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The Increasing Sustainability of Conventional Energy

by Robert L. Bradley Jr.

Executive Summary

Environmentalists support a major phase-down of fossil fuels (with the near-term exception of natural gas) and substitution of favored "nonpolluting" energies to conserve depletable resources and protect the environment. Yet energy megatrends contradict those concerns. Fossil-fuel resources are becoming more abundant, not scarcer, and promise to continue expanding as technology improves, world markets liberalize, and investment capital expands. The conversion of fossil fuels to energy is becoming increasingly efficient and environmentally sustainable in market settings around the world. Fossil fuels are poised to *increase* their market share if environmentalists succeed in politically constraining hydropower and nuclear power.

Artificial reliance on unconventional energies is problematic outside niche applications. Politically favored renewable energies for generating electricity are expensive and supply constrained and introduce their own environmental issues. Alternative vehicular technologies are, at best, decades away from mass commercialization. Meanwhile, natural gas and reformulated gasoline are setting a torrid competitive pace in the electricity and transportation markets, respectively.

The greatest threat to sustainable energy for the 21st century is the global warming scare. Climate-related pressure to artificially constrain use of fossil fuels is likely to subside in the short run as a result of political constraints and lose its "scientific" urging over the longer term. Yet an entrenched energy intelligentsia, career bureaucrats, revenue-seeking politicians, and some Kyoto-aligned corporations support an interventionist national energy strategy based on incorrect assumptions. A "reality check" of the increasing sustainability of conventional energy, and a better appreciation of the circumscribed role of backstop technologies, can reestablish the market momentum in energy policy and propel energy entrepreneurship for the new millennium.

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Natural gas combined-cycle generation has a commanding lead over the three technologies most supported by environmentalists.

Introduction

Joseph Stanislaw of Cambridge Energy Research Associates envisions the energy company of the 21st century operating under two essential assumptions:

- Oil, gas, and coal are virtually unlimited resources to be used in any combination.
- "Supply security" becomes "environmental security." Technology has made it possible to burn all fuels in an environmentally acceptable manner.[1]

Although overshadowed by the post-Kyoto interest in carbon-free energy sources, the technology of fossil-fuel extraction, combustion, and consumption continues to rapidly improve. Fossil fuels continue to have a global market share of approximately 85 percent,[2] and all economic and environmental indicators are positive. Numerous technological advances have made coal, natural gas, and petroleum more abundant, more versatile, more reliable, and less polluting than ever before, and the technologies are being transferred from developed to emerging markets. These positive trends can be expected to continue in the 21st century.

Unconventional energy technologies by definition are not currently competitive with conventional energy technologies on a systemic basis. Oil-based transportation holds a substantial advantage over vehicles powered by electricity, natural gas, propane, ethanol, methanol, and other energy exotics in almost all world markets. In the electricity market, natural gas combined-cycle generation has a commanding lead over the three technologies most supported by environmentalists—wind, solar, and biopower—even after correcting for the estimated cost of negative externalities.[3] Where natural gas is not indigenous, liquefied natural gas is becoming a substitute fuel of choice. In less developed nations such as China and India, oil and coal often set the economic standard as a central-station electricity source, not biopower and intermittent alternatives such as energy from sunlight and naturally blowing wind.

Can the unconventional energies favored by the environmental lobby to meet the emission-reduction targets of the Kyoto Protocol (essentially requiring the United States to reduce fossil-fuel emissions by one-third by 2012) mature into primary energy sources in the next decades or later in the 21st century? Or will such alternatives continue to be subsidy dependent in mature markets and niche or bridge fuels in remote or embryonic markets? This study addresses those questions,

The first section examines trends in fossil-fuel supply and concludes that, contrary to popular belief, fossil fuels are growing more abundant, not scarcer, a trend that is likely to continue in the foreseeable future.

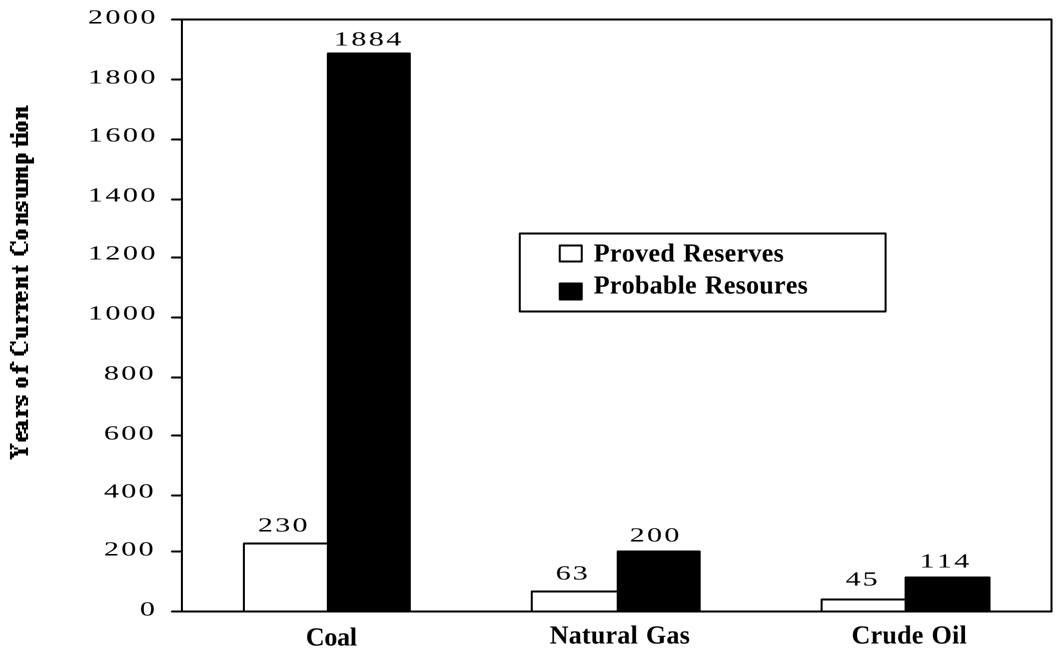
The second section investigates the "negative externalities" of fossil-fuel consumption and finds that they are largely internalized and becoming more so. Thanks to technological advances and improved practices, environmental quality has continued to improve to such an extent that *increased fossil-fuel consumption is no longer incompatible with ecological improvement*. Moreover, America's reliance upon imported oil should not be of major foreign policy or economic concern.

The third section considers the economic competitiveness of non-fossil-fuel alternatives for electricity generation and finds that a national transition from natural gas, coal, oil, and nuclear power to wind, solar, geothermal, and biomass is simply not conceivable today or in the near term or midterm without substantial economic and social costs.

The fourth section examines the economic competitiveness of non-fossil-fuel alternatives for transportation markets and concludes that rapidly improving gasoline-based transportation is far more economically and socially viable than alternative-fueled vehicles for the foreseeable future.

The fifth section examines America's failed legacy of government intervention in energy markets and concludes that environ-

Figure 1
World Fossil-Fuel Reserves and Resources



Sources: U.S. Department of Energy; *Oil & Gas Journal*; *World Oil*; Enron Corp.; World Energy Council.

mentalists and some energy planners have failed to learn the lessons of the past.

The sixth section investigates the science of global warming and the economics of reducing greenhouse gas emissions. The issue is important because many analysts believe that only by significantly reducing the use of fossil fuels can we stop global warming. The magnitude, distribution, and timing of anthropogenic warming, however, contradict the 1980s and early 1990s case for alarm about climate. Furthermore, the cost of displacing fossil fuels with politically correct renewable alternatives is so steep that the costs of preventing anthropogenic warming swamp the benefits.

The Growing Abundance of Fossil Fuels

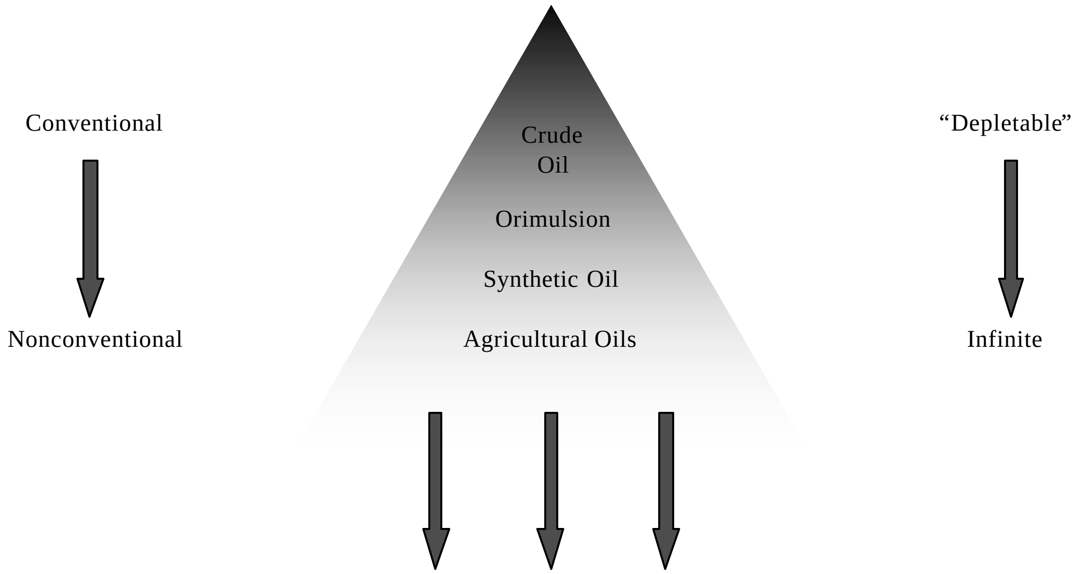
Only a few years ago academics, businessmen, oilmen, and policymakers were almost uniformly of the opinion that the age of energy scarcity was upon us and that the depletion of fossil fuels was imminent.[4] While some observers still cling to that view today, the intellectual tide has turned against doom and gloom on the energy front. Indeed, resource economists are almost uniformly of the opinion that fossil fuels will remain affordable in any reasonably foreseeable future.

Resources As Far As the Eye Can See

Proven world reserves of oil, gas, and coal are officially estimated to be 45, 63, and 230 years of current consumption, respectively (Figure 1). Probable resources of oil, gas, and coal are officially forecast to be 114, 200, and 1,884 years of present usage, respectively.[5]

Moreover, an array of unconventional fossil-fuel sources promises that, when crude oil, natural gas, and coal become scarcer (hence, more expensive) in the future, fossil-fuel substitutes may still be the best source fuels to fill the gap before synthetic substitutes come into play.

Figure 2
Resource Pyramid: Oil



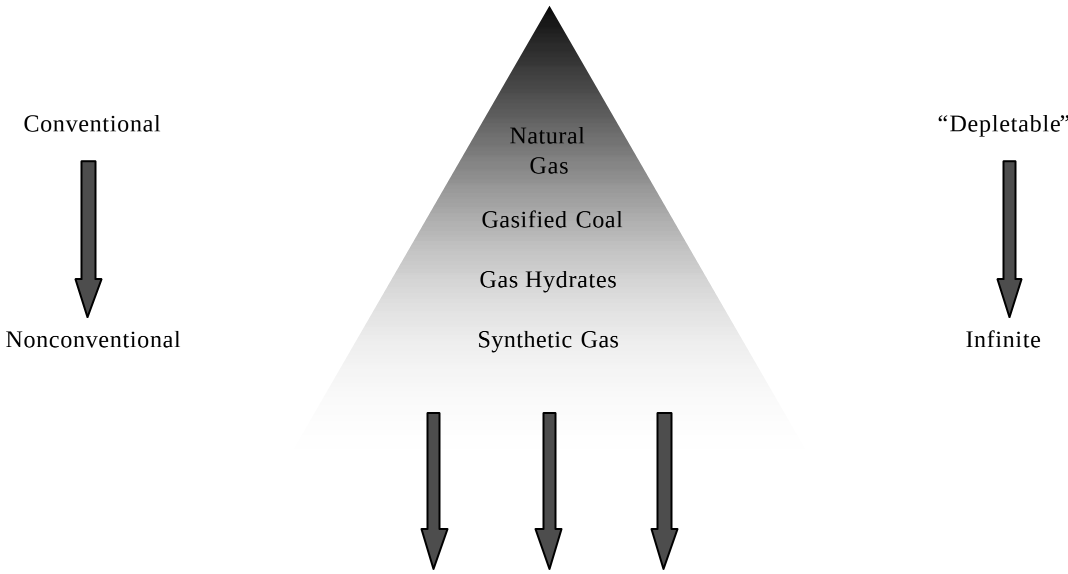
The most promising unconventional fossil fuel today is orimulsion, a tarlike substance that can be burned to make electricity or refined into petroleum. Orimulsion became the "fourth fossil fuel" in the mid-1980s when technological improvements made Venezuela's reserves commercially exploitable. Venezuela's reserve equivalent of 1.2 trillion barrels of oil exceeds the world's known reserves of crude oil, and other countries' more modest supplies of the natural bitumen add to the total.

With economic and environmental (post-scrubbing) characteristics superior to those of fuel oil and coal when used for electricity generation, orimulsion is an attractive conversion opportunity for facilities located near waterways with convenient access to Venezuelan shipping. While political opposition (in Florida, in particular) has slowed the introduction of orimulsion in the United States, orimulsion has already penetrated markets in Denmark and Lithuania and, to a lesser extent, Germany and Italy. India could soon join that list. Marketing issues aside, this here-and-now fuel source represents an abundant backstop fuel at worst and a significant extension of the petroleum age at best.[6]

The significance of orimulsion for the electricity-generation market may be matched by technological breakthroughs commercializing the conversion of natural gas to synthetic oil products. For remote gas fields, gas-to-liquids processing can replace the more expensive alternative of liquefaction. In mature markets with air quality concerns, such as in California, natural gas could become a key feedstock from which to distill the cleanest reformulated gasoline and reformulated diesel fuel yet.[7] A half dozen competing technologies have been developed, several by oil majors who are committing substantial investments relative to government support. The widespread adaptation of gas-to-oil technologies could commercialize up to 40 percent of the world's natural gas fields that hitherto have been uneconomic.[8]

In addition to orimulsion and synthesized natural gas, tar sand, shale oil, and various replenishable crops also have great promise, however uneconomic they now are, given today's technology and best practices (Figure 2).[9] Michael Lynch of the Massachusetts

Figure 3
Resource Pyramid: Gas



Institute of Technology estimates that more than 6 trillion barrels of potentially recoverable conventional oil and another 15 trillion barrels of unconventional oil (excluding coal liquefaction) are identifiable today, an estimate that moves the day of reckoning for petroleum centuries into the future.[10]

The gas resource base is similarly loaded with potential interfuel substitutions, with advances in coal-bed methane and tight-sands gas showing immediate potential and synthetic substitutes from oil crops having long-run promise (Figure 3). If crude oil and natural gas are retired from the economic playing field, fossil fuels boast a strong "bench" of clean and abundant alternatives. Even the cautious Energy Information Administration of the U.S. Department of Energy conceded that "as technology brings the cost of producing an unconventional barrel of oil closer to that of a conventional barrel, it becomes reasonable to view oil as a viable energy source well into the twenty-second century."[11]

Technological Advances and Increasing Resources

Despite a century of doom and gloom about the imminent depletion of fossil-fuel reserves, fossil-fuel availability has been increasing even in the face of record consumption. World oil reserves today are more than 15 times greater than they were when record keeping began in 1948; world gas reserves are almost four times greater than they were 30 years ago; world coal reserves have risen 75 percent in the last 20 years.[12] Thus, today's reserve and resource estimates should be considered a minimum, not a maximum. By the end of the forecast period, reserves could be the same or higher depending on technological developments, capital availability, public policies, and commodity price levels.

