POWER TO THE PEOPLE

How the Coming Energy Revolution
Will Transform an Industry, Change Our Lives,
and Maybe Even Save the Planet

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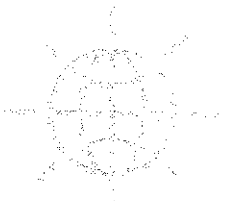

Introduction: The Coming Energy Revolution

THIS BOOK IS about the future of our planet. The needlessly filthy and inefficient way we use energy is the single most destructive thing we do to the environment. Whether it is the burning of coal in industrial power plants or the felling of tropical forests, our appetite for energy—which is essential to modern life—seems insatiable. With enough clean energy, most environmental problems—not just air pollution or global warming but also chemical waste and recycling and water scarcity—can be tackled, and future economic growth can be made much more sustainable.

The problem is that change comes slowly in the energy realm. Old ways of thinking have encouraged monopolies, shielded polluters, and stifled innovation. That has burdened the rich world with an energy system locked into outmoded technologies—such as America's many coal plants—that are dirty and inefficient. That's bad enough, but now it seems that giants of the developing world, like China and India, may follow the same path as their economies surge over the next couple of decades. If they do, then many mil-

lions of unfortunates will die needlessly from the resultant pollution—as will the world's hopes of curbing the carbon emissions that are fueling global warming. That is why this is the key question: Can we move beyond today's dirty energy system to one that is cleaner, smarter, and altogether more sustainable?

Absolutely. Though cries of shortage and crisis are often heard these days in the energy world, there is actually more reason for hope than there has been in decades. This book argues that there are three powerful trends going on below the radar that promise to rewrite the rules of the energy game: the global move toward the liberalization of energy markets, the growing popular appeal of environmentalism, and the recent surge of technological innovation in areas such as hydrogen fuel cells. Taken together, they could lead to an energy system that meets the needs and desires of future generations while still tackling serious problems like global warming and local air pollution. If this clean energy revolution is really going to take off, though, we must first be ready to think the unthinkable: we must end our addiction to oil. Ironically, it may happen for reasons entirely unrelated to concerns about the environment and human health.

The problem is economic and political as much as ecological. Consider a simple question: How much is a barrel of oil worth? You might think that the price would be whatever the market will bear. Yet the price of oil is influenced less by the free interplay of supply and demand than by the whims of the Organization of Petroleum Exporting Countries (OPEC)—the ill-disciplined cartel led by Saudi Arabia. Small wonder, then, that the oil price has yo-yoed, from around $20 a barrel for much of the 1990s down to $10 in 1998 to more than $30 a barrel in early 2003.

If you could ask Osama bin Laden that same question, though, you would get a very precise figure: $144. Several years ago, before the al Qaeda terrorist group carried out its attacks on America, bin Laden made some curious comments on energy economics. In that little-noticed diatribe, he accused the United States of "the biggest theft in history" for using its military presence in Saudi Arabia to

keep oil prices down. He calculated that this hostile takeover of his country's patrimony added up to some $36 trillion in lost revenues—and, he insisted, America now owes each and every Muslim in the world around $30,000. And counting.

That chilling calculation points to the nightmare scenario that keeps "energy security" experts up at night: a hostile regime seizes the oil fields of the Middle East and either raises prices sky-high or cuts off oil supplies altogether. Before September 11, scenario planners reassured themselves that if this ever happened, America would just send in its troops to quash the troublemakers and ensure safe passage for the oil supplies. After all, that was the main outcome of the Gulf War, when the coalition led by the elder George Bush booted Saddam Hussein out of the oil fields of Kuwait. And when George W. Bush began to prepare for an invasion of Iraq a decade later, even those who agreed that Saddam Hussein should be ousted took note of the fact that Iraq happens to have a bit of oil: the largest reserves in the world, in fact, after Saudi Arabia.

America's military supremacy is now unchallenged. Even so, the attacks of September 11 revealed the limits of American power in at least one realm: they have exposed the vulnerability of the global energy system to a postmodern oil shock. Today we have to consider the possibility that revolutionaries or terrorists could possess nuclear weapons—and might use them on American troops or the oil wells. Such an outcome could precipitate a global economic and political crisis of the sort never seen before. The good news is that such a scenario is extremely unlikely, even in light of recent events. The bad news is that it might still happen, and not even America's mighty military can prevent it. Even short of such an extreme outcome, though, the monopoly grip that petroleum has on the world's transport infrastructure might result in an energy crisis sometime over the next few decades.

Surprising as it may seem, the reason is not scarcity. Back in the 1970s, in the aftermath of the oil shocks of that decade, many people fretted that the energy was running out. With the arrival of the younger Bush in the White House, Americans once again heard

talk of an energy crisis. Yet it's abundantly clear that there is enough oil to keep the world's motors humming for decades to come.

The real problem is not scarcity but *concentration*. The lion's share of that remaining oil—and most of the oil that is cheap to extract—lies under the desert sands of a small handful of countries in the Persian Gulf. Today, Saudi Arabia and its immediate neighbors sit atop nearly two-thirds of the world's proven oil reserves—that's right, *two-thirds*. However, those countries are not producing oil nearly as fast as they can. As the world continues to deplete expensive, non-OPEC oil in places like the deep waters of the Gulf of Mexico and the frigid reaches of Siberia in coming years, OPEC's market share is set to increase dramatically—and with it, the power of those Middle Eastern regimes. The potential for supply disruption by anti-Western terrorist bands like al Qaeda can therefore only grow. This threat is particularly acute for the United States, which is both the biggest oil guzzler and the de facto guarantor of oil supplies for its allies.

Unfortunately, there is no immediate solution, because there is no practical alternative to oil-fired transport. In the short term, all governments can do is buy some insurance against politically inspired supply disruptions and the panics that tend to accompany them. The way to do that is to expand dramatically their buffer stocks of petroleum, such as those stored in salt domes in Louisiana. To his credit, George Bush started to do this in 2001. Structural changes in the oil industry resulting from mega-mergers, cost-cutting, and a move to just-in-time inventories make the matter particularly urgent, because the private sector has greatly reduced its levels of stocks from the 1970s. Add to this the official neglect of government stockpiles, which are inadequate in the rich world and practically nonexistent in the developing world, and you get a world needlessly vulnerable to the next oil shock.

As for longer-term policy responses, three views typically dominate the energy debate raging around the world post–September 11: *Relax*; *Keep pumping*; and *Ride your bicycle*. The first

camp insists that the very premise of the argument is false and that "energy security" is a bogus notion not worth worrying about. The second camp sees the threat as real, but argues that it can be countered effectively through supply-side measures that boost non-OPEC sources of oil. The final camp argues that conservation is the only way forward. They tend to perpetuate a number of popular myths about energy:

- The oil's about to run out
- Without fossil fuels, we'd return to the Stone Age
- Windmills and warm sweaters will save the planet
- Rampant economic growth is the root cause of our environmental problems
- Clean technologies will emerge spontaneously, without the need for government action or difficult policy measures like energy taxes
- Sport-utility vehicles (SUVs) are the work of the devil

This book will explode these and other nonsensical notions, and explain why none of these three camps gets it quite right.

