as demand increases. In a little over a hundred years, the number of humans on planet Earth has more than tripled to more than 6.6 billion. An inevitable consequence of this population growth has been a massive expansion in the demand for energy.

Worldwide, fossil fuels currently account for more than 85 percent of energy consumption. Our thirst for energy is expected to grow by 60 percent over the next two decades. With demand rapidly increasing and available petroleum reserves going the other direction, prices at the pump have nowhere to go but up. The era of cheap petroleum energy is over.

Pollution is another serious consequence that goes with carbon-based fuels. The challenges presented by combustion-generated pollutants have grown ever more serious as fossil fuel use has expanded. We are now releasing tens of billions of tons of combustion waste into the atmosphere every year. The health consequences of breathing dirty air are

well documented. Eight hundred thousand deaths annually around the world have been linked to fossil-fuel air pollution.<sup>1</sup>

As the unequivocal scientific evidence has indicated, the greatest threat posed by our dependence on carbon-based fossil energy seems to be the phenomenon known as global warming. The massive amount of pollution we are releasing every year from our use of these fuels is causing the atmosphere to trap heat and grow warmer. In addition to rising sea levels, atmospheric warming is also linked to a dramatic increase in extreme weather events. The monstrous hurricane Katrina, which devastated New Orleans and large areas of Mississippi and Louisiana in 2005, appears to be an ominous harbinger of things to come.

The arrival of the third millennium is not just a major crossroad in chronological time. It is also a major transition point in the evolution of man. To stay the course would be perilous at best, totally calamitous at worst. A positive future requires new direction and a new kind of energy.

Amory Lovins, president of the Rocky Mountain Institute, is recognized as one of the world's leading energy policy innovators. He believes the moment for hydrogen has arrived. "The technology has now developed at the same time we need it so we can get out of the business of digging up carbon, burning it, and blowing it out the tailpipe and smokestack. We will get better services at lower costs so this will not be a sacrifice; it will be a considerable advance in our way of life."<sup>2</sup>

As we begin the twenty-first century, we are embarking on the most exciting and profound energy transition in the history of mankind. We are moving beyond the dependence on oil and the other forms of fossil energy we have built our lives around since the time of the cave dweller. We are moving into *The Hydrogen Age*.

About 90 percent of all the atoms that exist in the universe are hydrogen atoms. The fuel that powers our sun and all the stars is hydrogen. It is nontoxic and virtually limitless in supply because you can find it as part of the chemical makeup of virtually everything that exists. The most obvious of these hydrogen-rich substances is something we find all around us . . . water. In a single hour, enough water falls on Earth in the form of rain or snow to meet our annual energy needs ten thousand times over.

To produce energy, hydrogen can be burned in a combustion engine or on its own. It can also be used in something called a fuel cell, a device that operates electrochemically to break down hydrogen atoms into electrons and protons, the end result being electricity with water and heat as by-products. When hydrogen is converted to electricity in a fuel cell, the process results in zero pollution. Already, researchers are developing ways to use fuel cells to meet virtually all the world's energy needs. Fuel cells are now being designed to power cell phones and laptop computers, railroad locomotives, ships of all types, and every variety of motor vehicle including trucks and buses. They may also be used in the aircraft of the future.

While the promise is enormous, there are still challenges ahead. The process of transforming the world's energy infrastructure from one that relies on fossil fuels to one that delivers hydrogen will take place over decades. A cooperative effort among nations is now underway to develop universally accepted codes and standards for the safe design and

operation of hydrogen systems. Despite the remaining challenges, momentum is building and a transition to hydrogen appears inevitable.

Robert M. Zweig, MD, to whom this book is dedicated, was a pulmonary specialist and a family practitioner who spent his entire medical career practicing in Riverside, California. Zweig's community is in the direct path of the Los Angeles basin smog as it is carried eastward by prevailing winds. A great many of Zweig's patients in Riverside were seriously affected by the heavy blanket of pollutants generated by traffic and industry fifty miles west in Los Angeles. In the late 1960s, distressed by this circumstance, Zweig thoroughly investigated every option available that might help his patients. Ultimately, he zeroed in on hydrogen as the best cure. When nobody was looking at alternatives to fossil fuels, Zweig became a relentless champion for clean hydrogen energy. He paid to have a small Dodge D50 truck converted to run on hydrogen. In an effort to build awareness, he connected one end of a hose to the truck's exhaust pipe. He taped the other end of the hose to a breathing mask, which he then wore while jogging behind the truck. He also liked to hold a cup under the truck's exhaust and capture the hot water dribbling from the pipe, which he would then drink with relish. Zweig preached hydrogen to anyone who would listen. He profoundly influenced public officials and the business community with his vision. California is now leading the nation and the world into the Hydrogen Age. Bob Zweig passed away in 2002. He was not the first person to recognize the transformative possibilities that go with hydrogen, but he did see it as a healthy prescription for the planet that could benefit every member of the human family.

In the pages ahead, we begin with a close look at the character of the hydrogen atom, what it looks like, and why it's the principal element in the dynamic structure of the universe and life on Earth. From there, we'll take a look at man's relationship with energy through the ages. We then move on to hydrogen as an energy carrier; how we can put it to work; how it's been used with great success in the space program; how it will be used in the future. Finally, after looking at the many ways hydrogen energy can be put to work, we'll examine closely the challenges that remain. We end with a life-affirming vision of the kind of inclusive and fundamentally fair world we can have with hydrogen as our primary energy currency.

The message of this book is hopeful. In a world fraught with economic imbalance and uncertainty, with political instability rampant, with nature and the biosphere being pushed to the limit by human activity, clean, inexhaustible hydrogen promises to level the energy playing field for all the world's people, clearing the air and opening pathways to a sustainable future where the human family can and will choose to live in harmony within our planet's ability to provide.

1 WORLD HEALTH ORGANIZATION (WHO), "The Health and Environment Linkages Initiative" (accessed Mar. 15, 2007), <http://www.who.int/heli/risks/urban/urbanenv/en/index.html>.

2 AMORY LOVINS interview with Geoffrey B. Holland on Aug. 14, 2003.