Technological advances continue to substantially improve finding rates and individual well productivity.[13] Offshore drilling was once confined to fields several hundred feet below the ocean, for instance, but offshore drilling now reaches depths of several thousand feet. Designs are being considered for drilling beyond 12,000 feet.[14]

Predictably, advances in production technology are driving down the cost of finding oil. In the early 1980s finding costs for new

Fossil-fuel availability has been increasing even in the face of record consumption.

crude oil reserves averaged between $11.50 and $12.50 per barrel in the United States and most areas of the world. In the mid-1990s finding costs had fallen to around $7 per barrel despite 40 percent inflation in the interim. In the United States alone, finding costs dropped 40 percent between 1992 and 1996.[15] That is perhaps the best indicator that oil is growing more abundant, not scarcer.

Finally, the amount of energy needed to produce a unit of economic goods or services has been declining more or less steadily.[16] New technologies and incremental gains in production and consumption efficiency make the services performed by energy cheaper even if the original resource has grown more (or less) expensive in its own right.[17]

Understanding Resource Abundance

How is the increasing abundance of fossil fuels squared with the obviously finite nature of those resources?[18] "To explain the price of oil, we must discard all assumptions of a fixed stock and an inevitable long-run rise and rule out nothing a priori," says M. A. Adelman of MIT. "Whether scarcity has been or is increasing is a question of fact. Development cost and reserve values are both measures of long-run scarcity. So is reserve value, which is driven by future revenues."[19]

Natural resource economists have been unable to find a "depletion signal" in the data. A comprehensive search in 1984 by two economists at Resources for the Future found "gaps among theory, methodology, and data" that prevented a clear delineation between depletion and the "noise" of technological change, regulatory change, and entrepreneurial expectations.[20] A more recent search for the depletion signal by Richard O'Neill et al. concluded:

> Care must be taken to avoid the seductiveness of conventional wisdom and wishful thinking. While the theory of exhaustible resources is seductive, the empirical evidence would be more like the bible story of the loaves and fishes. What matters is not exhaustible resource theories (true but practically dull) but getting supply to market (logistics) without disruption (geopolitics). While it is easy to see how political events may disrupt supply, it is hard to contrive an overall resource depletion effect on prices.[21]

The facts, however, are explainable. Says Adelman:

> What we observe is the net result of two contrary forces: diminishing returns, as the industry moves from larger to smaller deposits and from better to poorer quality, versus increasing knowledge of science and technology generally, and of local government structures. So far, knowledge has won.[22]

Human ingenuity and financial wherewithal, two key ingredients in the supply brew, are not finite but expansive. The most binding resource constraint on fossil fuels is the "petrotechnicals" needed to locate and extract the energy.[23] Congruent with Adelman's theory, wages in the energy industry can be expected to increase over time, while real prices for energy can be expected to fall under market conditions. Under political conditions such as those that existed during the 1970s, however, the record of energy prices can be quite different.

There is no reason to believe that energy per se (as opposed to particular energy sources) will grow less abundant (more expensive) in our lifetimes or for future generations. "Energy," as Paul Ballonoff has concluded, "is simply another technological product whose economics are subject to the ordinary market effects of supply and demand."[24] Thus, a negative externality cannot be assigned to today's fossil-fuel consumption to account for intergenerational "depletion." A better case can be made that a positive intergenerational externality is created, since today's base of knowledge and application subsidizes tomorrow's resource base and consumption.

The implication for business decision-making and public policy analysis is that "depletable" is not an operative concept for the world oil market as it might be for an individual well, field, or geographical section. Like the economists' concept of "perfect competition," the concept of a nonrenewable resource is a heuristic, pedagogical device—an ideal type—not a principle that entrepreneurs can turn into profits and government officials can parlay into enlightened intervention. The time horizon is too short, and technological and economic change is too uncertain, discontinuous, and open-ended.

The Shrinking (Negative) Externalities of Fossil-fuel Consumption

Fossil fuels are not being depleted and will probably continue to grow even more plentiful for decades to come. But now that the traditional rationale for a government-assisted transition to unconventional fuels is removed, new rationales have arisen. Does our reliance on imported oil risk the nation's economic security? Is not fossil-fuel consumption at the heart of most environmental problems, and can we "save" the environment only by repairing to unconventional energies? This section examines those questions and finds that the economic and environmental externalities of fossil-fuel consumption are vastly overstated and dwindling in importance.

The Chimera of Energy Security

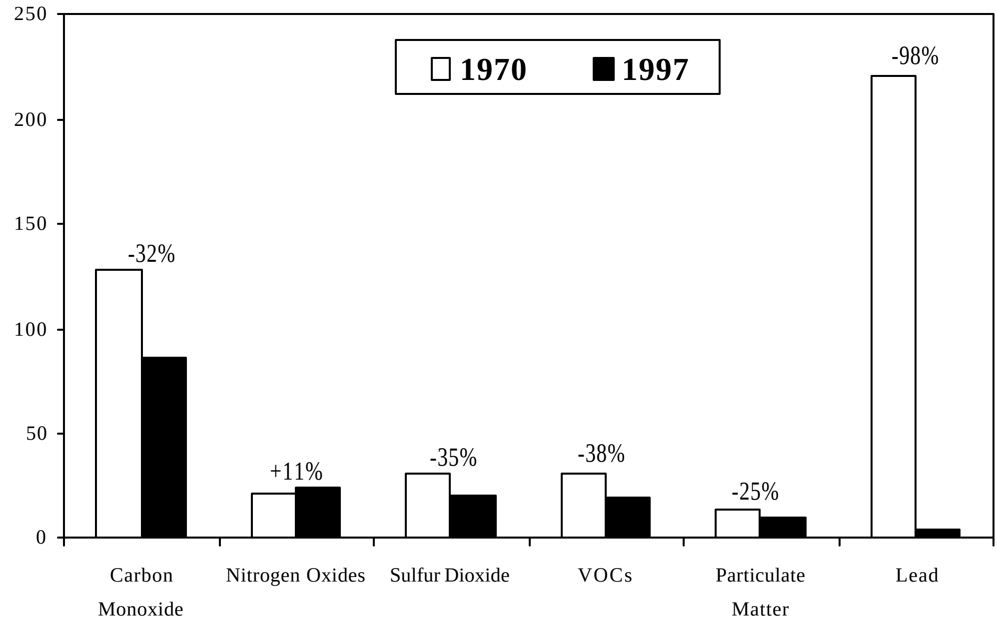
Although the underlying physical stock of crude oil has always been plentiful, critics can point to interruptions in oil imports to the United States and other net importing regions as the operative constraint. Energy security became a concern in the United States and other industrialized nations with the "oil shocks" and oil product shortages of 1973–74 and 1979. Enhancing "energy security" has been a major mission of the U.S. Department of Energy and the International Energy Agency of the Organization for Economic Cooperation and Development ever since the troubled 1970s.

Energy security, like resource exhaustion, has proven to be an exaggerated rationale for government intervention in petroleum markets (such as emergency price and allocation regulation, publicly owned strategic oil reserves, international contingency supply-sharing agreements, and crash programs to fund new electricity sources or transportation alternatives). The lesson from the 1970s energy crises is that government price and allocation regulation can turn the process of microeconomic adjustment to higher energy prices into a "macroeconomic" crisis of physical shortages, industrial dislocations, lost confidence, and social instability.[25] The "oil crises that were not," during the Iran-Iraq War of 1980–81 and the UN ban on Iraqi oil exports of a decade later, demonstrated that freer markets can anticipate and ameliorate sudden supply dislocations without physical shortages, the need for price and allocation regulation, or strategic petroleum reserve drawdowns.[26]

The international petroleum market is subject to geopolitics, which will occasionally lead to supply disruptions and temporarily higher world prices. But the risk of higher prices must be balanced with the normalcy of price wars and a "buyers' market," given an abundant resource base and natural pecuniary incentives to find and market hydrocarbons. Markets learn, adjust, and improve over time as technology and wealth expand. "Market learning" from the 1970s has resulted in increased energy efficiency; greater diversity of supply; enlarged spot-market trading, futures trading, and risk management; and greater integration and alignment of producer interests with consumer interests.[27] Future oil crises like those of the 1970s are highly improbable because of the ameliorating effects of the new market institutions.

"Depletable" is not an operative concept for the world oil market.

Figure 4
U.S. Air Emissions Summary: 1970–97 (million short tons)



Source: Environmental Protection Agency.

Transient price flare-ups as a result of politically driven supply reductions are, of course, possible. In the developed world, such "worst-case" events for motorists are not qualitatively, or even quantitatively, different from abnormally cold winters for natural gas consumers and abnormally hot summers for electricity users. They are transient economic burdens, not macroeconomic or national security events worthy of proactive "energy policy."

World oil markets are more fluid and efficient than ever before, and this improvement can be expected to continue as more economies are liberalized in future decades. Any alleged "energy security premium," making the social cost of oil greater than its private cost, is small and largely internalized by the market.[28] Thus investments such as the U.S. Strategic Petroleum Reserve, which holds oil with an embedded cost several times the recent market price of crude oil in present dollars, and international oil-sharing agreements in the event of a shortfall, such as those under the auspices of the International Energy Agency, are unnecessary, create bad incentives, and are potentially costly as well.

Air Pollution: A Vanishing Problem?

Technology has a remarkable record not only in unlocking, upgrading, and marketing fossil-fuel resources but also in controlling air emissions upon combustion. The progress of the United States in reducing outdoor air pollutants is a political, technological, and economic achievement that was accomplished despite growing industrialization and robust energy usage. In the United States between 1970 and 1997 significant reductions were recorded for carbon monoxide, volatile organic compounds, sulfur dioxide (SO_2), particulate matter, and lead. Only nitrogen oxides (NO_x) increased in that period, but under the Regional Transport Rule and Acid Rain program NO_x emissions are expected to decline[29] (Figure 4). Summarized the Environmental Protection Agency, "Since 1970, national total emissions of the six criteria pollutants declined 31 percent, while U.S. population increased 31 percent, gross domestic product increased 114 percent, and vehicle miles traveled increased 127 percent."[30]

Emission reductions by power plants and on-road vehicles have been an important part of the above improvement. Emissions of carbon monoxide and volatile organic compounds from on-road vehicles dropped 43 percent and 60 percent, respectively, between 1970 and 1997. Emissions of particulate matter from on-road vehicles fell 40 percent in the same period. Lead emissions from vehicles were virtually eliminated, dropping from 172 thousand short tons in 1970 to only 19 short tons in 1997. Nitrogen oxide emissions from vehicles fell slightly in the same 27-year period. On the power plant side, while NO_x emissions increased 26 percent, emissions of SO_2, particulate matter, and lead fell by 25 percent, 84 percent, and 80 percent, respectively, between 1970 and 1997.[31]

Entrepreneurial responses to future air quality regulations can be expected to result in improved air quality and not be stymied by technological barriers so long as the regulations are based on sound science and realistic marketplace economics, not punitive disrespect for the energy and end-use sectors.

Indoor air quality has not shown the improvement of outdoor air quality and, in fact, has worsened. State and federal energy policies subsidizing home and building insulation in the name of energy conservation are at issue. Ben Lieberman explained:

> Insufficiently ventilated offices and residences use less energy for heating and cooling . . . [but] also hold in more airborne pollutants, such as biological contaminants, volatile organic compounds, and formaldehyde. Consequently, those and other compounds sometimes reach indoor concentrations that can cause physical discomfort, or more serious illnesses. Indoor air pollution and its health effects are in large part an unintended consequence of the energy efficiency crusade.[32]

The EPA has recognized that "indoor levels of many pollutants may be two to five times, and on occasion more than one hundred times, higher than outdoor levels," an important problem, since people spend far more time indoors than outdoors.[33] While this could lead to a heavy-handed expansion of regulation in an attempt to correct the unintended consequences of previous regulation, it may also be addressed by relaxing building codes and removing subsidies to let individuals decide between heavy insulation and letting more (increasingly cleaner) outside air indoors.

Cleaner Electricity

More electricity is being produced with less pollution in the United States despite the oldest and most polluting coal plants being exempted from the emissions reductions required under the Clean Air Act of 1990. Electricity generation increased 14 percent between 1989 and 1996, while NO_x emissions increased 3 percent and SO_2 emissions fell 18 percent.[34] Those changes resulted primarily from

- a one-fourth increase in nuclear output,[35]
- a nearly 50 percent increase in the amount of coal being "scrubbed" by high-tech pollution control technologies,[36] and
- a drop in sulfur content of coal (a nearly one-half drop in sulfur content of coal was registered between 1972 and 1994 alone).[37]

Lower emissions from retrofitted oil and gas units, and the entry of gas plants in place of more polluting coal units, are also important factors in pollution reduction.[38] The environmental advantages of natural gas over coal in modern facilities have led many environmentalists to welcome gas as a "bridge fuel" to a "sustainable" energy mar-

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ket, displacing coal and oil before being displaced itself by renewables later in the next century.[39]

Natural gas combined-cycle and cogeneration technologies also have some environmental advantages over their renewable rivals. A state-of-the-art natural gas plant can favorably compare with wind farms in terms of land disturbance, wildlife impacts, visual blight, noise, and front-end (infrastructure-related) air emissions. Back-end air emission reductions are where wind turbines must stake their entire environmental claim.[40] Solar farms (in contrast to distributed solar applications) are so land intensive, resource intensive, and economically impractical that Christopher Flavin of the Worldwatch Institute has stated a preference for on-site power generation options, including natural gas microturbines.[41]

Coal-fired electricity generation is far less polluting today than it was in the 1970s. However, it originally was the most polluting technology of all fossil-fuel alternatives and remains so today, relative to modern oil and natural gas technologies. In one sense that is a problem; in another sense it is an opportunity for further reductions of emissions to help produce what is rapidly becoming an environmentally benign mix of electricity-generating resources as defined by environmental regulators themselves.

Cleaner Vehicles

The internal combustion engine and "antiseptic automobile traffic" solved the environmental problem of "horse emissions" earlier this century. James Flink explained:

> In New York City alone at the turn of the century, horses deposited on the streets every day an estimated 2.5 million pounds of manure and 60,000 gallons of urine, accounting for about two-thirds of the filth that littered the city's streets. Excreta from horses in the form of dried dust irritated nasal passages and lungs, then became a syrupy mass to wade through and track into the home whenever it rained. New York insurance actuaries had established by the turn of the century that infectious diseases, including typhoid fever, were much more frequently contracted by livery stable keepers and employees than by other occupational groups. . . . The flies that bred on the ever present manure heaps carried more than thirty communicable diseases. . . . Traffic was often clogged by the carcasses of overworked dray horses that dropped in their tracks during summer heat waves or had to be destroyed after stumbling on slippery payments and breaking their legs. About 15,000 dead horses were removed from the streets of New York each year. Urban sanitation departments, responsible for daily cleaning up of this mess, were not only expensive but typically graft- and corruption-ridden. . . . These conditions were characteristic in varying degree of all of our large and medium-sized cities.[42]

The internal combustion engine would create its own emission problems, but nearly a century after its introduction it has become far more environmentally benign and is continually proving itself compatible with improving environmental conditions.