What, Me Worry?

Perhaps unsurprisingly, Saudi Arabia is at the forefront of the Panglossian camp. In 1999, Ali Naimi, its oil minister, gave a speech in which he vigorously challenged the notion that his country's growing market power will be a problem: "Oil is a global market . . . those who propagate the issue of supply insecurity, dangers of import dependence and perceived instability of the Arabian Gulf are ignoring realities."

He pointed out that his country intentionally maintains a cushion of excess capacity to counter any supply disruption. It was his country's buffer, not any non-OPEC production, he noted, that came to the rescue when previous disruptions resulted from the

Iranian revolution, the Iran-Iraq war, and the Gulf War. True, but this hardly answers the question as to what will happen if his regime is toppled by a rabidly anti-Western cabal.

Lord Browne, the boss of BP, countered such fears, observing that "however fundamentalist, a regime still needs money to look after its people." Many economists agree, insisting that oil is a "fungible" commodity that is worthless unless it gets to market. In the long term, that is doubtless true. But even short-term disruptions can wreak havoc on the world economy. For example, when the Iranian revolution booted out the shah, Iran's oil exports did in fact collapse for some time, and even years later reached only two-thirds their previous level. Just imagine the chaos if willfully irrational zealots toppled the Saudi regime—and then decided to deny themselves oil revenues in order to punish the Great Satan.

Another part of the *Relax* camp of energy policy relies on free-market arguments to make its case. Libertarians argue, quite rightly, that the pain associated with previous oil shocks had more to do with foolish policy responses by Western governments meddling in the market (by imposing oil price controls, for example) than with any actual lack of supply. On one estimate, America spent some $60 billion a year during the 1990s to guard oil from the Persian Gulf, when the actual cash value of those oil imports totaled only around $10 billion a year—a mind-boggling subsidy for fossil-fuel energy. Such folk contrast this overcautious approach with America's relaxed attitude to semiconductors: these silicon sandwiches are, after all, the backbone of the digital economy and also come chiefly from just one place (in this case, Taiwan), but America's military clearly does not guard chip plants.

All that sounds quite plausible until one considers the differences between semiconductors and petroleum: the American economy can manage fine without new semiconductors for some time, but the country would grind to a halt the minute that oil dried up. Also, semiconductor plants can be built anywhere—but oil wells can go only where there is oil. The gasoline riots that brought Britain and parts of continental Europe to a standstill in late 2000

showed how quickly a modern industrial economy (even one that produces a lot of its own oil and gas, like Britain) can be crippled when its flow of oil is interrupted. That vulnerability is as good a reason as any to start weaning the world economy off petroleum.

Supply-Side Chimera

If the first camp wants you to relax, the second camp wants to get you all riled up to *Keep pumping*. To do so, these folk have tried to hijack the concerns about energy security to support domestic energy firms. Explicitly citing the need to enhance America's "energy independence," George W. Bush tried in his early days in office to push a bill through Congress that would throw open part of the Arctic National Wildlife Refuge (ANWR) to oil drilling. Environmentalists were outraged by Bush's plan because they believed that it would inevitably spoil a pristine wilderness. Yet he redoubled his efforts after September 11, arguing that the case for Alaskan oil was only strengthened. He did not even blush when critics pointed out that the pipeline through which that oil must flow is itself more insecure than oil purchased on the global market: the pipeline has been shot at, bombed, and otherwise attacked a number of times already by drunks and delusional locals. A determined band of terrorists would probably find this vital conduit, which transports over a million barrels of oil a day to the lower forty-eight states, a nearly indefensible target.

An even bigger flaw in the Alaskan proposal was that it was based on the false premise that America could ever get close to energy independence. All the oil trapped in Alaska—for that matter, in all protected lands in the country—would not provide energy independence. America consumes a quarter of the world's oil but sits atop merely 3 percent of its proven reserves.

Even assuming that oil majors invest enough money to develop new fields in non-OPEC areas like the Gulf of Mexico and Russia, the "call on OPEC" will still double over the next twenty years. In

order to meet the world's unchecked thirst for oil, leading energy forecasters are hoping that Saudi Arabia and its neighbors will invest the vast sums necessary to expand output dramatically. If they do not, their output will stagnate or decline, and the consumers of the world will pay the price. But if OPEC does crank out all that extra oil, as economic self-interest would seem to dictate, consumers will still suffer. That is because the cartel's grip on the world's oil market—and therefore its ability to dictate prices—will then grow much stronger. And Russia, which has received a lot of attention of late as a potential "anti-OPEC," simply does not have enough reserves to challenge Saudi Arabia over the long haul. Alaskan oil or not, the future of the world economy will increasingly become a gamble on Middle Eastern oil. That's surely reason enough to begin the transition away from petroleum now.

CAFE Culture

"Conservation may be a sign of personal virtue, but it is not a sufficient basis, all by itself, for a sound, comprehensive energy policy." So proclaimed Vice President Dick Cheney in April 2001. The political backlash against that speech was so great that conservation is now firmly on the American political agenda. Cheney, the most forceful of those who argued that we should keep pumping, even became the poster boy for the third camp of energy thinkers: the *Ride your bicycle* gang.

At first blush, a focus on energy conservation seems an entirely good thing for America. The United States, unlike Europe, has done little to discourage the inefficient use of fossil fuels in recent years. The country imports over 11 million barrels of oil per day. America could have reduced that greatly if it had made a serious, sustained effort at curbing oil use during the last two decades.

Still, many people will always wonder how important reducing oil demand is when compared with adding supply. That is because some people's gut instinct about the nature of depletion of natural

resources may be misleading. Evar Nering, a mathematician at Arizona State University, explained to readers of *The New York Times* in 2001 that the nature of exponential growth means that curbing demand is more important than adding supply: "If consumption of an energy resource is allowed to grow at a steady 5% annual rate, a full doubling of the available supply will not be as effective as reducing that growth rate by half—to 2.5%. Doubling the size of the oil reserve will add at most fourteen years to the life expectancy of the resource if we continue to use it at the currently increasing rate, no matter how large it is currently. On the other hand, halving the growth of consumption will almost double the life expectancy of the supply, no matter what it is."

Using less oil is critical, but how exactly to do that? There is actually reason to think Cheney's skepticism about conservation is justified after all (though perhaps not for the reasons he had in mind): conservation may be morally appealing to the *Ride your bicycle* camp, but it could end up being a bad thing if it merely resulted in far less mobility, trade, and other things made possible by energy that enhance human welfare. In contrast, increasing energy efficiency is a very good thing—and policies that end subsidies or other sorts of support for inefficient or dirty technologies are even better. This is particularly true given how inefficient, in energy terms, the American economy is: Europe and Japan squeeze considerably more economic output out of the energy that they use than does the United States.