Vehicle pollution has declined in recent decades thanks to a combination of greater fuel efficiency per vehicle, cleaner motor fuels, and onboard technological improvements, such as catalytic converters. Those developments mean that more cars and increased travel mileage no longer increase pollution in the aggregate. As older cars leave the fleet, progressively cleaner cars are taking their place. New passenger cars in the United States have reduced major emissions by more than 90 percent. A newer car making the 230-mile trip from Washington, D.C., to New York City, for example, emits less pollution than a gasoline-powered lawnmower emits cutting an average-sized yard. Appreciated another way, sports utility vehicles today emit less pollution than small cars did several decades ago.[43]

The big three domestic automakers (Chrysler, Ford, and General Motors) have announced a National Low Emission Vehicle program for year-2001 models (and as early as model-year 1999 in the Northeast). Those vehicles will emit, on average, 99 percent less smog-forming hydrocarbon emissions than cars made in the 1960s. Car size and comfort will not be affected. The new technology incorporates upgraded catalytic converters, improved computer engine control, and enhanced air-fuel mixtures—all for about $60 a car.[44]

The motivation for automakers to introduce cars that exceed federal standards is to prepare for the next generation of federal requirements and discourage states from implementing zero-emission vehicle (ZEV) mandates. The only ZEV is the electric vehicle, which qualifies only because it is not penalized by the air emissions associated with its upstream electricity-generation phase. California already has rescinded its requirement that 2 percent of all vehicles sold in 1998 be ZEVs and postponed its requirement that 5 percent of all vehicles sold in 2001 be ZEVs. The 2003 ZEV requirement, 10 percent of all new vehicle sales, remains on the books in California as do ZEV requirements in New York, Massachusetts, Maine, and Vermont. The automakers' National Low Emission Vehicle program will apply to 45 states and any other states that abandon their ZEV requirements.

Reformulated Fuels

Reformulated gasoline, coupled with advances in internal combustion engine technology, has been setting the competitive standard for transportation energy in the United States since the early 1970s, and particularly in the 1990s. That began on the first day of 1992 when the California Air Resources Board (CARB) of the California Environmental Protection Agency required the manufacture and sale of the nation's first reformulated gasoline (known as Phase 1 reformulated gasoline). The new gasoline—at an incremental cost of 1 to 2 cents per gallon[45]—lowered Reid vapor pressure, phased out lead, and added engine deposit control additives. Federal gasoline regulation pursuant to the Clean Air Amendments of 1990 followed later the same year. In November 1992, 39 cities in 20 states not in compliance with the Clean Air Act began using gasoline blended with oxygenates, primarily MTBE but also ethanol, during the four-month winter driving season to reduce carbon monoxide emissions. Major East Coast cities were prominently represented, as was the entire state of California. An increased cost of several cents per gallon and a 1 percent to 4 percent loss of fuel mileage initially resulted.[46]

The winter oxygenated-gasoline program of 1992 was supplemented on January 1, 1995, with a federal year-round reformulated gasoline requirement for nine areas around the country with the worst ozone (summertime urban smog) problems, as well as other "opt-in" areas. Six southern California counties formed the largest geographical concentration in the program, and 15 other states were represented as well. Compared with conventional gasoline, EPA Phase 1 reformulated gasoline reduced benzene (a carcinogen), lowered Reid vapor pressure specifications by reducing butane, increased oxygenates, and reduced heavy metal content. The reduction of emissions of volatile organic compounds contributing to summer smog and the reduction of year-round toxic emissions were achieved at an initial premium of 2 to 5 cents per gallon in addition to some loss in fuel efficiency. Refiners reported the changeover as "blissfully uneventful," while consumers reported no operational problems with the cleaner reconstitution.[47]

The Natural Resources Defense Council praised the reformulated oil product:

> Changing fuel formulations is an essential element to improving air quality, in part because it has immedi-

Reformulated gasoline has been setting the competitive standard for transportation energy in the United States.

The quantity of oil spilled in U.S. waters has fallen by 67 percent in the last five years.

ate results: it reduces dangerous air toxics and ozone-forming substances even from old cars. New vehicle technology, by contrast, affects the air quality slowly as new vehicles are purchased and older vehicles are gradually retired.[48]

Effective June 1, 1996, CARB required even cleaner reformulated gasoline (known as Phase 2 reformulated gasoline) to further address ozone precursors. Six counties in southern California and the greater Sacramento area were subject to both EPA Phase 1 and CARB Phase 2 reformulated gasoline requirements. The new blend was twice as effective at reducing smog as was EPA Phase 1 reformulated gasoline and reduced SO_2 emissions as well. The added cost was estimated at between 3 and 10 cents per gallon with a slight loss of fuel economy. That made the total estimated cost increase for reformulated gasoline over the cost of pre-1995 grade gasoline in California between 5 and 15 cents per gallon with a 3 percent loss of fuel efficiency.[49] Californians were paying around 15 cents per gallon, inclusive of fuel efficiency loss, more than they had paid for 1980s pre-reformulated gasoline,[50] an "environmental premium" that can be expected to fall over time as refinery costs are amortized and technology improves. Meanwhile, southern California has registered a 40 percent drop in peak ozone levels since the late 1970s.[51]

The next requirement, effective January 1, 2000, will mandate the use of EPA Phase 2 reformulated gasoline in all areas now required to use EPA Phase 1 reformulated gasoline. The new gasoline will reduce NO_x and volatile organic compounds in particular. The EPA is considering new rules (Tier 2 standards) to become effective in model-year 2004 or later to bring light-duty trucks (including sports utility vehicles) under the same emission standards as passenger vehicles and reduce the sulfur content of gasoline.

A federal low-sulfur reformulated diesel program took effect for the entire country on October 1, 1993. On the same day CARB adopted for California a tighter standard that also required a reduction in aromatics. CARB's clean diesel standard applied to off-road vehicles as well as to on-road vehicles.[52] The CARB standard was calculated to reduce SO_2, particulate matter, and NO_x by 80 percent, 20 percent, and 7 percent, respectively, at an initial incremental cost of around 6 cents per gallon.[53] Improved engine technology, which has increased the energy efficiency of diesel from 37 percent to 44 percent in the last 20 years, has also reduced emissions.[54] Those improvements may be matched by innovations of new alliances between General Motors and Amoco and GM and Isuzu to develop cleaner diesel fuels and diesel engines, respectively, in the years ahead.[55]

Internationally, leaded gasoline has been phased out of 20 countries, but high lead content is still common in many areas of Asia, Africa, Latin America, and Eastern Europe. As older cars with more sensitive valve systems leave the fleet and more sophisticated refineries are constructed that can substitute other octane boosters for lead, more countries will phase out leaded gasoline. Reformulated gasoline and diesel standards are beginning to be introduced in more wealthy nations such as Finland, Sweden, Norway, Japan, and across Europe. In the 2000–2005 period, Latin America and Caribbean countries will introduce standards for all motor fuels, and Europe is scheduled to introduce tighter standards. The clean transportation movement is an international phenomenon, not just a U.S. initiative.[56]

The Controlled Problem of Oil Spills

Major oil spills such as those at Torrey Canyon (1967) and Santa Barbara (1969) and from the *Valdez* (1989) tainted the upstream operations of the oil industry as environmentally problematic, downstream combustion aside. Yet trends have been positive in this area as well. The quantity of oil spilled in U.S. waters has fallen by 67 percent in the most recent five years compared with the five previous years when comprehensive record keeping began. Even subtracting the 10.8 million gallons of oil leaked from the *Valdez* from the base period, spillage fell by more than 50 percent. The spillage in 1996 of 3.2 million gallons was approximately one-thousandth of 1 percent of the 281 billion gallons moved and consumed in the United States. Moreover, what is spilled is controlled more quickly and has less impact on the ecosystem owing to improved cleanup technology such as bioremediation.[57]

Those advances have been accelerated by the problems the industry has experienced. Just months after the *Valdez* accident, the American Petroleum Institute, concluding that government and industry had neither "the equipment nor the response personnel in place and ready to deal with catastrophic tanker spills" in U.S. waters, recommended forming an industrywide oil-spill response organization. The result was a $400 million, 20-member organization—the Petroleum Industry Response Organization—financed from a small fee levied on transported tanker barrels.[58] The group was reorganized in 1990 as the Marine Spill Response Corporation, and a $1 billion five-year commitment ensued.[59] Federal legislation was passed (the Oil Pollution Act of 1990) that required double hulls in new tankers operating in domestic waters to provide greater protection in case of accidents. Not only the local environment but ecotourism is booming in Prince William Sound in Alaska thanks to the monies collected and the attention gained as a result of the *Valdez* oil spill.[60] Thus, a worst-case environmental event turned out to be a temporary problem that in the longer run has proven positive for the local environment and the environmental movement in the United States.

The Competitive Quandary of "Green" Electricity

Unfortunately, few analysts outside the energy field fully grasp the explosion of technological advances in conventional electricity generation. Such progress easily compares with the technological progress of unconventional energies, given that the starting point of conventional energies was so far ahead. So even if the rate of improvement (or rate of growth) of an unconventional technology is greater over a certain time frame, the relative end points are what are relevant.

To use an analogy, a weekend athlete could achieve greater improvement than could a professional athlete as the result of full-time training for a given period of time, but it would be incorrect to infer that the rate of progress implies that the amateur's improvement is sustainable or that the professional athlete will eventually be displaced. The same may be true today of alternative energy technologies, most of which have longer histories and more competitive challenges than is commonly realized in our politicized context.

The Emergence of Natural Gas–Fired Technologies

Natural gas technologies are setting the competitive standard for all conventional energies in the electric market where methane reserves are abundant. In North America, gas-fired combined-cycle plants can generate large quantities of electricity at around 3 cents per kilowatt-hour (kWh) where demand conditions support continuous ("baseload") operation.[61] Smaller gas units can also be constructed without a great loss of scale economies, allowing the flexibility to meet a range of market demands.[62] Quicker construction and less capital outlay figure into those economies.

Even as stand-alone, off-grid generators, natural gas microturbines sized from 500 watts to several hundred kilowatts can produce electricity for as little as 4.5 cents per kWh on a fully utilized basis where generated steam is utilized in addition to electricity. Moderate usage (a lower capacity factor) without cogeneration doubles the nominal cost.[63] Rapidly improving microturbine tech-

Even as stand-alone, off-grid generators, natural gas microturbines can produce electricity for as little as 4.5 cents per kWh.

The California Energy Commission concluded that gas plants were both privately and socially the least cost generating option for the state.

nologies offer self-generating opportunities for large commercial and industrial customers facing high electric rates (with or without a stranded cost recovery surcharge), an argument supportive of rate deregulation of the electricity grid.[64]

On the other extreme are combined-cycle plants run on liquefied natural gas. The hardware required to liquefy the gas for tanker shipment and vaporize the gas for use in a combined-cycle plant increases the cost to around 5 cents per kWh,[65] about 50 percent more than the cost of using natural gas. This price, however, is still competitive with coal in some applications and is below the cost of nuclear power.

Electricity generation from natural gas is the cleanest fossil-fuel option. Gas-fired combined-cycle plants produce substantially less air pollution and less solid waste than do scrubbed coal plants and oil-fired power plants.[66] Nitrogen oxides, the major emission of gas plants, have been substantially reduced in recent decades by technological upgrades. That is why the environmentally conscious California Energy Commission (CEC) concluded that gas plants were both privately and socially the least cost generating option for the state.[67]

The superior economics of gas-fired generation explains why the large majority of new capacity being built in North America is gas fired, not coal fired.[68] State-of-the-art scrubbed-coal plants and advanced light-water reactor nuclear plants can produce electricity at around 4.5 cents per kWh and 7.5 cents per kWh, respectively, costs 50 percent and 133 percent greater than those of baseload natural gas combined-cycle units.[69] A 1996 study by two researchers at the Electric Power Research Institute concluded that the costs of an advanced nuclear power plant built after the turn of the century had to be "sufficiently less" than 4.3 cents per kWh "to offset the higher capital investment risk associated with nuclear plant deployment."[70] At least in North America, and also in much of Europe and in South American where natural gas is becoming more available, the environmental debate between conventional energies is being settled on economic and not political grounds.

Arlon Tussing and Bob Tippee summarized the success of gas technologies relative to coal and nuclear research:

> The use of gas-fired combustion technology in the production of electric power is the leading natural gas success story of the 1980s. Despite the huge research budgets committed in the 1970s and 1980s by the U.S. Department of Energy and the Electric Power Research Institute to improve coal and nuclear-generation technologies, the greatest technological breakthroughs in generator design stemmed from the efforts of the aircraft industry to improve jet engines. . . . The result was the development of smaller, more dependable, and more fuel-efficient jet turbines, which were manufactured in sufficiently large numbers so that parts supply and maintenance were greatly simplified.[71]

Jason Makansi summarized the current competitive picture of natural gas versus coal:

> Advanced coal technologies—ultra-supercritical steam generators, state-of-the-art circulating fluidized-bed boilers, integrated gasification/combined cycle, and pressurized fluidized-bed combustion combined-cycle—look good compared to the conventional pulverized coal–fired plant, which has been the workhorse of electric power generation for decades. Gains in efficiency and overall environmental performance are significant. . . . [Yet] none of these coal-based options provide anywhere near the efficiency, simplicity, flexibility, and emissions profile of today's natural gas–fired combined-cycles. . . .