One efficiency measure that is always controversial in America is the strengthening of the Corporate Average Fuel Economy (CAFE) law: raising it for cars, and closing the loophole that allows light trucks and sport-utility vehicles (SUVs) to use more gas. The automotive industry has long fought such a move, arguing that it would impose an unacceptably high cost. Yet a look at the history of CAFE suggests otherwise. The years after Jimmy Carter's presidency saw the average fuel-efficiency of America's new car fleet rise by seven miles per gallon. From 1977 to 1985, America's GDP rose by more than a quarter even as total American imports of oil fell

by two-fifths; over that period, America's productivity in oil use soared. In other words, fuel-efficiency measures need not equal disaster. Even so, a far better way to encourage efficiency would be a price signal—for example, the imposition of a higher gasoline tax designed to reflect the environmental harm and energy security risks involved in using petroleum.

The car industry put on a full-court press in Washington to kill the effort to strengthen CAFE, insinuating that it would be the death of the American car industry. However, its bluff was called by a nonpartisan study done by America's National Academy of Sciences (NAS) in 2001. That analysis debunked the industry's arguments by identifying readily available technologies that could "significantly reduce fuel consumption of new cars over the next fifteen years." The experts were certain that reductions in fuel use up to 20 percent could be achieved easily.

What's more, the NAS group left the door open for even bigger reductions if radical new technologies that are now getting close to commercialization penetrate the market. Their optimism was based on the exciting new combination of hydrogen energy and fuel-cell cars, which makes it possible for the first time to contemplate a system of personal mobility that is completely free of harmful emissions and does not rely on the iron nexus of gasoline and the internal combustion engine. If that magical technology really takes off, and it will probably take a decade or more before it hits the big time, it could signal the end of the Age of Oil—and bring with it the death of OPEC, the collapse of Middle Eastern dictatorships, and a radical realignment of geopolitics. Because the hydrogen energy required to feed those fuel cells can be produced in all sorts of ways all over the world, and not just in the Middle East, this brave new energy world would not see any wars waged over energy resources and could never be held hostage by a future Osama bin Laden.

Impossible, you say? Not at all. In fact, this energy revolution is already well under way, as a trek to the mountaintop home of Amory Lovins reveals.

The Sage of Snowmass Speaks

If you want to catch a glimpse of our planet's future, visit the Rocky Mountain Institute (RMI). Nestled away in Old Snowmass, a quaint hamlet high in Colorado's snowcapped peaks, this curious think tank and "do tank" attracts visitors from all over the world who are interested in new ideas about energy and the environment. Upon arrival, visitors often find themselves on a tour whose highlights include a superefficient toilet and an indoor banana farm, "perhaps the world's highest," as one staffer boasted without hint of irony. Despite the elevation, the people who run this place do not really have their heads stuck in the clouds.

Amory Lovins is the intellectual force behind RMI. Like all visionaries, he gets things wrong, but he has also gotten some big things spectacularly right. In an article published in *Foreign Affairs* in the gloom after the first oil shock in the 1970s, he famously predicted that improvements in energy efficiency would lead to the decoupling of economic growth and energy use. At the time, most were convinced that America would continue to suck up more energy in lockstep with economic growth, and Lovins was widely ridiculed. Even America's Department of Energy had predicted that by the year 2000, oil prices would have skyrocketed to more than $150 a barrel in today's money. Though Americans will always complain about gasoline prices above a buck a gallon at the retail pump, the DOE's predictions were clearly wrong. America has learned to use energy more efficiently than it did in the 1970s—though, it must be noted, still not as efficiently as Japan or Europe—and history has vindicated Lovins.

For some years now, the Sage of Snowmass has been making another sweeping forecast for the future of energy, and again he is sounding fanciful: "This breakthrough will be like the leap from the steam engine to the diesel locomotive, from the typewriter to the laptop computer . . . it's a really disruptive technology." He gestures toward a covered object in the center of a spacious high-tech

workshop where his team of engineers has been beavering away for years. With a flourish befitting a mad scientist, he unveils his creation: the Hypercar.

After nearly a decade of work, and with the support of big industrial firms from Europe, Japan, and the United States, his outfit has developed a concept car that it believes will be the clean power plant of the future: it features electric propulsion, a 100 percent composite-plastics body, highly sophisticated electronics and software, and a radically simplified and integrated design. Most important, his roomy and stylish SUV will be powered by a stack of fuel cells.

What exactly are fuel cells? According to Lovins and others, these nifty inventions are the Next Big Thing. They are essentially big batteries that produce electricity by combining hydrogen fuel and available oxygen. They do this much more efficiently than a conventional car engine that uses gasoline. They run nearly silently. Best of all, their only by-product is harmless water vapor. They are already beginning to appear in stationary applications, such as generating power for clusters of homes and factories, and are likely to appear within a few years in portable applications: laptop computers, cellular phones, even climate-controlled bodysuits for tomorrow's soldiers.

Greens, consumers, and industrialists alike should rethink their prejudices. With fuel-cell technology, even a gargantuan Ford Expedition could sip hydrogen and emit absolutely none of the usual tailpipe gases that contribute to smog and global warming or that damage human health. There's a dream that avid consumers and righteous environmentalists might share.

But Lovins has his eye on bigger game. He is convinced that consumers will be able to use the fuel cell under the hood as a "micropower" plant that can power their homes or offices. Such cars might also be used as backup generators, or while traveling in remote areas. He sees nothing preventing consumers from plugging these electric cars into a wall socket during peak hours, when the power grid is overloaded, and selling the electricity they generate back to the utilities for a profit.

In a nutshell, Lovins thinks that some version of the Hypercar will turn the modern world upside down. It is tempting to dismiss his latest forecast as hopelessly utopian. Oddly enough, though, just days before Lovins unveiled his Hypercar on the other side of the world, another wild-haired visionary, Ferdinand Panik, had introduced a similar hyper-green power plant on wheels. At that unveiling, in Berlin, there had also been talk of revolution, and even the promise of an Energy Internet: "We can use the energy unit in this car for homes or stationary power. When linked together by smart electronics, our customers can buy and trade energy freely." Panik's boss, Jürgen Schrempp, was even more effusive: "The problem of how to ensure sufficient supply of energy that is environmentally friendly is the key challenge of the future, and we see fuel cells as the solution."

Schrempp and Panik were not pundits or pie-in-the-sky dreamers: they were, respectively, the chairman and the chief fuel-cell expert at DaimlerChrysler, one of the biggest carmakers in the world. The company has already spent $1 billion to develop its "new electric car" (NECAR), and Panik expects the company to shell out another billion or so over the next decade to ensure its success. Daimler now expects to have its first commercial fuel-cell cars on the road by 2005, and mass-market volumes in about a decade.