> For new plants, coal continues to dominate only in countries with (1) protectionist tendencies for important indigenous industries, such as Germany [and Great Britain], or (2) surging economic growth and massive domestic supplies, such as China and India. Coal is also an important factor in new construction for countries such as Japan and Korea, which import most or all their energy. . . . In most other countries with healthy coal industries, large [coal] projects tend to get pushed farther out on the planning horizon [because of competition from gas technologies].[72]

If you cannot beat them, join them. A strategy to reduce emissions at existing coal plants is cofiring: for less than $25 per kWh natural gas is burned along with coal in the primary combustion zone of a boiler to reduce SO_2 emissions and increase electricity output. Optimized cofiring can reduce emissions more than proportionally to the emission reduction associated with the percentage of natural gas used. Another option is gas reburning by which NO_x as well as SO_2 emissions are reduced.[73]

Advances in Nuclear Plant Design

The size of the world's nuclear power industry qualifies uranium as a conventional energy source that complements fossil fuels. Nuclear fuel is also the largest emission-free energy source for electricity generation in the world, even after accounting for the "embedded energy" pollution associated with infrastructure (primarily cement). While fossil-fuel alternatives, as well as hydroelectricity, have eclipsed nuclear fuel on economic grounds in many regions, nuclear plants are becoming more standardized and economical. For large-scale needs in future centuries, nuclear technologies may be the leading backstop to fossil fuels for primary electricity generation.[74]

The performance of nuclear power is improving with existing units and new-generation technologies. Of the United States' 103 operating reactors, more than 90 percent have improved capacity, safety, and cost factors.[75] In the eight-year period ending in 1997, average plant capacity factors and total output per facility increased by 7 percent and 6 percent, respectively. Total output increased 9 percent as well, owing to a net increase of three units.[76] Between 1990 and 1996 (the last year for which information is available), the average production cost (marginal cost) of U.S. plants fell 21 percent.[77] The Department of Energy expects continued increases in operating efficiencies through its 2020 forecast period. However, the average is for fewer units because of the retirement of uneconomic capacity and an absence of new entry because of cheaper fossil-fuel alternatives and political opposition.[78]

New advanced light-water reactor designs have been certified for the market, led by the 600-megawatt Westinghouse design and two 1,350-megawatt designs by General Electric and Combustion Engineering. An overarching goal of the new designs is standardization and simplification to reduce costs, speed construction, improve reliability, and ensure safety. While domestic interest in new nuclear capacity is absent, overseas business is bringing the new technology to market. In 1996 a new generation of nuclear plant design came of age with the completion of a 1,356-megawatt advanced boiling-water reactor in Japan. The plant took four and a half years to build (compared with some U.S. nuclear plants that took 11 years or more to construct) and came in under budget. Its standardized design will minimize maintenance and reduce worker risks during its future decades of operation.[79] A new design for U.S. operation based on "simplification and a high degree of modularity" could reduce construction time to three years, according to the Electric Power Research Institute.[80] This is a very aggressive estimate for the near future, however.

Regulatory streamlining and a political resolution of the nuclear waste problem are

More than 90 percent of nuclear power plants in the United States have improved capacity, safety, and cost factors.

Abandoning coal altogether to reduce carbon dioxide emissions is not warranted.

necessary but not sufficient conditions for the United States to join Asian countries in installing a new generation of nuclear reactors. The other hurdles for nuclear power are market related. Gas-fired plants are not only substantially cheaper but can be flexibly sized to meet the demand of a variety of markets. Coal at present is also substantially cheaper than nuclear fuel for large-sized units (small coal plants have severe scale diseconomies and are rarely constructed). Nuclear power will also need to outgrow its federal insurance subsidy (the Price-Anderson Act) as the U.S. court system moves toward more rational liability laws.[81]

The Economic Resilience of Coal-Fired Electricity

The economics of coal-fired generation eclipses that of natural gas (and liquefied natural gas) in some major international markets such as China and India because of those countries' huge indigenous coal reserves relative to methane. Yet reliance on coal in Asia has created severe air quality problems, which call for installing the latest emission-control technologies to reduce particulates and NO_x in particular.[82] China, for example, has shown rudimentary interest in a "clean coal technology system with coal preparation as the starting point, high-efficiency combustion of coal as the core, coal gasification as the precursor and mine area pollution control as the main component."[83] That would narrow but not eliminate the cost advantage of coal over natural gas and liquefied natural gas plants in those areas.

The price of coal for electricity generation has been declining over time as a result of falling upstream minemouth prices, reduced midstream transportation costs, and improving downstream combustion technology. The U.S. Department of Energy identified technological advances in underground mining, large-scale surface mining, higher labor productivity, and the consolidation of coal transportation as "revolutionizing economies of scale in mining, marketing, and shipping coal in the large quantities required by electricity generation plants."[84] Numerous improvements such as modularity of plant design have lowered cost and enhanced energy conversion efficiencies,[85] but environmental retrofits have canceled out some of this improvement.

Abandoning coal altogether to reduce carbon dioxide (CO_2) emissions is not warranted if economics dictates otherwise. It is economically wasteful to substitute alternative energies with an additional cost that is greater than the externality associated with the traditional pollutants. Sound economic calculation will prevent developing countries, which can least afford it, from substituting for superior energy technologies others that are inferior in terms of quantity, reliability, and cost.[86]

Renewable Energies: Ancient to Old

A salient historical insight for the current debate over renewable energy is how old hydropower is and how both wind and solar enjoyed free-market sustainability until cheaper and more flexible fossil fuels came of age. A history of energy use in England revealed that in 1086 more than 6 thousand watermills and windmills dotted the landscape.[87] The long history of wind and solar in the United States was documented by a Greenpeace study:

> In the late 1800s in the United States, solar water-heaters were introduced commercially because they offered hot water conveniently inside a building without the trouble of heating it on a stove or on a fire out of doors. Despite cheap fossil fuel and the invention of the domestic water-heater, solar water-heaters enjoyed commercial viability well into the 1940s. . . . Five decades ago, wind systems were fairly common in many countries for water-pumping and mechanical power, and some small-scale electric-power generation. Then, except in certain

limited locations, cheap fossil fuels wiped them from the market.[88]

Hydropower predated fossil fuels on the world stage as noted by the Worldwatch Institute,[89] and hydroelectric construction peaked during the New Deal in the United States. Continuous geothermal production dates from 1913 and became a mature industry prior to the 1970s.[90] Biopower is the youngest member of the renewable family, having emerged in systemic fashion during and immediately after the 1970s energy crisis.

Subsidized Renewables: A Legacy of Falling Short

Shell, the world's second largest energy company, has announced an expansion into biopower, solar, and possibly wind on the assumption that fossil fuels will become scarcer in the "next few decades."[91] British Petroleum is increasing its long-standing investment in solar energy on the premise that man-made global warming is a potentially major social problem.[92] Enron Corp. entered into solar energy in 1995 and wind energy in 1997 to complement its focus on the cleanest burning of the fossil fuels, natural gas.[93]

To environmentalists critical of fossil fuels, this burst of interest on the part of some of the world's prominent energy companies signals the beginning of the end of the fossil-fuel era. Yet these ventures are very modest compared with overall corporate investment in energy[94] and are inspired as much by transient government subsidies and public relations as by underlying economics. To put the issue in perspective, the highly publicized $500 million that Shell has committed to spend over five years on international renewable projects is half as much as the company's far less publicized budget to develop three previously located deepwater Gulf of Mexico oil and gas fields.[95]

Unconventional energy sources have long mesmerized both government and—to a lesser but still real extent—private investors. Investments in these technologies in the last quarter century have, with few exceptions, been disappointing, as a historical review shows.

As fossil-fuel prices began their ascent in 1973, a solar-energy boom began in the United States and abroad. By the mid-1970s more than a hundred companies, many responding to government subsidies and preferences, had entered the business of converting the sun's energy into electricity or substituting it for electricity altogether. Some of the biggest names in the energy business—Exxon, Shell, Mobil, ARCO, and Amoco—were among the entrants. More than a dozen other large oil companies had patents or were conducting research in the field. Other companies, such as General Electric, General Motors, Owens-Illinois, Texas Instruments, and Grumman, entered the solar collector heating and cooling market or the photovoltaics market, or both. The head of Royal Dutch Shell's solar subsidiary declared in late 1980, "The solar electric market could explode."[96]

Declining energy prices in the 1980s set back an industry that, like synthetic fuels (discussed below), never approached economic viability even when fossil-fuel prices were at their peak. While the use of solar power in niche markets and some remote applications remained viable, central-station electricity generation was another story. Few, if any, major solar companies showed a profit in the 1980s, although some survived. *Fortune* in 1979 stated, "It has proved harder than the pioneer imagined to overcome the inherent difficulties of harnessing an energy form that is stupendous in the aggregate, but dilutes in any given setting."[97] The verdict was the same more than a decade later. The liquidation in December 1991 of Luz International, previously the world's leading solar power development firm, marked the end of an era.

The wind power boom started a few years later than the solar boom, but the results were the same. First-generation technology was very expensive, and unintended environmental consequences affecting land and

Investments in subsidized renewable technologies have, with few exceptions, been disappointing.

Geothermal sites are often located in protected, pristine areas.

birds emerged. The first-generation problems required a government-funded $100 million cleanup and repowering effort in California, the heart of the U.S. wind industry.[98]

Oil companies did not diversify into the wind industry as they had into solar power. Profitable sites and applications for wind power were narrower even than those for solar power, although wind power had one clear advantage over its renewable rival—it was substantially less uneconomic as a source of electricity for the power grid. Nonetheless, the economics of wind power remained relatively poor, particularly compared with the economics of natural gas combined-cycle generation, which was rapidly improving. The bankruptcy in 1996 of the world's largest wind developer, Kennetech, like the bankruptcy of solar industry leader Luz five years before, marked the end of an era.

The heavy political promotion of wind and solar power in the 1970s and 1980s cannot be characterized as successful. Billions of taxpayer, ratepayer, and investor dollars were lost, bearing little fruit except for experience. But for proponents of alternative energy, hope springs eternal. Two decades of "broken wind turbines, boondoggle wind farm tax shelters, and leaky solar hot-water heaters" are ancient history. "The world today," the faithful believe, "is already on the verge of a monumental energy transformation . . . [to] a renewable energy economy."[99]

A survey of today's leading renewable alternatives, however, demonstrates that this predicted transformation is just as questionable now as it was two or more decades ago.

Solar and Wind as Kyoto Energies

Wind and solar power are the two energy sources most favored by the environmental community to displace fossil fuels to help meet the goals of the Kyoto Protocol. Other sources have met with greater environmental ambivalence if not concern. Biopower is an air emission renewable energy source that can contribute to deforestation.[100] Geothermal sites are often located in protected, pristine areas and so create land-use conflicts, and toxic emissions and depletion can occur.[101] Hydroelectric power is the least environmentally favored member of the renewable energy family owing to its disruption of natural river ecosystems.[102] Nuclear power, although it is air emission free like renewable energy after plant construction, is less popular than hydroelectricity with mainstream environmentalists and is rejected because of its risk profile and waste disposal requirements.[103]

The respective costs of wind and solar have dropped by an estimated 70 percent and 75 percent since the early 1980s.[104] Extensive government subsidies for research on and development and commercialization of these technologies—much greater than for other renewables and fossil fuels on an energy production basis—have been a primary reason for this substantial improvement.[105] Mass production has resulted in fewer material requirements, more product standardization, automated manufacturing, and improved electronics. Larger wind farms have also introduced economies of scale. Improvements in information management, just-in-time inventory techniques, and lower energy costs—factors at work across the economy—have also been responsible for the reduced infrastructure cost of these two alternative energy sources. One recent study of wind technologies concluded:

> [Wind] costs have declined from around US$ 0.15–0.25 per kWh to the US$ 0.04 to 0.08 per kWh today in favorable locations. Technical developments have been rapid and impressive, most notably in the areas of increased unit size, more efficient blade designs, use of light-weight but stronger materials, variable speed drives, and the elimination of reduction-gear mechanisms through the introduction of electronic controls for frequency and voltage regulation.[106]

But that is only half the story. The long-awaited commercial viability of wind and sun as primary energy sources has been set back by natural gas combined-cycle and cogeneration technologies. Natural gas technology today can produce electricity at half the cost (or less) and with more flexibility and reliability than power generated from well-sited wind farms on a tax-equalization basis.[107] The competitive gap with solar power is much more pronounced, since solar power is triple (or more) the cost of well-sited wind. Simply put, the technological improvements in wind and solar power have also occurred for traditional fuels. In Europe, for example, an executive of Siemens AG recently reported that prices of electricity from fossil-fuel plants have fallen by an estimated 50 percent in the last five years alone.[108]

This competitive gap, which environmentalists once thought to be surmountable, may persist for a long time. A joint study in 1997 by the Alliance to Save Energy, the American Council for an Energy-Efficient Economy, the Natural Resources Defense Council, Tellus Institute, and the Union of Concerned Scientists concluded:

> Although the cost of renewable electric generating technologies has declined substantially and their performance has improved, the cost of competing fossil technologies has also fallen. In particular, the average price of natural gas paid by electric utilities has been low (about $2.30/MMBtu) since the mid-1980s and is widely expected to remain so for the next 10 years or longer.[109]

A factor as important as cost and reliability for national energy policy is the enormous quantity disparity between gas-fired electricity (and other fossil alternatives) and solar- and wind-generated energies. A single large combined-cycle gas plant can produce more electricity than all the wind and solar facilities in the United States combined. One of the world's largest gas-fired combined-cycle plants, the 1,875-megawatt Teesside plant in England, produces more electricity each year than the world's millions of solar panels and 30,000 wind turbines combined—and on fewer than 25 acres of land.

The quantity differential partially reflects relative capacity factors, which are around 95 percent for baseload gas combined-cycle plants and 20 percent to 40 percent for solar and wind that operate only when the natural energy source is available.[110] It also reflects siting prerequisites in light of natural conditions and consumer demand. A wind site, for example, must have steady high winds, be away from large bird populations, avoid slopes that may erode, and be in remote (and sometimes pristine) areas because of high noise levels and poor aesthetics. Yet for economics' sake, wind farms need to be near population centers that have a power deficit because of high transmission investment costs and physical losses of electricity.[111] This combination works against many sites, making well-sited wind, ironically, a "depletable" energy option. So while ideal wind sites may generate grid power at a cost only double that of new technologies using natural gas, other sites, for example, ones from which the electricity must be transported long distances, worsen this already sizable cost disadvantage. Consequently, wind is not a generic resource like a conventional energy. Wind sets up a growing economic and environmental conflict as more and more sites must be tapped to meet external political demands.

Other Renewables Also Problematic

The other basket of "renewable" alternatives to fossil fuels—geothermal, hydropower, biopower, and fuel cells—may be even less likely to gain market share in the foreseeable future than are wind and solar power.

Geothermal and hydroelectricity are more akin to conventional energies than to unconventional ones. Each has a long his-

The commercial viability of wind and sun as primary energy sources has been set back by natural gas combined-cycle and cogeneration technologies.

Biopower plants are more expensive than well-sited wind projects but far less expensive than solar plants.

tory of economic competitiveness that predates the air quality movement, although in today's political discussion they are often lumped together with wind and solar power as renewables for "sustainable energy development." Ironically, wind and solar advocates who do not favor hydroelectricity (which comprises almost 90 percent of total world renewable generation) can be said to be more critical of renewable fuels per se than are fuel-neutral, free-market energy proponents.

The most prominent of existing "exotic" renewable fuels is biopower. Biopower is biomass converted to electricity (often, municipal garbage converted to electricity in incinerator plants) as opposed to the simple burning of wood, dung, and other waste feedstocks for cooking and heating. Today, biopower is the second largest renewable energy next to hydropower in the United States and the world.

Although scattered biopower projects existed before 1978, it was the Public Utility Regulatory Policies Act of 1978 that put this energy source on the map.[112] That federal law, which applied to other renewables and certain nonutility nonrenewables, required utilities to purchase power from "qualifying facilities" at the utility's "avoided cost," which in an era of higher fuel prices locked in favorable economics for the waste-to-energy plants. These first-generation plants have been characterized by their "high costs and efficiency disadvantages" in comparison with conventional energies.[113] Like nuclear power, the biopower industry is an artificial creation of government policy and would never have emerged as a significant energy source in a free market.

Biopower plants are more expensive than well-sited wind projects but far less expensive than solar plants. The current generation of biopower projects has an estimated cost of around 8 cents per kWh versus wind plants at around 6 cents per kWh (prime sites without tax preferences) and solar at 30 cents per kWh or more.[114] As noted earlier, the environmental lobby has serious misgivings about biopower as a major electricity alternative because of a potential problem of deforestation, occasional competition with recycling facilities for waste disposal, and air emissions.

Fuel cells, while perhaps further from market penetration than other renewables, hold potentially greater promise. Several fuel-cell technologies are commercially available for distributed generation so long as a liquid fuel is available. The electrochemical devices that convert energy to electricity and usable heat without requiring combustion are actually a competitor to wind and solar projects on the one hand and gas microturbines and diesel generators on the other.

Fuel cells have a number of technical and environmental advantages. They do not have moving parts and are easy to maintain. They can be sized for a home or for a large industrial facility. Fuel cells can be run on a variety of fuels, including methane, natural gas, and petroleum. (Natural gas is the most probable input where it is available.) They are noiseless. They convert energy into electricity relatively more efficiently than do other generation processes. And since fuel cells are more energy efficient and do not require combustion, they are environmentally superior to fossil-fuel plants and microturbines.[115]

Those advantages are lost on the economic side. The average cost of a fuel cell today is around $3,000 per kWh when $1,000 per installed kWh is necessary for market penetration. Subsidies from the Department of Energy for as much as one-third of the total installation cost ($1,000 per kWh) have been necessary to attract interest.[116] The fuel cell for stationary electricity generation is a backstop energy source that competes against unconventional technologies more than conventional ones at present. To break into the marketplace, fuel cells must become competitive against another natural gas user—microturbines. But "where very strict air emissions requirements apply, fuel cells may be the only option for distributed generation."[117]

Distributed Energy: How Big a Market Niche?

In dispersed developing markets where electricity is being introduced, distributed generation (power that is distributed locally and does not come through a regional grid) is typically more economical and practical than central-station, long-distance transmission of electricity. Since some renewable energy technologies have proven adaptable to markets where transmission and distribution of electricity are relatively nonexistent, environmentalists hold out the hope that distributed energy (which is becoming more economical relative to centrally dispatched power) will revolutionize electricity markets and usher in a new era of decentralized industrialized renewable energy.

Renewable energy is not dominant in off-grid areas and may not be in the future. Traditionally, propane- and diesel-fired generators have been the most economic power option. Improvements in solar technology have made this technology increasingly viable in remote markets, but the intermittency problem requires very expensive battery technologies to ensure reliable electricity service.[118]

Niche markets for solar power have grown over time and today range from the hand-held calculator to data-gathering ocean buoys to space satellites. Wind power is often thought of as distributed generation, but a limited number of homes or businesses are located in perpetually windy areas necessary to give the turbines a capacity factor high enough to make them viable and competitive with other distributed options.

Distributed generation is more expensive and problematic than central-station generation where demand conditions can support both.[119] Thus, as a developing region matures and gains greater economic infrastructure, first-generation electricity sources may give way either to a distributed generation upgrade or to central generation. Just as bicycles and motorbikes are a bridge to automobiles and trucks in many developing regions, solar panels or a wind turbine may become a bridge technology to gas-fired (or oil-fired) microturbines or much larger combined-cycle or cogeneration plants. Thus some renewable technologies could be bridge sources to conventional energies rather than the other way around.

Will Subsidies Rescue Nonhydro Renewables?

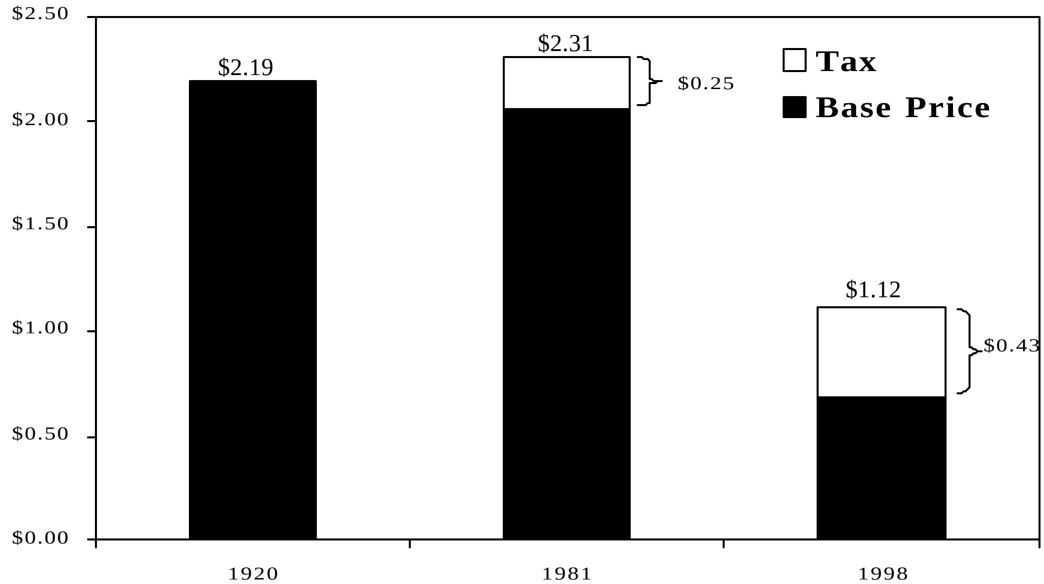
The competitive predicament of renewable energy—reflecting both the economic, if not the environmental, problems of wind power, solar power, and biopower and environmentalist opposition to hydropower—could lead to a decline in renewable capacity in the United States. While "green pricing" and a new round of government subsidies are providing some support, older projects are coming off-line because subsidies are expiring, and new projects are encountering financing difficulties in an increasingly competitive electricity market. Only a national quota for qualifying renewables, a federal "Renewables Portfolio Standard," can save unconventional energies from the "harsh realities" of competition, concluded a study by two advocates of renewable energy.[120] The Department of Energy in a business-as-usual scenario predicts an overall decline of renewables from 12.5 percent to 9.2 percent of domestic consumption by 2020 due to flat hydropower and geothermal power and aggressive entry by fossil fuels, natural gas in particular.[121] On the other hand, quota requirements and cash subsidies for qualifying renewables as part of state-level restructuring proposals are coming to the rescue.[122]

The Department of Energy predicts a decline of renewables from 12.5 percent to 9.2 percent of domestic consumption by 2020.

The Uncompetitiveness of Alternative-Fueled Vehicles

Although conventional fuels have a significant advantage over unconventional fuels in the electricity market, their advantage is even more pronounced in the transportation market. Of the world's approximately 650 million motor vehicles, fewer than 1.5 million (0.2 percent) are not gaso-

Figure 5
U.S. Gasoline Price Comparison (1998 $/gallon)



Sources: American Petroleum Institute; Energy Information Administration.

line or diesel powered. Liquefied petroleum gas or compressed natural gas powers almost all alternatively fueled vehicles. This gives fossil fuels more than a 99.9 percent share of the world motor vehicle transportation market, a market share not unlike their share in California or the United States as a whole.[123]

The cost of buying, driving, and maintaining gasoline-powered vehicles has steadily declined over time. Adjusted for inflation and taxes, the price of a gallon of motor fuel in 1995 was the lowest in the recorded history of U.S. gasoline prices. The weighted average price of gasoline of $1.27 per gallon[124] included 45 cents of local, state, and federal taxes, leaving the "free-market price" of crude acquisition, refining, and marketing at between 80 cents and 85 cents per gallon. Some of the "free-market price" includes the aforementioned "environmental premium," given that environmental compliance costs are built into the price.

The price of regular unleaded gasoline averaged $1.12 per gallon in 1998—a new record low and less than half the price of 1981's high (in present dollars) of $2.39 per gallon, despite a higher burden of state and federal taxes (Figure 5).[125] Of the many retail liquid products, only low-grade mineral water is cheaper than motor fuel today.[126] This points to the triumph of technology in converting crude oil into motor fuel and other products, a story not unlike the one of improving economies of turning natural gas, oil, and coal into electricity.[127]

The affordability of motor fuel has also improved in terms of work-time pricing (the amount of work time an average laborer must put in to buy an asset). In the 1920s a gallon of gasoline cost more than 30 minutes of labor time. In the mid-1990s the cost was 6 minutes and falling.[128]

The declining work-time cost of an automobile, even with numerous advances in vehicle comfort and environmental performance, has been documented by W. Michael Cox and Richard Alm:

> In the currency of work time, today's Ford Taurus costs about 17 percent less than the celebrated 1955 Fairlane

> and more than 70 percent less than the first Model T, introduced in 1908. And that's without any adjustment for quality. Early cars rarely had an enclosed body, tires couldn't be removed from rims and buyers had to purchase a separate anti-kickback device to prevent broken arms. Today's models embody literally hundreds of standard features—from air-conditioning and antilock brakes to computer-controlled carburetors [and injection systems] and CD players—making driving safer, more economical and more fun.[129]

"Price war" conditions for automobile sales beginning in 1997 and continuing into 1999, coming on top of intense gasoline competition, are continuing this trend.[130]

The price of renting an automobile, not only buying one, has significantly declined. The Cox and Alm study found that car rentals in 1997 were 60 percent cheaper than in 1970 in terms of work-time pricing.[131]

The economic and efficiency progress of the internal combustion engine can be expected to continue. Direct fuel injection as well as turbochargers to improve combustion and intercoolers are promising technologies for diesel engines.[132] Continuous transmission has great promise for reformulated gasoline engines as well. Improving today's energy conversion efficiency factors of around 24 percent for gasoline and 44 percent for diesel will be an important component of future emissions reduction.[133]

A survey of the various alternatives to fossil-fueled transportation, on the other hand, suggests that the market dominance of conventional vehicles will continue long into the foreseeable future.

Ethanol

Ethanol is a high-octane motor fuel derived from grain and waste products, primarily corn, and mixed with 15 percent gasoline ("E85"). Special governmental treatment of ethanol began with a federal tax exemption in 1906, and farm states such as Nebraska subsidized the fringe substitute for conventional motor fuel during the Great Depression. Despite encouragement from the U.S. Department of Agriculture, ethanol produced from surplus grain proved to be no match for the surplus of crude oil that came from the new discoveries in Texas, Oklahoma, and other states in the 1920s and 1930s.[134]

The subsidy floodgates for ethanol opened during the 1970s energy crises when tax breaks and government grants for ethanol conversion projects become commonplace. The Biomass Energy and Alcohol Fuels Act of 1980 earmarked $900 million for ethanol projects and set a goal for the farm fuel to capture 10 percent of the entire U.S. motor fuel market by 1990.[135] Despite such government support, ethanol blends would be as much as twice the cost of gasoline on an energy-equivalent basis. Ethanol's market share in 1990 was four-tenths of 1 percent (0.4 percent),[136] making the legislative goal 25 times greater than the actual result. The market share of transportation biomass has not appreciably changed despite state and federal tax subsidies of 54 cents per gallon.[137]

Current interest on the part of Ford and Chrysler in "alternative-fuel flexible" vehicles that can run on either ethanol or gasoline is due more to the desire to use a loophole to achieve compliance with the corporate average fuel economy (CAFE) minimum mileage standards than to true consumer demand. In fact, ethanol flexible vehicles register 25 percent less fuel economy than do vehicles running on CARB Phase 2 reformulated gasoline—with no reduction in air emissions per mile.[138] Adding to the problem, only 40 service stations in the Midwest sell ethanol, ensuring that the several hundred thousand alternative vehicles produced by the two automakers will run exclusively on gasoline.[139]

Ethanol output, even after receiving preferential tax subsidies, can be disrupted by high corn prices, as occurred in 1996.[140]

The economic and efficiency progress of the internal combustion engine can be expected to continue.

The major environmental problem of ethanol combustion is the higher evaporative emissions of smog-producing volatile organic compounds.

Ethanol also has an "embedded fuel" problem, since the created energy is largely canceled by the energy used to plant, harvest, ferment, and distribute the agricultural fuel.[141]

Environmentalists have not given ethanol a free ride despite qualifying it as a renewable resource. One analysis complained that "heavy use of fossil fuels by current agricultural practices renders ethanol . . . from corn fermentation . . . non-sustainable as now produced."[142] As it does on the electricity-generation side, "sustainability" would require renewable energy inputs and a "closed loop system" in which the agricultural inputs were grown in proportion to usage.

The major environmental problem of ethanol combustion is the higher evaporative emissions of smog-producing volatile organic compounds, which must be balanced against ethanol's reduction of the other smog precursor, NO_x. The recent extension of ethanol's federal tax break from 2000 to 2007[143] was more a victory for agricultural interests for than the environmental community, which has traditionally been ambivalent if not hostile toward this motor-fuel alternative.[144]

Methanol

Methanol is a sister fuel to ethanol and can be distilled from natural gas, coal, or wood products mixed with 15 percent gasoline to produce a fuel known as M85. In the 1970s and 1980s, methanol attracted large government favor as a more viable and near-term choice than other alternative-fuel vehicle technologies. In a congressional hearing in 1986, General Motors called methanol "America's energy 'ace in the hole,'" while the American Automobile Association described it as "the number one alternative fuel of the future." The EPA also tagged methanol as "the most promising alternative to motor vehicle fuel for this country."[145]

The political home for methanol in these high-water years was the CEC, the nation's largest state energy agency in the world's third largest transportation market (after Russia and the rest of the United States). Under the leadership of Charles Imbrecht, the CEC was attracted to a liquid fuel that could promote "energy security" by eroding the 99 percent market share of petroleum, while offering the near-term potential of reducing ozone-forming emissions by 50 percent, compared with gasoline vehicles, and reducing particulate emissions by 100 percent, compared to diesel vehicles.[146] Government-subsidized vehicle purchases and conversions and public-private partnerships with ARCO, Chevron, and Exxon to offer methanol in service stations were undertaken. Distributions from the Petroleum Violation Escrow Account (money collected from oil companies to settle disputes under the federal oil price regulation of the 1970s) also helped fund this alternative-fuel program.

Despite a 100-million-mile demonstration program with "no negative results,"[147] the methanol initiative proved to be more of a pilot exercise than a jump-start to a mass market. The political hope and favor for methanol would fade in the 1990s as successive reformulations of gasoline and improvements in onboard vehicle technology significantly reduced emissions at an affordable cost with no inconvenience to motorists.

More important, however, was the fact that consumers were discouraged by a variety of additional costs of methanol, including car conversion, higher fuel costs, more frequent oil changes, and lower vehicle resale value. A General Services Administration study in 1991 estimated that those extras amounted to a $8,000 premium compared with a conventional vehicle.[148] Because methanol fuel tanks were necessarily much larger than gasoline tanks (because of the lower energy density of methanol), motorists were also faced with less storage space in methanol-fueled cars. The absence of flame luminosity during methanol combustion also posed a safety problem.

The beginning of the end for methanol as a viable transportation alternative came in late 1993 when the Los Angeles County Metropolitan Transit Agency terminated its

$102 million methanol bus program in favor of the latest diesel options. Breakdowns were occurring in the city's 133 methanol buses twice as often as in conventional diesel buses because of the corrosive effect of methanol on engine parts. Seattle and Marin County (California) also dropped their methanol bus programs for the same reason.[149]

The CEC's 20-year push for methanol has been quietly abandoned. Whereas in 1993 the CEC had predicted a million vehicles would be fueled by methanol by the year 2000, the number across the United States is around 20,000 and falling. Methanol was not even mentioned as a transportation-fuel alternative in the most recent *California Energy Plan*,[150] testament to the perils of picking winners and losers before the marketplace does.