Daimler is far from alone. Honda, Toyota, and GM also say their fuel-cell cars will be ready by then, and others claim they will follow. A number of car firms and oil companies have jointly opened up a hydrogen refueling station for their demonstration cars near California's capital of Sacramento. There is also a similar hydrogen station near Munich's airport. Daimler's top managers claim that in twenty years' time, fuel cells will power perhaps 20 percent of all new passenger vehicles, and possibly all urban buses.

What do the stodgy old utilities think of all this airy talk? Ask Kurt Yeager, the head of the Electric Power Research Institute, which is the research body of the utility business. You might expect him to be dismissive of all this talk of micropower and Energy In-

ternets. On the contrary, he can hardly contain his excitement: "Today's technological revolution in power is the most dramatic we have seen since Edison's day, given the spread of distributed generation, transportation using electric drives, and the convergence of electricity with gas and even telecommunications. Ultimately, this coming century will be truly the century of electricity, with the microchip as the ultimate customer."

If the lines between the auto industry and the power industry really do begin to blur, the impact on the economy, on industry, and on all our lives could be dramatic indeed. Consider just one killer statistic: the power generation capacity found under the hoods of cars in Germany or America is ten times that of all of the nuclear, coal, and gas power plants combined in those countries. In other words, Ford Motor Company alone could add more juice to America's power grid than all of America's conventional power utilities put together. That is what makes this recent pronouncement from Bill Ford—Ford's chairman and the great-grandson of the company's famous founder—such a bombshell: "I believe fuel cells will finally end the 100-year reign of the internal combustion engine."

That is nothing short of an endorsement of Lovins's vision, and the epitaph for today's motorcar—the filthy but durable workhorse of the twentieth century.

The Quiet Revolution

This book is a survey of something really big going on in the energy world. The first section looks at one of the three powerful forces behind that change: the rise of market forces. From California to Cologne to Calcutta, governments are liberalizing their cosseted energy markets and throwing open their borders to trade in gas and electricity. For example, about half of America's states, led by California, have forged ahead with some form of electricity deregulation. Europe and Japan are also liberalizing their gas and power markets in fits and starts. Though there will be some bumps

along the way, the resultant outpouring of entrepreneurship, financial capital, and innovation promises to transform today's energy world beyond recognition.

The second section of the book examines how the recent surge of environmentalism is now reshaping energy. Outrage over local air pollution, from California to China, is putting pressure on governments to explore clean power and transport. Equally important has been the concern over climate change, which will require mankind to make a slow but sure shift to a low-carbon energy system over the course of this century. Many countries now look unfavorably on fossil fuels, and encourage renewable energy. However, the recent move by George Bush to kill the UN's Kyoto treaty on climate change has led many environmentalists to despair that America will never do its fair share to combat global warming. Look beyond Bush's desire to please the energy business, however, and you find that his skepticism about Kyoto is shared by many others, who also worry how much fighting global warming will cost—and wonder if it is really worth doing whatever the price.

So is there no hope for meaningful action on global warming? Have Big Oil and the Bush Administration made a mockery of the efforts to green the energy industry? On the contrary. Today's debates over climate change are but a small taste of the broader environmental challenges to be faced by the world as it tries to meet its soaring energy needs, and a sign that Big Oil must change—or find itself relegated to the rubbish heap of history. The most promising development on this front is the growing popularity of market-based environmentalism, which applies commonsense tools of economics like cost-benefit analysis, emissions trading, and pollution taxes to problems like climate change. By leveling the energy playing field and using carrots as well as sticks to motivate companies, governments are much likelier to nudge the market in a greener direction.

The third section of the book describes the unprecedented wave of technological innovation now upending the energy business. The deregulation of markets, when combined with rising environ-

mental demands, is spurring the development of such promising technologies as fuel cells and microturbines. Thanks to the rise of the Internet and sophisticated command, control, and communications software, the creaky old power grid is about to leapfrog into an intelligent network worthy of being the true backbone of the digital economy.

Just a few years ago, talk of the energy sector as exciting or innovative would have inspired loud guffaws from Wall Street: after all, utilities have long been considered so safe and stable (read: boring) that they used to be called widows' and orphans' stocks. Thanks to deregulation, the rules of the game are now changing at a dizzying pace. The stock market interest in "energy technology" stocks, which even produced an Internet-style bubble in the late 1990s, is a clear sign that the broader public is waking up to the potential of fuel cells.

The happy collision of markets, environmentalism, and innovation explains the most powerful trend of all in energy today: micropower, which puts small, clean power plants close to homes and factories. That may sound unremarkable, or even like common sense, to the reader—but in the energy business it is near heresy. It is in fact a dramatic reversal of the age-old utility practice of building giant power plants far from the end user. The most surprising aspect of the micropower revolution is that tomorrow's energy world will be based as much on silicon chips, software, and superconductors as on soot and sulfur. Dramatic advances in software and electronics offer new and more flexible ways to link parts of electricity systems together. Today's antiquated power grid, designed when power flowed from big plants to distant consumers, is being upgraded to handle tomorrow's complex, multidirectional flows (the result of micropower plants selling power into the grid as well as buying from it). It is this breakthrough that will finally make possible the intelligent homes and the Energy Internet of the squeaky-clean, not-too-distant future.

Bigger than the Internet

What is about to happen in the energy realm is every bit as dramatic as the telecommunications revolution of the past two decades, which, despite the recent rocky ride of telecom stocks, has brought the world such astonishing developments as cheap long-distance calls, cellular telephony, and the Internet. In fact, the coming energy revolution is quite possibly more important, for two reasons. One is that energy is the world's biggest industry, by far—America's electricity industry alone is bigger, in terms of revenues, than the country's long-distance telephony and cellular telephony businesses combined (that calculation does not even include Big Oil, Big Coal, or Big Anything Else). All told, the global energy game is nearly a $2 trillion–a–year business.

The second reason the energy revolution is so important is, of course, the impact our energy use has on the environment. The planet's health was the theme of the famous Earth Summit organized by the United Nations in Rio de Janeiro in 1992. The world's heads of state, along with thousands of activists, lobbyists, officials, scientists, and journalists, were there to push for their pet green causes—especially fighting global warming. After a decade of sketchy progress, the world's leaders gathered for a follow-up Earth Summit in Johannesburg, South Africa, in August 2002. Once again they sought to reconcile the demands of economic development with concerns about the environment—and once again energy-related problems such as global warming and local air pollution were at the top of their list of concerns.

This time, though, something interesting happened. After the usual squabbles—over whether to put the earth first or people first—subsided, the gathered heads of state hit upon a strategy that would do both: they agreed to help the world's poorest people gain access to modern energy in ways that are environmentally sustainable. In the next couple of decades, China and India will add thousands of new power plants and many millions of new vehicles as

their economies grow. The rich world should help them do so using clean technologies like renewables and micropower. If not, a window of opportunity to set the world on a clean energy footing may be lost forever. It would kill many Indians and Chinese prematurely and needlessly, and would undermine efforts to combat global warming. It may even radically alter geopolitics if the relationship between an energy-starved China and an oil-rich Saudi Arabia begins to threaten America's web of alliances in the Middle East.

The world is at a crossroads. Decisions taken in the next few years about energy in big countries like the United States will shape the investments made in energy infrastructure around the world for a generation or more. After all, coal plants and oil refineries last for decades—and that sunk investment displaces or discourages nimbler, cleaner, and more distributed options like micropower. If we want to shift to a clean, secure, low-carbon energy system during this century, the time to start is now.

If the three camps in the energy debate remain so intransigent and shortsighted, the road ahead might prove a tortuous one. Happily, there are already signs that the dizzying pace of innovation out in the real world is bringing with it entirely new and better ways of thinking about energy that may yet render their arcane policy debates irrelevant. If micropower really takes off, then there is every reason for optimism about our planet's future. Let the revolution roll!

MARKET FORCES

The Invisible Hand Ascendant

Fast Forward to
second half of last chapter
Micropower Meets Village Power

complex processes bring with them greater risks of capture by special interests and failure due to a cacophony of voices." In other words, no matter which approach to reform you take, it isn't going to be easy.

Bombay Dreams

It has become clearer than ever before that it is the rural rich, not the subsistence farmer too poor to afford a water pump, who benefit from the billions of dollars spent every year on subsidizing power for agriculture. Many of the electricity "losses" attributed to unmetered consumption in agriculture never reach farmers. Commercial and residential users, in cahoots with crooked SEB officials, pilfer that power. The best proof of this once-contentious notion is in Delhi: the local SEB has virtually no agricultural clients, yet investigations into its books a few years ago revealed that it "lost" a staggering 55 percent of its power. The myth of the politically untouchable Indian farmer is finally being debunked, and consumers have started to grow impatient: impatient with power cuts; impatient with power losses; above all, impatient with the failed promises of populists. They seemed to be giving reformers a chance to do better. In the Indian state of Uttar Pradesh, efforts assisted by the World Bank to reform the SEB led to a noisy strike by the state's electricity union in early 2000. Yet the union found no popular support. In elections that followed in Andhra Pradesh state, Chandrababu Naidu, the state's reform-minded chief minister, faced an opponent who promised free electricity. Naidu stuck to his guns: "Get free electricity for one hour a day, or pay and get power twenty-four hours a day." Against all expectations, voters reelected him.

Indian consumers, even poor ones, are willing to pay for electricity, so long as they get enough of it. Experience in the state of Rajasthan demonstrated that farmers are happy to be metered, and to pay higher tariffs, if they see a reliable supply. This is true of the

urban poor too, as a visit to Maratha colony, a slum near the airport in Mumbai, made clear. The dwellings are slapdash, the tenants have no proper title to their land, and children play among piles of rotting garbage and open sewers. It hardly seemed a promising market for private power. Yet peering into the tenements, I found that each had electricity: a bulb and a fan, perhaps a small fridge or television. Bombay Suburban Electric Supply (BSES), the private firm that serves Maratha, estimated that perhaps 60 percent of its 1.8 million customers live in such slums.

I was taken aback. I asked R. V. Shahi, then the head of BSES, how he could possibly turn a profit servicing slums. He explained with pride that his firm was unique in India in that it had been providing power privately to Mumbai for more than seven decades. The firm had thus avoided becoming ensnared in red tape or populist quagmires like power giveaways to favored groups. Because BSES was run like a proper corporation, he explained, it had invested heavily to provide even these downtrodden consumers with "safe, reliable, quality power"—and they returned the compliment, he explained, by paying their bills. I remained unconvinced. Then his field managers took me on a detailed tour of the innards of the slum's electrical system. They showed me how every home was metered with tamper-proof equipment of the sophistication you would expect in a rich country. They explained that the bills were computerized and that the quality and quantity of energy delivered were carefully monitored. What about the culture of corruption? My guide grinned broadly as he explained, "No problem. We cross-check the meter readings with surprise audits!"

As I was jotting all this down, a curious resident of the Maratha colony stuck his head out of his doorway to see what all the fuss was about. I seized the opportunity to put the BSES propaganda to the test. I ducked into his humble apartment and asked him if I could see an electricity bill. Within moments he produced an envelope containing a computerized printout detailing his power usage and charges. Ah, I thought to myself, now I'll look him straight in the eye and ask him the zinger: Do you really pay the bill? I was

sure that such an obviously poor resident of an urban slum, in a country rife with corruption and pilferage of electricity, must have some misgivings. He was genuinely astonished by the question: "What? Do you think the power will come for free?" Even Bangalore's Internet billionaires could not put the case for market-minded reforms more succinctly.

Hope can be found in the dramatic shift, linked to the move to competitive energy markets, away from big energy projects at international financial institutions and aid donors. It can also be found in the growing power of grassroots activists. Taken together, these changes suggest that the centralized, fossil-fuel-based power grid that is the mainstay of developing economies may be surpassed in the future by a much nimbler and far cleaner energy infrastructure that can serve the needs of the poor. Nowhere is this convergence of forces more apparent than in the heated debate over the future of big dams.

Dam Shame

"Big Dams are to a Nation's 'Development' what Nuclear Bombs are to its Military Arsenal. They are both weapons of mass destruction. They're both weapons governments use to control their own people. Both twentieth-century emblems that . . . represent the severing of the link, not just the link—the *understanding*—between human beings and the planet they live on." So says Arundhati Roy, the celebrated Indian novelist turned protester. Those are controversial—if not explosive—charges she's lobbing at hydroelectric power, and at first blush, they seem pretty absurd.

Jawaharlal Nehru, a hero of India's independence struggle and its first prime minister, felt that dams were "the temples of modern India." A third of the world's countries—including some of the poorest—depend on hydropower for more than half of their electricity. A substantial portion of the world's irrigated land depends on dams too. Reliable and inexpensive irrigation water helps farmers and ensures that consumers benefit through cheaper food.

In fact, this seems to be the era of the Big Dam. Asia is home to much of the world's dam building, including two of its most ambitious projects: those in India's Narmada Valley (which so outraged Roy) and China's Three Gorges. Indian and Chinese officials are quick to point out the many splendid benefits of these megaprojects. The Three Gorges dam is designed both to generate some 20 gigawatts of electricity and to help control the floodwaters of the temperamental Yangtzi River. India's planners promise that the Narmada project will likewise deliver electricity and irrigation. Such ambitions are admirable. Lack of irrigation relegates millions of Indians to subsistence farming. In China, massive floods in 1998 destroyed five million homes.

So is there any reason to take Arundhati Roy seriously? Actually, she's onto something. All across the world, and even in India and China, a backlash against the Big Dam is gaining momentum. Ecological, social, and financial arguments can be made against dams, but they all point to the same conclusion: megapower is going out of fashion. And, while activist-novelists are unlikely to admit it, it is the liberalization of the poor world's energy sector that is dealing the deathblow to these monstrosities.