Electric Vehicles

Electric vehicles once dominated the mechanized transportation market in the United States. A study from the Renewable Energy Policy Project summarized:

> In 1900, electric vehicles outnumbered gasoline vehicles by a factor of two to one; an electric race car held the world land speed record. Their quiet, smooth ride and the absence of difficult and dangerous hand crank starters made electric vehicles the car of choice, especially among the urban social elite. Early in this century, there were more than one hundred electric vehicle manufacturers.

Improvements in the internal combustion engine and plentiful oil and oil products reversed the competitive equation. The same study explained:

> The weight, space requirements, long recharging time, and poor durability of electric batteries undercut the ability of electric cars to compete with much more energy-dense gasoline, an energy carrier manufactured from crude oil. One pound of gasoline contained as much chemical energy as the electricity held in one hundred pounds of the lead acid batteries then in use. Refueling a car with gasoline was measured in minutes, on-board storage was a snap, supplies appeared to be limitless, and long-distance fuel delivery was relatively cheap and easy. With these attributes, gasoline dominated the fuel marketplace. By 1920, electric cars had virtually disappeared.[151]

The Worldwatch Institute has also documented the rise and fall of electric vehicles. "Although electric cars and a variety of other [alternative-fuel] vehicles were popular at the turn of the century," summarized Christopher Flavin and Nicholas Lenssen, "they were pushed aside by improvements in the internal combustion engine and the falling price of the gasoline used to run it."[152] Disputing the claim that the electric vehicle is the car for the 21st century, the American Petroleum Institute noted that it was "more suitable for the late 19th century, when society was geographically compact and people tended to travel much shorter distances."[153]

Electric cars entering the commercial market today are much more costly and less convenient to operate than conventional vehicles. Since introducing its electric vehicle in late 1996, General Motors has sold that model (EV1) to carefully screened, upper-income customers who treat the cars more as showpieces than as substitutes for their conventional vehicles. The select customers receive a variety of subsidies and special services. In return for its substantial investment, General Motors receives favorable publicity and goodwill from regulators weighing a "zero emission vehicle" mandate, as they are in California. Ordinary consumers receive little: the cars are more expensive even with subsidies, require extra expenses such as home recharging facilities, are less safe (40 percent lighter than regular

The CEC's 20-year push for methanol has been quietly abandoned.

Environmentalist Amory Lovins has called electric vehicles "elsewhere emission" vehicles.

vehicles), and are less convenient because of the lack of driving range and the necessity of long refueling times. New battery options to increase driving range aggravate the cost disadvantage.[154]

Electric vehicles are touted as being 97 percent cleaner than conventional vehicles. But studies have shown that the tradeoffs with economics and convenience are not matched by emission reductions, since most of the electricity is generated by fossil fuels.[155] Environmentalist Amory Lovins has called electric vehicles "elsewhere emission" vehicles.[156] A team of experts from the Massachusetts Institute of Technology concluded that electric vehicles yield an "imperceptible overall environmental benefit" since up to 65 percent of fossil energy is lost when burned to generate electricity, and 5 percent to 10 percent of the generated electricity is lost in transmission and distribution.[157]

Battery wastes are another unique environmental problem with electric vehicles, given that gasoline is now lead free. Complained Dan Becker of the Sierra Club, "[Electric vehicle] batteries are filled with badness—things like lead and cadmium."[158] Sodium-sulfur batteries and other substitutes introduce their own set of environmental and safety problems.[159] But even if the environmental problems with batteries are overcome, their sheer size, weight, and expense are formidable arguments against their replacing the $50 fuel tank of conventional vehicles.[160] Operational problems with batteries in cold-weather climates add to those problems.[161]

A hybrid electric vehicle, which combines an internal combustion engine with battery-powered electronics, shows promise, particularly in heavy-duty trucks using diesel. Onboard recharging offers advantages over dedicated electric vehicles. Yet the use of diesel or gasoline reduces the alleged environmental benefits of onboard recharging, and the complexity of the hybrid design results in a significant cost premium compared with conventional vehicles. That is why a study by a committee of the National Academy of Sciences and the National Academy of Engineering criticized the technology as not environmentally cost-effective.[162]

Natural Gas and Propane Vehicles

Like electric vehicles and solar and wind applications, gas-powered vehicles were once economically viable without government subsidy. At the turn of the century demonstration coal-gas vehicles could be found in major metropolitan areas. Decades later propane vehicles became commonplace in rural settings (farms in particular) where refueling limitations were less of a constraint and the fuel was not subject to motor fuels taxation. Vehicles fueled by compressed natural gas have been fewer and more recent.[163]

Largely because of ratepayer subsidies, which allowed utilities to pass fleet conversion costs on to their captive customers, a number of natural gas distribution companies converted fleet vehicles to natural gas and erected related infrastructure in the 1970s and early 1980s. But conversions proved to be technologically problematic as well as expensive and inconvenient relative to conventional vehicles.[164] The effort also lost momentum as gasoline and diesel prices fell beginning in 1981.

In the late 1980s a second effort to promote natural gas vehicles commenced with greater emphasis on dedicated vehicles than on converted conventional vehicles. In addition to support from state utility regulators, subsidies and vehicle purchase mandates from the federal government (such as those in the Energy Policy Act of 1992) were adopted. Falling natural gas prices and plentiful supply were also coming into play. The improved position of natural gas vehicles was evident when the CEC reported in the *1995 Fuels Report*:

> In the late 1980s, methanol was touted as the alternate fuel of choice in the transportation sector. Now natural gas is beginning to assume that role,

> not only in California but in the rest of the United States.[165]

By the mid-1990s it was evident that natural gas and propane vehicles were winning the alternative-fuel battle but losing the motor fuel war. While Ford, General Motors, Chrysler, Honda, Toyota, and Volvo offered select natural gas models as either dedicated or dual-fuel vehicles, sales to the general public were rare, and commercial fleet sales were difficult. While some fleets were converting in the worst air quality markets such as Los Angeles and New York City, fleet conversions were more the result of mandates or special incentives than of market calculation. Several thousand dollars in up-front costs for dedicated or converted vehicles, a lack of refueling infrastructure and maintenance facilities, limited driving range, extra onboard storage requirements, extra weight lowering car performance, and falling gasoline and diesel prices were barriers to entry. A study by Battelle Memorial Institute determined that the overall cost of using compressed natural gas in FedEx's Los Angeles fleet was slightly greater than that of propane and substantially more than that of using reformulated gasoline.[166]

The one advantage of natural gas and propane—their substantially lower cost per gallon equivalent—was due more to gasoline and diesel taxes than to the gases' inherent energy and technology characteristics. Had enough market share been gained, chances are that motor fuel taxation would have been extended to natural gas and propane to reduce if not eliminate this benefit.

In a strategy shift in 1995, the Natural Gas Vehicle Coalition, the Gas Research Institute, and the American Gas Association deemphasized both the passenger market and government mandates:

> The high fuel-use vehicle market offers the greatest potential. . . . The most economical approach to achieving success in the high fuel-use market is to target fleets. Emphasis will be on developing products and technologies that satisfy customer needs. . . . This strategy does not encourage additional government mandates, or broad rate-based financing by the gas industry for NGV refueling infrastructure. . . . NGVs must . . . meet the needs of its stakeholders and the marketplace.[167]

A number of developments were behind the retreat to a niche market. Some nonattainment areas such as Houston tried and abandoned gas-powered vehicles in their light-duty and heavy-duty fleets. Enron Corp., the "world's first natural gas major," abandoned its transportation program in 1995 after two years of effort. The competition from reformulated gasoline in reconfigured engines was also rapidly raising the bar. A headline on page 1 of the February 19, 1996, issue of *Natural Gas Week* told this part of the story: "NGVs Pushed to the Back Seat as RFG Takes Over Favored Role."

Dedicated natural gas vehicles have lower air emissions than do vehicles run on reformulated gasoline, but they also have a number of economic disadvantages that typically restrict their market niche to fleet vehicles in select urban areas. There is little reason for ordinary motorists to pay a $1,000–$1,500 premium for a dedicated methane vehicle (a premium that would be closer to $3,500–$5,000 without subsidies) that has less range and less trunk space and does not have a national refueling network.[168] There is even less reason to convert vehicles from gasoline or diesel to natural gas or propane because vehicles run on those fuels have higher costs and poorer operating characteristics than do dedicated vehicles. A more robust market exists for heavy-duty dedicated vehicles that can be centrally refueled and maintained where heavy concentrations of diesel particulate emissions are displaced.

By the mid-1990s it was evident that natural gas and propane vehicles were winning the alternative-fuel battle but losing the motor fuel war.

Like wind, solar, and electricity for transportation, the fuel cell is hardly a revolutionary technology.

Natural gas and propane vehicles have found commercial viability in certain regions of the world where gasoline and diesel taxes are high compared with the United States. Argentina, Italy, and Russia account for 90 percent of the world's alternative-fuel vehicles; in the United States, large subsidies have spawned limited activity in only the most air-polluted markets in the country, such as Los Angeles and New York City. Yet of the approximately 400,000 alternative-fuel vehicles in the United States (a portion of which are dual fuel but may not be actually using alternative fuels), 90 percent are fueled by propane, compressed natural gas, or a close substitute.[169]

Hydrogen Fuel-Cell Vehicles

Because of the above problems of "conventional" alternatives to fossil-fueled vehicles, the environmental community has increasingly embraced a completely new transportation technology—the hydrogen fuel-cell vehicle.

Potentially reducing emissions by as much as 90 percent or more compared with conventional vehicles, the hydrogen fuel-cell vehicle—which uses a chemical reaction with hydrogen and oxygen to produce electricity to create horsepower—has become a popular technology in theory for meeting the aggressive goals for climate stabilization in the 21st century.

Like wind, solar, and electricity for transportation, the fuel cell is hardly a revolutionary technology. It was invented in 1839, and laboratories have been testing fuel cells for more than a century. Hydrogen fuel-cell vehicles were first designed and introduced in Germany in the 1920s and 1930s. Large-scale testing was a casualty of the war, and for the next few decades further development languished. A review of America's energy resources and technology for a U.S. Senate subcommittee in 1962 reported:

> The fuel cell is still an experimental idea, although close to some special commercial applications. . . . Specialty applications, where convenience is more important than cost, could become important soon. . . . Some experts believe such cells may be developed within a decade; others believe this is far too optimistic. The fuel cell for the home or for automotive use seems a long way off. In general there is more optimism about the fuel cell than about any of the other new energy conversion schemes.[170]

In the last two decades, prototype vehicles have been built and demonstrated in the United States, Germany, Japan, and several other countries. The U.S. space program proved to be the first commercial market for fuel cells, albeit a government-created one.

Mercedes Benz, Toyota, and Chrysler have been at the forefront of studying transportation-based fuel cells, and Ford and General Motors have joined in as well. The Department of Energy has steadily increased funding for its National Hydrogen Program, and a 1996 federal law—the Hydrogen Future Act—set forth a five-year, $100 million research and development program.[171]

A group of researchers at Directed Technologies, under contract to the Department of Energy, has unveiled "a technically and economically plausible market penetration plan that moves smoothly and seamlessly from today's total dependence on fossil fuel for transportation to a sustainable energy system based on renewable hydrogen."[172] The authors added, "Hydrogen in any realistic scenario will undoubtedly be produced initially from fossil fuels, before hydrogen produced by renewable energy sources becomes cost competitive."[173] Thus in the first decades of any transportation makeover, fossil fuels will still be dominant.

Hydrogen fuel-cell vehicles, despite having the advantages of simplified engine design, better fuel economy, and fewer greenhouse gas emissions, face a daunting problem. Gasoline-powered vehicles are entrenched with a huge sunk-cost asset base, general consumer goodwill, and rapidly improving technologies. The optimal hydrogen choice (direct hydrogen fuel-cell vehicles) is simply not achievable without staggering transition costs; it would require an entirely new refueling infrastructure, entailing an investment of tens of billions of dollars in the United States alone.

Hybrid fuel-cell vehicles (fueled by a liquid) could use the existing service-station infrastructure if they used gasoline, methanol, or diesel for onboard conversion to hydrogen. But such vehicles would require complicated engine designs with lower fuel-cell performance, have greater weight and need more space, and have overall higher vehicle cost. In either case, a chicken-and-egg problem exists between producing enough hydrogen vehicles to lower cost and having costs low enough to encourage mass consumption and production. In the case of direct hydrogen designs, today's hydrogen (produced primarily from natural gas) costs more than $9 per gallon of gasoline equivalent because of its limited scale of production.[174]

This predicament points toward one necessity—massive government involvement over and above a large private effort. The authors of the Department of Energy study state, "Government incentives such as the California zero emission vehicle (ZEV) mandate will probably be necessary to stimulate initial [fuel-cell vehicle] markets, in addition to government-supported research, development and demonstration projects."[175] Even under an aggressive scenario of government subsidies ($400 million by 2008 in this case) and mandates and private-sector investment, 1 to 2 million vehicles at most would be operating at the close of the Kyoto Protocol budget period (2012), according to this study. Only in the 2020-30 period would 10 to 30 million vehicles be hydrogen powered, still leaving fossil fuels with a 95 percent market share of the domestic auto fleet.[176]

A study by five environmental groups in 1997 concluded that hydrogen fuel-cell vehicles would begin to be marketed in 2010 at a $10,000 premium per vehicle over conventional vehicles.[177] Given that the vehicle today could cost $200,000, aggressive assumptions are being made here as well.[178]

Any analysis forecasting a transition to hydrogen fuel-cell vehicles must be considered with utmost caution. One researcher from Argonne National Laboratory explained:

> The idea that anyone can successfully project what fuel cell costs are going to be in 6–12 years . . . seems a ludicrous proposition. . . . Commercialization means virtually everything about current cells must change drastically. Furthermore, not only the fuel cell must change—we've got to drive down the costs of all parts of the electric drive train, that is, motor, power electronics, etc.—or consign fuel cells to a niche market. Nevertheless, someone willing to string together a prodigious number of "what if" calculations can come up with a semi-rationale approach to taking a stab at a number.[179]

Hope, hedging, and public relations—in addition to a dose of venture capitalism—spring eternal. Exxon, ARCO, Shell, Chrysler, and other companies are studying hydrogen and fuel-cell technology as a potential source of energy for transportation in the next century.[180] General Motors and Ford have announced production of a hydrogen fuel-cell vehicle by 2004.[181] The most aggressive initiative belongs to Daimler Benz (Chrysler's new European parent) that has announced a goal of having 100,000 fuel-cell vehicles on the road by 2005 and has entered into a $325 million program with Ballard Power Systems to that end.[182]

"The hydrogen economy," summarized *The Economist*, "will be a consequence not of the running out of oil, but of the development of the fuel cell—just as the oil economy was not a consequence of coal running out, but of the fact that the internal-combustion

Today hydrogen costs more than $9 per gallon of gasoline equivalent because of its limited scale of production.