Large dams were once welcomed by some environmentalists as a source of clean and endlessly renewable energy, but their green credentials are tarnished. The flooding that accompanies big dams in the developing world usually submerges large tropical forests. As vegetation decays, it can release lots of methane, a much more powerful greenhouse gas than carbon dioxide. Unlike giant dams in rich countries, dams in the tropics must endure the ravages of monsoons. One common result is silting up, which may cut the original generating capacity by 70 percent or even 80 percent within a few decades.

Many species are affected by hydroelectric projects, most famously the salmon in America's Columbia River. Big dams can suck nutrients out of rivers, change their temperature, alter their flow, and distort flood cycles—all of which harm some species living in the watershed. People can be hurt too, as some reservoirs act as breeding grounds for mosquitoes and therefore nasty diseases like malaria.

Putative dam builders must also contemplate the potential social cost: as many as 80 million people worldwide have been displaced by dams in recent decades. Governments usually make noises about giving them cash or land in compensation, but in practice, such promises are often forgotten. Given the steady advance of democracy around the world, it's getting hard for central planners to dismiss the voiceless millions. The Narmada project has displaced many tens of thousands. Pressure from grassroots groups has already forced the government to scale back its plans. The partially finished Sardar Sarovar dam, which is at the heart of the scheme, will probably never be completed. Of the several thousand dam-related projects in that valley, most will never see the light of day. Dams that are finished will be at a lower height than envisioned, and they will be redesigned to reduce their social and environmental impact.

Even in China, the big-dam juggernaut is not so formidable as it once seemed. Doris Shen of the International Rivers Network observed that the Chinese government was having terrible difficulties selling the electricity from earlier dam projects whose power proved much more expensive than power from smaller stations. The further China's electricity liberalization goes, the less competitive power from such white-elephant projects will be. Indeed, as the true costs of the Three Gorges dam soar skyward, Shen is convinced that only the hubris of an all-powerful regime—along with some kickbacks—has saved the project.

The economics of big dams make little sense. Even Asia's zealous dam builders "are being pulled into global principles by market forces," according to Achim Steiner. Today he heads the World Conservation Union, but he used to be the secretary-general of the World Commission on Dams, an innovative organization created by governments, development agencies, and NGOs to help forge a consensus on the big-dam problem. That commission's final report made it clear the future for big dams is not bright.

Large hydro-projects are being squeezed by both private and public investors. Aid money is drying up. Big dams are so controversial that even the World Bank, once the biggest force behind them, has grown skittish. The agency suffered a humiliating setback in the 1990s in India when an outside report it commissioned turned out to be sharply critical, leading it to abandon the Narmada project. That in turn prompted a broader internal review, which concluded that governments often fail "the acid test" the World Bank recommends for dams—"the restoration of incomes and standards of living of project-affected people."

Less aid money means higher costs of financing. And the inevitable protests and legal wrangles with NGOs adds financial risk, which also translates into higher costs. The sharpest blow, however, comes from the continuing deregulation of the global power industry. Why? Simply put, that shifts financing away from the state sector, where bureaucrats spend other people's money, to the private sector, where people spend their own money. The predictable and happy result is a move toward lower-risk projects with more reliable, quicker returns. Smaller plants fired by natural gas and even renewable energy are finding favor over dams and nuclear power plants.

Even if big dams are out, small ones need not be. They can achieve many of the benefits promised by big dams at a fraction of the cost—and with the support of locals. So it's not the end of hydropower. It's just one more part of the global move from megapower to micropower.

Small Is Beautiful

Central planners have lavished vast sums on grandiose schemes to build dams and nuclear- or coal-fired plants. Because these projects had little accountability or transparency, they have typically been completed late, over budget, and with a far greater social impact than estimated, and they are usually run at far lower efficiency levels than promised.

Market reforms in the production and delivery of power have in-

jected a strong dose of reality and risk assessment. Most of the financing of power projects in developing countries now comes from the private sector, a dramatic reversal from just a few years ago. As a result, from Honduras to the Philippines, energy investors are increasingly favoring small, efficient power plants fired by natural gas or other forms of distributed generation, bypassing the dinosaurs.

Liberalization is also leading to the reduction of subsidies for fossil fuels, which is sure to boost the penetration of clean forms of distributed generation. While the rich world is also guilty of such perverse distortions of the market (Germany and Spain still subsidize their coal industries, for example), the IEA thinks that the bias in favor of dirty energy sources is greater in many poor countries. A reliable study of eight of the biggest energy-consuming countries outside the rich world found that the average end-use prices for fossil fuels were about 20 percent below what market prices would have been. Removing these subsidies, it estimates, would reduce wasteful energy consumption by 13 percent, increase those countries' economic efficiency significantly, and even lower emissions of carbon dioxide by 16 percent. All told, the IEA experts think the GDP of those countries could be lifted by 1 percent or so—a big enough number to matter.

Piously claiming to defend the interests of society's poorest, governments in developing countries still lavish billions of dollars in blanket subsidies for gasoline, kerosene, and coal, and they waste outrageous amounts of electricity by giving it away free to politically important groups like rich farmers. Rarely do the truly indigent—landless peasants or laborers—benefit. Worse yet, argues the IEA, "the waste and inefficiency that subsidies have engendered in the electrified part of the economy have often blocked the expansion of the electricity grids."

Things are starting to change. Prodded by market reforms as well as by growing concerns about the environmental impact of fossil fuels, governments are removing some of these subsidies. The most dramatic example is China, which has stripped away many of its subsidies for dirty coal and has encouraged a shift to

cleaner natural gas. Though reliable figures are hard to come by, coal consumption in China appears to have moderated over the past few years even as its economy has grown by leaps and bounds.

Development banks have traditionally been among the biggest backers of giant power projects in poor countries. Now they are leaving such decisions to the market, pushing governments for deregulation and privatization of their power sectors. Donors are also taking into account the high interest cost incurred by inevitable construction delays, and taking aim at export credits, another hidden subsidy for dirty power projects.

Encouraging as these top-down developments are, the best reason to believe that a cleaner energy future awaits the world's poor comes from the bottom up. Conventional wisdom holds that poor countries will not care about the environment or cleaner energy—and will certainly will not pay for it—as long as the masses are mired in poverty. Tell that to the Grupo de Cien, an environmental group in Mexico City that has been pushing for a cleanup of that city's foul air, or the Centre for Science and Environment (CSE), an environmental NGO in Delhi whose noisy and well-coordinated campaign to improve children's health led to a ban on diesel buses. Local activists all over the developing world, emboldened and enriched by activist brethren in the rich world, and informed and linked by the Internet, are clamoring for greenery.

Perhaps surprisingly, this fervor is spreading to China too. Liang Congjie, the head of Friends of Nature, runs one of China's few NGOs. He explains why he is allowed to operate: the Communist bosses have judged that public outrage over pollution is so strong that they allow complaints about the environment to be voiced. Even the media are allowed to run riot on the issue, and investigative reports and undercover exposés of green cheats have now become the norm. That is not quite full-fledged democracy, but it's surely a step in the right direction.

Village Power: Meet Market Power

The soaring demand for energy in the poor world can be met in ways that empower people rather than bureaucracies, that are cleaner and ultimately more sustainable than today's. These are the foundations of a philosophy that is emerging as the energy paradigm for the next century. At a recent summit in Washington, D.C., dubbed Village Power, experts from donor agencies like the World Bank and America's Agency for International Development met with nongovernmental groups devoted to clean energy, as well as with private-sector companies promoting renewable energy.

The rallying cry for the gathering came from Frank Tugwell, the head of Winrock International, an Arkansas-based development NGO, who called on the attendees to commit to a specific target: "We must provide electricity to 500 million people currently without access to it by 2010 through investment in community-based renewable energy!" That is a noble goal, and certainly a pressing one. Making it reality, however, will be impossible unless the powers that be pay close attention to the lessons offered by the contrasting attitudes of Bill Gates and Gerardo Zepeda.

So who was right? India's Centre for Science and Environment weighed in on this matter recently. It ran a cover story in its magazine called "Computer Connected Villages: Is It Real?" After a detailed investigation of San Ramon–style experiments all over India, the group's researchers came up with this analysis: "No, IT [information technology] will not usher in the dawn of a brave new world, transforming Indian villages into stuff that makes advertising brochures. But yes, IT is a great tool, which, if properly used, could improve the life of millions. But some daunting problems need to be conquered first . . . [and] the greatest worry is electricity supply." The researchers pointed to some examples of makeshift power sources used to make those fancy computers work under Indian conditions: "A project in Pondicherry is combining the power supply from the grid with battery backup and solar power. Draught

power from livestock can be used to generate 40,000 megawatts of power in villages." Farm animals are probably not quite the sort of "village power" that the big shots in Washington had in mind, but evidently they do the trick. In other words, the Indian example suggests that Gates and Zepeda have each got it partly right.

Gates was certainly spot-on in pointing out that cost is often an obstacle: Who will pay for the fancy solar panels and other expensive equipment that undoubtedly improves lives? In stressing that many of the world's poor earn but one dollar a day, he made two good points: their primary need is for food and clean water, not snazzy electronics; and even accepting that access to electricity improves their chances of obtaining those necessities, subsidies are clearly required.

Zepeda, for his part, was right to stress that electricity can transform remote villages, helping them leapfrog from the Dark Ages to the twenty-first century. In San Ramón, locals started to take advantage of telemedicine and distance learning. The town's women learned how to peddle their arts and crafts through e-commerce. Some villagers earned money teaching Spanish, via video link, to students in Oklahoma (which had a shortage of Spanish teachers). An educational software package even identified several gifted children who went on to higher education.

However, both men were also wrong in important ways. Gates's pessimism, for example, oversimplified the matter. While the very poorest will always need subsidies, that does not mean there is no ability to pay for energy among the world's poor. Of the people without access to energy today, the World Bank estimates that perhaps half do have the ability to pay commercial rates for electricity. The rest, of course, will clearly need some government subsidies however the power is delivered.

The crucial—but often overlooked—point is that there is ample evidence that the poor already do pay, often heavily, for energy services that the state fails to deliver. The amount of money spent by those dirt-poor households on inefficient, dirty ways of delivering energy—such as kerosene, candle wax, and recharging batter-

ies—can be greater per kilowatt than what is spent by middle-class urban households or wealthy farmers on heavily subsidized grid electricity. Families in Peru's remote highlands now pay some $4 a month for candles. For just a bit more, they could afford the much-higher-quality power offered by village power units: experts say that local entrepreneurs can turn a profit by leasing out a small 35 kW solar unit (enough to power two bulbs and a radio) for just $80 a year.

In Yemen, where there are no legal barriers to entry into the "wires" business, dozens of tiny private generators have sprung up to service households not reached by the inadequate grid system. Though the price charged by these entrepreneurs is quite high and the frenzied competition occasionally unruly, even poor households scrape together the funds rather than live in the dark. As a result, electricity penetration in Yemen tops 50 percent of households, a far higher level than found in comparably poor countries. Yemen's remarkable experience suggests that there may be an enormous market in serving the energy-poor; it also highlights the gross inefficiency and unfairness of centralized grid systems.

While Zepeda's high-tech model is inspiring, some worry that it will simply prove unsustainable. What will San Ramón be like a few years from now, after the spotlight has faded and the government has either lost interest or lost power? Indeed, Zepeda himself is no longer a government minister. Zepeda insisted that the changes in the village are both cost-effective and irreversible, but development experts are more skeptical. "The developing world is just littered with examples of energy projects that have failed because donors or governments did not think about how they will be maintained and paid for," said Christine Eibs Singer of E+Co, a nonprofit organization specializing in financing renewable energy. She insisted that the key to sustainability lies in helping local entrepreneurs create markets for energy services. That is not as far-fetched as it may sound. Her outfit has been at the forefront of an innovative approach that helps locals to help themselves. Using aid money from the Rockefeller Foundation and others, E+Co invests

"risk capital" in start-up firms in developing countries that want to deliver clean micropower to villages; it also advises them on how to craft sensible business plans, sales and distribution strategies, and so on.

Bankers in developing countries refuse to accept the fact that the poor are usually excellent credit risks: the dozens of projects funded by innovative NGOs like E+Co have demonstrated repayment rates of 92 to 98 percent. Obviously, users must pay for services. Local firms have employed various approaches, ranging from up-front cash for some customers to fee-for-service or leasing approaches. A particularly promising technique, similar to that used by some mobile-telephone firms, employs prepaid tokens that can be purchased at shops. That eliminates the need for awkward credit checks and large up-front payments.

TERI's Raj Pachauri thinks that helping develop local entrepreneurs with incentives to maintain and expand the micropower infrastructure is the key. His group has worked for years to come up with techniques and tools for training such local micro-capitalists. He tells of the sheer astonishment expressed by an Indian cabinet minister when Pachauri took him to an extremely remote tribal village in Bihar, a particularly poor state in the east of the country: "He had seen the situation in the village earlier, when all the homes were full of soot and smoke. After the renewable energy interventions, he proclaimed that what he had seen was a silent revolution. He immediately directed his ministry to enhance resources for such programs."

Unfortunately, this successful model is not easy to scale up to the level of the Indian federal government—let alone the World Bank or big donors, "600-pound gorillas" that are accustomed to dealing directly with national governments on projects worth tens or hundreds of millions of dollars and are simply unable to disperse small loans to entrepreneurs. Through "investment pools" and other innovative approaches, E+Co is now hoping to reach small energy entrepreneurs (or perhaps even to create them) in poor countries neglected by the capital markets and those big gorillas.