Gasoline and diesel are becoming cheaper and cleaner, and conventional automobile technology is meeting the needs of both lower income and higher income consumers.

engine was a better technology than the steam engine."[183] Such optimism is tempered by the realization that the hydrogen dream is more than a half century old and the petroleum-based transportation market grows stronger economically and technologically by the day, despite disproportionately large government support for rival technologies. Every year adds 50 million new conventional vehicles, and a net gain of approximately 15 million to 20 million vehicles, to a global fleet of 650 million passenger cars and commercial vehicles.[184] With gasoline and diesel becoming cheaper and cleaner, and conventional automobile technology meeting the needs of both lower income and higher income consumers, hydrogen technologies will have to catch a rising star.

The Failure of Government-Promoted Alternative Energy

As demonstrated in the last section, a mountain of subsidies, preferences, and government-promoted advocacy campaigns has failed to sustainably commercialize alternative energy in the marketplace. The market share of alternative energies in the transportation economy is not large enough to be reportable; excluding environmentally incorrect hydropower, government-sponsored renewables account for about 2 percent of the electricity sector.[185] The failure of alternative fuels cannot be seen as a failure of government will. As discussed below, even the most aggressive government interventions have failed to significantly tilt the energy economy, given the economic and social premiums required by nonfossil substitutes.

The California Experience

California, the world's eighth largest economy, provides a useful test case for the proposition that, with enough government favor, alternative fuels could reasonably compete with fossil fuels. In terms of investment and experimentation with alternative energy, California has led the nation and the world in ratepayer and taxpayer financing over the last quarter century. Wind power, solar power, biopower, and geothermal power have been generously subsidized for electricity generation. Ethanol, methanol, natural gas, and electricity have received government largesse for transportation.

While many of the subsidies are continuing, the verdict is all but in. The victor on the transportation side is reformulated gasoline and the revamped internal combustion engine, which have proven to be technologically feasible at reasonable cost.[186] The CEC has put alternative transportation fuels on notice in its latest energy plan:

> California . . . must consider the costs to create new or flexible fuel infrastructures to support new alternative-fuel delivery systems, particularly for personal transportation. Alternative fuels will not be viable unless they are readily available and competitively priced.[187]

The victor on the electricity side is natural gas combined-cycle technologies—despite $540 million in ratepayer subsidies earmarked for qualifying renewables in the next four years. The CEC states:

> By 2015, California is expected to increase its consumption of natural gas by 1,500 million cubic feet a day or 23 percent. New power plants are likely to be fueled by natural gas because of economic and environmental benefits. In many cases, these new efficient plants will replace power plants that use as much as twice the fuel-equivalent per kilowatt-hour generated.[188]

The state's energy conservation policy, liberally subsidized through a several-billion-dollar ratepayer cross-subsidy for more than two decades,[189] has also moved toward the market.

> Policies directing conservation and efficiency programs over the past 20 years have changed from "use less fuel" to "use energy more effectively." . . . Sustainable changes in the energy services market . . . favor the voluntary adoption of more efficient products and services.[190]

A representative of the South Coast Air Quality Management District in California testified before Congress in 1993 that between 10 percent and 30 percent of the state's transportation market would be powered by an alternative fuel by the turn of the century.[191] A small fraction of 1 percent of the market is now expected to be powered by natural gas, methanol, and electricity combined. This collapse of the alternative-fuel market is not cause for environmental regret, given the positive contribution of reformulated motor fuels and changes in engine design. This is not to say that challenges do not remain but that traditional alternatives can be revamped to be the least cost solution in a technologically dynamic world.

Synthetic Fuel Production

Although it is hardly part of the "alternative energy" dialogue today, the campaign to promote renewable energy is strikingly similar to the campaign a few decades ago to promote synthetic fuels. The spectacular and costly failure of syn-fuels, however, is a lesson that has unfortunately been ignored by today's energy planners.

Synthetic fuels attracted many of the "biggest and brightest" energy investors in the 1970s and 1980s. The idea of converting coal and other solids into oil, despite having failed as a U.S. government program between 1944 and 1955,[192] was considered ripe for technological exploitation, given high and rising oil and gas prices under the "theory of exhaustible resources." Producing synthetic oil and gas was thought of simply as an engineering challenge, solvable by new increments of entrepreneurial will and financial capital.

The result was the $88 billion federal Synthetic Fuels Corporation, established in 1980 as "the cornerstone of U.S. energy policy." The corporation set a production goal of 2 million barrels of syn-fuel a day by 1992.[193] Shell, Exxon, Mobil, Chevron, Union Oil, Occidental, Ashland, Tenneco, Transco, and other firms championed the effort from the private side with their own investments, sometimes without government help. Exxon chairman C. C. Garvin in 1980 reflected industry opinion when he estimated that U.S. syn-fuel production could reach as high as 4 million to 6 million barrels per day by 2000.[194] His company's planned international syn-fuel investments of $18 billion, almost double that amount in today's dollars, reflected his belief.[195]

Falling crude oil prices in the early 1980s shook the popular vision. Planned investments were scaled back or scrapped, and the Synthetic Fuels Corporation was abolished in December 1985 with most of its monies unused. Some projects lingered as technological successes before economic reality won out. Shell, for instance, did not close its privately funded coal gasification project until 1991, and Unocal terminated its oil shale plant a year later. The only syn-fuel project left today is the $2.1 billion Great Plains Coal Gasification Project in North Dakota, which survived on the strength of $700 in federal tax credits and a high-priced syn-gas purchase contract after the original owners lost their equity investment.[196] The plant was sold by the Department of Energy to a consortium of North Dakota electric cooperatives for a mere $85 million. The difference was a combination of investor ($550 million) and taxpayer loss.[197]

The failed economic experiment with synthetic fuels can be blamed on the technological limitations of synthetic fuel processes. But the deeper reasons for failure are relevant to today's subsidized renewable energy debate:

- Pervasive government intervention made oil and gas prices artificially high

The spectacular and costly failure of syn-fuels is a lesson that has been ignored by today's energy planners.

The 20th century has revealed most alternative and unconventional energy technologies to be "primitive" and "uneconomical."

relative to the price of coal, and deregulation and market adjustments not only returned prices to "normal" levels but made hydrocarbon prices lower than they would have been without the initial government intervention (the boom-bust price cycle).

- Technological improvement was occurring with both conventional and unconventional energies, not just unconventional energies.
- Rising energy prices were increasing not only revenue from the sale of synthetics but also the cost of making them, given the sensitivity of capital-intensive synthetic fuel plants to energy costs.

Those reasons may apply to the next generation of government-subsidized energies being touted as substitutes for crude oil, natural gas, and coal.

Energy Technologies—Environmental Motivations

Despite the demonstrable failure of government intervention to assist politically favored fuels, environmentalists continue to hold out hope and to strike an optimistic pose on the basis of a particular interpretation of technological progress. The words of Christopher Flavin and Seth Dunn of the Worldwatch Institute typify the environmentalist rejoinder.

> Although some economists argue that it will be expensive to develop alternatives to fossil fuels—and that we should delay the transition as long as possible—their conclusions are based on a technological pessimism that is out of place in today's world. Just as automobiles eclipsed horses, and computers supplanted typewriters and slide rules, so can the advance of technology make today's energy systems look primitive and uneconomical. The first automobiles and computers were expensive and difficult to use, but soon became practical and affordable. The new energy technologies are now moving rapidly down the same engineering cost curves.[198]

Yet the 20th century has time and again revealed most alternative and unconventional energy technologies to be "primitive" and "uneconomical" compared with fossil-fuel technologies, particularly for transportation but also for the stationary market. Alternative energy technologies are not new; they have a long history. As the Department of Energy stated back in 1988, "The use of renewable energy dates back to antiquity."[199] Conventional energy technologies, on the other hand, are not mired in the past. They have been setting a torrid pace for unconventional energies and can be expected to continue to do so in the decades ahead, if not longer.

Environmentalists are quite discriminating with their "technological optimism"; they will have none of it for fossil fuels and even less for nuclear power. In 1988 the Sierra Club opposed congressional interest in subsidizing research on a "safe" nuclear plant, since "we have doubts that development of such a plant is possible."[200] A decade later more than 100 environmental organizations railed against a $30 million proposed allocation in the Clinton administration's $6.3 billion Climate Change Action Plan (.5 percent) to help extend the operating life of existing nuclear plants. In their judgment, the risk of radiation poisoning was as great as or greater than that of global warming.[201] Would mainstream environmentalists support ongoing research by Pacific Gas and Electric Company to seed clouds to increase rainfall to increase hydroelectricity output,[202] or would they reject enhancing this renewable resource as an intervention by man in nature? In reality, opponents of fossil fuels and nuclear energy—and even hydroelectricity—can be characterized as pessimistic about the most prolific technologies in the electricity market today.

The same pessimism—or disinterest—applies to geoengineering approaches to address atmospheric concentrations of CO_2 instead of reducing fossil energy combustion. The National Academy of Sciences concluded in a 1992 study that such geoengineering options as reforestation, stimulating ocean biomass with iron, and screening sunlight "have large potential to mitigate greenhouse warming and are relatively cost-effective in comparison to other mitigation options."[203]

This raises the following question: are the real concern and mission of mainstream environmentalism to reduce climate change and eliminate the risk of radiation or to arrest the high levels of global development and population sustainability that increasingly abundant energy affords?

Environmentalist and fossil fuel critic Paul Ehrlich believes that "giving society cheap, abundant energy . . . would be the equivalent of giving an idiot child a machine gun."[204] And when cold fusion seemed briefly to be the ultimate renewable energy, the environmental movement recoiled in concern. Jeremy Rifkin spoke for many when he told the *Los Angeles Times* that cold fusion was "the worst thing that could happen to our planet."[205]

The cold, hard fact remains that the mainstream environmental movement supports those carbon-free energies that are the most expensive and the least reliable. Wind and solar power are not only costly on a per unit basis but have low capacity factors, are site constrained, and are intermittent. Nuclear and hydro, which enjoy much less environmentalist support, on the other hand, can be flexibly generated on a mass scale.

Indeed, higher prices and less availability translate into less usage, which is conservation by another name (enforced conservation). Ehrlich and others have complained about the environmental impact of energy from any source:

> No way of mobilizing energy is free of environmentally damaging side effects, and the uses to which energy from any source is put usually have negative environmental side effects as well. Bulldozers that ran on hydrogen generated by solar power could still destroy wetlands and old-growth forests.[206]

Ehrlich has stated elsewhere, "In a country like the United States, there is not the slightest excuse for developing one more square inch of undisturbed land."[207] To Ehrlich the inherent energy use of such development would be environmentally destructive as well. Yet a moratorium on development, ironically, would condemn renewable energy technologies in particular, since they require much more space and pristine acreage than do conventional power plants per unit of output.[208]

Another example of the environmental tension created by environmentalist energy goals was stated by a former executive of US Electricar: "I worry that the focus on producing zero-emission cars distracts us from concentrating on redeveloping decent mass transit."[209] If the most optimistic scenarios with hydrogen fuel-cell vehicles play out in several decades and inexpensive, environmentally benign driving becomes the norm, will environmentalists rejoice or be concerned about the side effects of affordable, decentralized mobility?

All energy technologies should be evaluated *realistically* in the short run and optimistically but *realistically* in the longer run. In this sense one can be *optimistic* about all energies and their technologies, conventional and unconventional, yet still appreciate the current sizable competitive edge of the former. Such an appreciation is not a call for companies to forgo being "venture capitalists" to seek out new energy technologies and alternatives that currently are out of the market. The public policy issue is not whether the completely new should overthrow the old. There is always the chance that revolution will join day-by-day evolution. The call is to establish and protect market institutions to encourage research and development in a nonpolitical

The mainstream environmental movement supports those carbon-free energies that are the most expensive and the least reliable.

For most of its scientific history CO_2 has been considered an environmental tonic.

setting to reduce inefficiency and waste, given that human wants are greater than the resources to meet them.[210]

Global Warming: The Last Challenge to Fossil Fuels?

The greatest threat to fossil fuels' market share in the 21st century comes not from competing energies but from politicians and special interests professing concern about anthropogenic global warming. Accelerating accumulation of CO_2 (the chief industrial greenhouse gas) in the atmosphere is primarily the result of fossil-fuel consumption. Fossil fuels, however, cannot be "reformulated"—nor their emissions "scrubbed"—to remove CO_2. Mark Mills explains:

> Carbon dioxide emissions are the intended outcome of oxidizing the carbon in the fuel to obtain energy. There is thus no avoiding, or cleaning up, carbon from the fuel source. This perhaps obvious, but oft ignored, reality highlights the reason that restraints on carbon dioxide emissions are, by definition, restraints on the use of energy for society. There are thus only three ways to [significantly] reduce carbon emissions: regulate CO_2, raise the price of carbon fuels to discourage use, or offer non-carbon alternatives.[211]

For most of its scientific history CO_2 has been considered an environmental tonic, enhancing photosynthesis to increase plant biomass and agricultural yields.[212] Carbon dioxide and other heat-trapping gases were also credited with warming the earth to make it habitable—the incontrovertible "greenhouse effect" theorem. Carbon dioxide has never been considered a pollutant that affects human health like particulate matter, lead, carbon monoxide, volatile organic compounds, or NO_x—all regulated by the EPA.

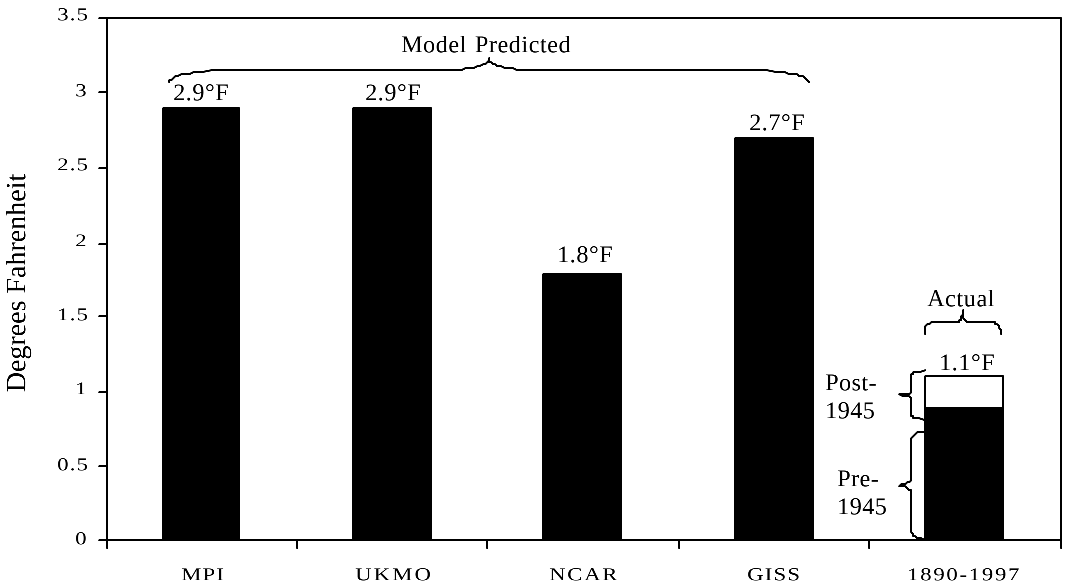
Atmospheric levels of CO_2 have increased 30 percent or more since the Industrial Revolution, and the "warming potential" weighting of all six greenhouse gases has increased around 50 percent in the same period.[213] Virtually all scientists believe that a doubling of greenhouse gas concentrations in the atmosphere, estimated to occur over a 70- to 150-year period, would increase global average temperatures, other things being the same.[214] Consensus evaporates, however, on the magnitude, distribution, and timing of warming and how much other emissions, such as man-made sulfate aerosols or even conventional urban smog, might offset the potential warming.[215]

The controversy also extends to public policy. If harmful climate effects are possible, are the costs of mitigation greater than those of a strategy of unabated economic development and social adaptation (a wealth-is-health approach)? If a mitigation strategy is followed, is the least cost strategy to transform the energy economy to reduce carbon sources or to substitute geoengineering techniques, such as tree planting and seeding the ocean with iron to increase carbon sinks? A political question is the role of the United States in such efforts. While the United States is the leading emitter of greenhouse gases in the world, America vitally contributes to a robust carbon cycle. A recent study found that North America is a net carbon sink,[216] which in the parlance of the climate change debate would make America and Canada a net "global cooling region."