One approach is the "negative concession," through which governments privatize the provision of basic services to the very poor or to scattered rural populations, awarding these contracts to the bidder that requires the smallest subsidy. Chile considered the use of this approach in water provision, and Nepal in telecommunications. South Africa embraced this concept in a promising way too: rather than expand the central power grid to remote areas at a cost of a few hundred dollars per household, the government declared that it would offer that subsidy instead to the firms that win concessions to provide off-grid, renewable power to those villages now without grid access.

So is it time for the world's energy-poor to start cheering? José Goldemberg, a Brazilian expert in energy poverty, offers these words of caution: "We cannot simply ignore the energy needs of the two billion people who have no means of escaping continuing cycles of poverty and deprivation . . . But changing energy systems is no simple matter. It is a complex and long-term process—one that will require major and concerted efforts by governments, businesses, and members of civil society . . . we need to do more to promote energy efficiency and renewables, and to encourage advanced technologies that offer alternatives for clean and safe energy supply and use. We also need to help developing countries find ways to avoid retracing the wasteful and destructive stages that have characterized industrialization in the past."

In sum, we need a happy collision of clean energy, microfinance, and community empowerment. Mobilizing investor interest will be critical to unleashing the power of markets. So too will intelligent government policies, argues WRI's Navroz Dubash: "Market reforms will support a transition to a micropower future only if reforms are intentionally designed to do so." And the good news is that this is beginning to happen. Micropower is beginning to join forces with village power.

Grace Yeneza of Preferred Energy, a Philippine NGO, could not contain her excitement as she described the success her group has had implementing this approach in several remote villages along a

small river in the highlands of Luzon. "These villages had no access to the electricity grid," she explained. Working with the local councils called *barangays*, her group built a micro-hydroelectric plant that delivers electricity to the common areas of several villages through a mini-grid. Donor agencies paid for the equipment, but she said the key was the fact that the villagers pitched in "equity" in the form of labor and local materials. They also organized themselves into a management committee to run the plant. Those who want power for their households can receive it, but they must pay for the privilege. Then she got to the best part of her story: "Thanks to this project, the villages not only got power but they also learned to cooperate and stop fighting over the river!"

With more success stories like that, even Bill Gates and Gerardo Zepeda would probably agree that the future for the world's poor need not be so dark after all. Or to put it in Arundhati Roy's words, "The dismantling of the Big. Big bombs, big dams, big ideologies, big contradictions, big countries, big wars, big heroes, big mistakes. Perhaps it will be the Century of the Small." And how fitting it would be if the fuel of choice for that century were to be the lightest element of all—hydrogen.

Epilogue: The Future's a Gas

AS FAR BACK as 1874, during the foulest days of the industrial revolution, Jules Verne envisioned a world based not on fossil fuels but on clean hydrogen energy. He wrote in *The Mysterious Island*:

> Yes, my friends, I believe that water will one day be employed as fuel, that hydrogen and oxygen which constitute it, used singly or together, will furnish an inexhaustible source of heat and light, of an intensity of which coal is not capable . . . water will be the coal of the future.

Could the man who forecast the development of such technological marvels as submarines, helicopters, and space travel have gotten energy right too?

Fuel cells are as good a bet as any to deliver that energy, given the dramatic progress that has already been made in bringing them to market, but the beauty of the hydrogen model is that it is not wedded to any specific primary energy source or technology.

Hydrogen can be made from fossil fuels as well as from renewables; and it can be used in internal combustion engines as well as in fuel cells. That flexibility, as much as its cleanliness, ensures hydrogen a bright future.

Of course, no one knows what the future holds for our planet. A century from now the world may continue to be happily, if unhealthily, addicted to fossil fuels. Still, after a century in which talk of hydrogen energy has been strictly the domain of crackpots, there is at last conclusive evidence to think that Jules Verne was onto something. It turns out that the world has slowly been shifting away from heavy hydrocarbons like coal and toward lighter ones like natural gas for many years. In molecular terms, all are combinations of carbon and hydrogen—but today's fuels have less carbon content and so burn cleaner. Hydrogen, which has no carbon attached and can produce electricity without any emissions whatsoever, is the ultimate energy carrier.

Jesse Ausubel of Rockefeller University describes the trend this way: "The most important, surprising and happy fact to emerge from energy studies is that for the last 200 years, the world has progressively favored hydrogen atoms over carbon . . . the trend toward 'decarbonization' is at the heart of understanding the evolution of the energy system." Even before industrialization, societies started shifting from dirty solid fuels with a high carbon content to liquid hydrocarbons and ultimately to clean-burning gases, shifting from wood and cow dung to coal to oil and natural gas. Comfort, convenience, and cleanliness have long driven the decarbonization trend—and these are the best reasons to think that the world will one day reach the hydrogen era.

It is encouraging that the most powerful force for decarbonization through the ages has been the free will of ordinary people, expressed through choices made in the free market. It is no coincidence that the historical trend has stalled in recent decades, when governments have taken to meddling heavily in energy markets. Robert Hefner of the GHK Company, an American energy firm, observed: "For more than a hundred years, free markets and the ingenuity of mankind worked efficiently to decarbonize our energy systems. It was only in the 1950s, when governments began to tinker with price controls and later, reacting to cries of shortages by the energy industry, allocated fuels among sectors of consumers, that we began to recarbonize the energy system." He is not exaggerating. Many governments, including America's, actually banned the use by factories of natural gas in the 1970s, mistakenly believing that the clean and abundant fuel was scarce. That needlessly led many companies to rely on dirtier power from coal.

If governments level the energy playing field, the trend away from carbon could well resume. Hydrogen thinkers like Hefner argue that by 2050, natural gas and hydrogen will surpass oil and coal as the energy carriers of choice, and that by the end of this century, these energy gases could have 75 percent of the global energy market, the same as King Coal in his heyday. That vision is increasingly finding converts even among mainstream forecasters at government agencies and companies.

The International Energy Agency argues that the great hope for environmentally benign energy lies in "crosscutting" technologies that can exploit energy from several different sources. In particular, the IEA highlighted hydrogen fuel cells and carbon sequestration as technologies that, alone or together, could "have a profound impact on the long-term prospects for energy supply." Royal Dutch/Shell, a world leader in scenario planning, was even more enthusiastic about the prospects for a hydrogen economy. In late 2001 the oil giant unveiled two energy scenarios that it reckons could unfold by 2050. One sees fossil fuels and incumbent technologies maintaining supremacy over time, but the other predicts a dramatic burst of innovation and experimentation that could usher in the hydrogen age. According to this second scenario, half of the new cars sold in the rich world in 2025 will use fuel cells, and oil demand will slacken to the point that the commodity becomes dirt cheap. OPEC: you have been warned.

Epilogue Continues