Declining Estimates of Future Warming

The warming estimates, made by general circulation climate models, of increased anthropogenic greenhouse gas concentrations in the atmosphere have declined in the last 5 to 10 years. Whereas the estimate of warming from a doubling of CO_2 in the atmosphere was often around 4°C in the 1980s models, estimates from newer models, such as the latest iteration at the National Center for Atmospheric Research in Boulder, Colorado, are closer to 2°C.[217] The latest "best guess" Intergovernmental Panel on Climate

Figure 6
Model Warming vs. Recorded Warming under 50 Percent Greenhouse Gas Buildup Assumption



Source: Author's calculations.

Note: MPI = Max Planck Institute, UKMO = United Kingdom Meteorological Office, NCAR = National Center for Atmospheric Research, GISS = Goddard Institute for Space Studies.

Change (IPCC) forecast for the year 2000 is 2°C, an almost 40 percent drop since the first IPCC estimate in 1990.[218]

The downward revisions to date have been primarily due to a lower assumed atmospheric buildup of greenhouse gases and the inclusion of the alleged warming offset factor of sulfate aerosols. More realistic model equations and calculations responsible for determining climate sensitivity (discussed below) remain to be incorporated. One-half of the predicted warming in the revised models is still substantially greater than the recorded warming, given a 50 percent increase in greenhouse gas buildup to date (Figure 6). This suggests that further downward revisions may be necessary.[219]

Defenders of the models argue that a lag effect produced by ocean absorption of heat energy reconciles the past and portends an acceleration of warming in the second half of the greenhouse gas doubling period.[220] The "unrealized warming" has led noted modeler James Hansen to predict that the greenhouse "signal" of heat and drought will "increase notably" in the coming years.[221] Separating the recent El Niño effect from the "record" warming will be the difficult first step in testing the Hansen prediction, at least in the short run.

Lags or not, two recent developments may portend a further reduction in model warming estimates. First, the rate of greenhouse gas buildup has been even slower than assumed because of flat methane emissions, a phaseout of chlorofluorocarbons, and greater biomass intake of CO_2.[222] Second, the crucial water vapor climate feedback, which in climate models doubles the warming estimated from doubled CO_2 alone, is likely to have been overestimated.[223]

Scientific revisions in the last decade have moderated the case for climate change alarmism.

Benign—or Positive—Warming Trends

Given the observed surface warming of the last half century, and particularly of the last two decades, the distribution of the predicted warming would be relatively benign, occurring in the coldest air masses during the coldest times of the year and more often during the night than during the day. Maximum summer temperatures, which are of more discomfort and create more negative climate consequence in many areas of the world, have been less affected.[224]

Other unresolved issues are important in the debate over climate change and public policy. The apparent incongruence between steadily rising CO_2 levels and surface temperatures for much of the present century, namely the "overwarming" prior to 1945 and "global cooling" between 1945 and 1975, has led to ad hoc adjustment factors in the climate models with sulfate aerosols to reconcile the data with predicted results.

There is also a well-known discrepancy between atmospheric temperature readings by satellite and balloon sensors (showing a slight cooling in the lower troposphere, where the models predict a stronger "greenhouse signal" than at the surface) and surface thermometer readings, which show a warming trend over the past 20 years. Bias corrections in the satellite data have lessened the discrepancy, but significant differences remain that, if verified, would suggest that either the surface warming has been overstated or the surface warming has not been driven by anthropogenic greenhouse gas buildup—both signaling vindication for the skeptics of warming alarmism.[225]

In addition to the increase of surface temperatures at a fraction of the rate predicted by general circulation models in the last five decades (0.15°C), sea levels have risen only modestly (only seven inches over the last century), and extreme-weather events have not occurred with any more frequency than in the past.[226] Critics ask, where is the alarmist "greenhouse signal," given a 50 percent buildup of the warming potential of greenhouse gases in the atmosphere to date?

The best argument for climate alarmism may not be what is known but what is not known—climate "surprises" from "rapidly forced nonlinear systems."[227] Yet as climate model revision and actual data lower the warming estimates, the potentially negative climatic "surprises" predicated on high warming evaporate also. That leaves the positive "surprises" from a higher level of CO_2 in the atmosphere: a decreasing diurnal cycle, a moderately warmer and wetter climate, and enhanced photosynthesis for a richer biosphere.

Scientific revisions in the last decade have moderated the case for climate change alarmism. Scientific thought today favors greater movement toward the lower end of the warming estimates from climate models. The scientific justification for the Kyoto Protocol is more than just unsettled. It is speculative and unconvincing, given actual weather records to date and ongoing scientific revisions. The more settled side of the scientific debate, the positive effects of higher CO_2 concentrations on plant life, strongly favors the status quo even before the political and energy-economic dimensions of the climate change issue are examined. But for purposes of analysis, a stronger scientific case currently exists for assigning a positive externality value to CO_2 than for assigning a negative one.

Kyoto Quandaries

The Kyoto Protocol, which requires signatory Annex 1 (developed) countries to reduce global greenhouse emissions by an average of 5.2 percent from 1990 levels in the 2008–12 budget period, begins the process of stabilizing atmospheric concentrations of anthropogenic greenhouse gases believed to be responsible for problematic climate change. Approximately 134 developing countries are exempt, including China, which is projected to surpass the United States as the world's leading CO_2 emitter in the coming decades. The Department of Energy and the Clinton administration project that exempt non–Annex 1 countries will emit more CO_2

than will covered Annex 1 countries beginning sometime between 2015 and 2020.[228]

Both the exemptions for developing countries and the inertia of past and current greenhouse gas emissions limit the climatic impact of a "perfect" Kyoto. Full compliance with the protocol would reduce anthropogenic warming (as estimated by the climate models) by only 4 percent to 7 percent (0.1°C–0.2°C) by the year 2100.[229] That is why one prominent climate modeler has estimated that "thirty Kyotos" are necessary to effectively address the alleged problem.[230] Thus, the environmental benefits achieved by full compliance with the treaty are infinitesimal and probably not even measurable—at least for "many decades."[231]

What are the costs of complying with the treaty? Carbon dioxide emissions cannot be reduced without reducing fossil-fuel consumption.[232] So the question is, how expensive would it be to reduce fossil-fuel consumption to 7 percent below 1990 levels (or around 30 percent below what would otherwise have been consumed by 2012)?[233]

Close examination of the Clinton administration's economic projections regarding reductions in greenhouse gas emissions reveals that "the political struggle over U.S. compliance with the Kyoto Protocol is really a fight about the future of the coal-fired generation of electricity," according to Peter VanDoren.[234] Some administration officials believe that coal-fired power plants can be cheaply replaced by natural gas–fired power plants; others in the administration are less certain.[235] The belief that politically favored renewable energy sources represent low-cost, "silver bullet" solutions to global climate change is not taken seriously even by the president's own Council of Economic Advisers, as discussed below.

The absence of a viable supply-side strategy option places the burden of meeting the Kyoto Protocol requirements squarely on the demand side. Yet there is no economically viable solution based on substantial absolute reductions in energy usage despite the fantastic pronouncements from Amory Lovins, such as "America's energy-saving potential—sufficient 'to cut industrial energy use in half' . . . tags along [with Kyoto compliance] almost for free."[236] Even a far more modest assertion by a U.S. Department of Energy technology group that government-directed energy efficiency investments could substantially assist in meeting the Kyoto Protocol's emission-reduction requirements[237] was downplayed by the Council of Economic Advisers in its July 1998 report on minimizing compliance costs with the Kyoto Protocol.[238] The council's dismissal of such an approach probably was due to the Department of Energy's understatement of the costs of energy efficiency subsidies and mandates and a gross overstatement of the potential for reductions in energy consumption.[239]

Increased energy efficiency or lowered energy intensity per unit of output does not translate into reduced energy consumption per se. Despite a one-third reduction in energy intensity in the United States since 1973, total domestic energy use has risen 20 percent.[240] The rise has been due to robust economic growth (gross domestic product doubled in that period) and new applications using the energy "saved" from traditional applications (consumer substitution and wealth effects). Such energy-growth factors can be expected to continue indefinitely in free-market economies.

As long as electricity rates fall, all other things being equal, ratepayers will consume more at the margin. Overall, national electricity rates are expected to fall in real terms by 20 percent to 40 percent over the next two decades as competition and customer choice drive average costs down toward marginal costs by increasing the utilization rate of surplus capacity and attracting new low-cost capacity.[241] Falling electricity rates will increase energy demand, and greater usage, in turn, will lower rates further.[242] Both economic growth and competitive electric rates will work against "conservation for its own sake."

The absence of a viable supply-side strategy option places the burden of meeting the Kyoto Protocol requirements squarely on the demand side.

Positive economic and environmental trends suggest that fossil fuels will be increasingly sustainable in the 21st century.

Emissions Trading: The Great Escape?

It is an open secret that remixing energy supply and reducing net energy use are not capable of meeting America's obligation under the Kyoto Protocol, short of politically intolerable economic hardship. That is why the Clinton administration is counting heavily on "effective international trading" of CO_2 emission permits.[243] Such trading in the Clinton administration's estimate is responsible for lowering the cost of compliance as much as 80 percent to 85 percent.[244]

The use of a 1990 baseline in the Kyoto Protocol creates a large pool of emissions credits for Russia, Germany, and other countries that have reduced emissions for reasons unrelated to climate change policy. American industry could purchase "cheap" Russian emission credits to avoid more costly measures, such as internal emissions reductions. So the emission reductions that Russia might not have used itself for many years allow present emissions—though at some cost compared with there being no trading requirement at all. That is why a number of mainstream environmental groups, the European Union, and environmental ministers of the G-8 industrialized nations have raised the concern that emissions trading would promote business as usual instead of substantial emissions reductions in the United States in the first (and probably the easiest) budget period, 2008–12.[245]

Emissions trading can be described as "market conforming" and "efficient" to the extent that the lowest cost emission reductions can be discovered, as opposed to a mandated facility-specific approach, under which particular firms must rigidly reduce emissions. But such a program assumes that the transaction costs (monitoring and enforcement costs) of an international program with more than 160 sovereign nations (and the enforcement weapon of international trade restrictions) do not sabotage the economic gains of the program.[246] Moreover, an international trading regime must include a large pool of developing nations to secure low-cost emissions reductions. With most developing countries currently unwilling to join such a trading regime, the benefits of emissions trading will be greatly attenuated.

Free-Market "No Regrets" Policies

Fossil fuels are compatible with environmental quality and otherwise "sustainable" for several reasons. First, the science is much more settled with respect to the benefits of higher atmospheric levels of CO_2 for plant growth and food supply than it is with respect to the ecological harms from man-caused climate change. Second, a moderately warmer and wetter world is economically and environmentally better. Third, robust energy markets and economic growth would substantially eradicate "poverty pollution."[247] Bringing hundreds of millions of individuals into the modern world with electricity and transportation energy is not an "unsustainable" extension of the fossil-fuel age but a prerequisite to improving living standards so those people can afford a better environment. Substituting affordable, sophisticated fossil energy for the burning wood or dung indoors to heat, cook, and light is essential to this end.[248] For today's several billion mature energy users, on the other hand, energy upgrades of appliances and fuel inputs will improve mobility, convenience, and comfort just as they have in the past. Increasing energy affordability will also promote universal water desalinization, irrigating ("greening") massive areas of barren desert, and development and implementation of electrotechnologies that improve the environment in many subtle ways.[249]

The greater the cost and improbability of success of a proposed course of action, the more compelling is a public policy of wealth creation in an energy-rich economy. Violating market preferences by mandating inferior energies and forcing energy conservation (energy rationing) reduces the wealth and societal resiliency that may be needed to adapt to whatever uncertainties the future holds and to deal with major social problems, including the possible negative effects of climate change, whether natural or anthropogenic in origin. Turning scientific inches into public policy miles to "stabilize climate" is not prudent under the precautionary principle or any other standard of social welfare.

Conclusion

The following conclusions and hypotheses can be drawn from this essay:

- Despite a one-third reduction in energy intensity in the United States since 1973, total domestic energy use has risen 20 percent.
- Improving trends with oil, gas, and coal will require that the breakthrough "discontinuities" needed for substitute technologies to become competitive grow over time.
- The weakening scientific case for dangerous climate change makes the global warming issue a transient political problem for fossil fuels rather than a death warrant.
- The Kyoto-inspired energy strategy of mass energy conservation and substitutions of preferred renewable energies will self-destruct if the enabling technologies do not improve enough to ensure affordability and convenience for consumers. Reduced living standards in the developed world and continued poverty in the developing world are not politically or ethically tolerable.
- "Green pricing" in electricity markets will be increasingly problematic and ultimately unsustainable because of internalized externalities with fossil fuels, subjective consumer preferences, and the necessity of political intervention to define what is "green."
- Currently uneconomical energy technologies are backstop sources for the future. At present they include synthetic oil and gas from coal, central-station wind and solar electricity, biopower, fuel cells, and renewable-energy-powered and electric vehicles. Because of relative economics, nuclear power is already a backstop technology for new capacity in the United States and other areas of the world with abundant fossil fuels.
- The increasing range of backstop energies enhances "energy security" over very long time horizons, although such security can be and has been "overbought" by government policies in the near term.
- The market share of fossil-fuel energy is likely to increase in the 21st century if the environmental movement succeeds in discouraging existing and new capacity of the two largest carbon-free energy sources, hydroelectricity and nuclear power. This is because of sheer relative size: the current world market share of hydropower and nuclear power is thirteen times greater than that of nonhydro renewables.
- Major economic and environmental advances are as likely (and perhaps more likely) to occur within the fossil-fuel family as outside it. One promising possibility for early in the next century is commercially converting natural gas into cleaner reformulated gasoline and diesel fuel.
- The intermittent characteristic of wind and solar energy could make those energies bridge fuels to conventional energy in nonelectrified regions of the world. If so, those technologies would remain as backstop rather than primary energies in the 21st century.
- The range of viable solar applications can be expected to increase over time, especially as space commercialization and remote ocean and desert activities accelerate in the 21st century. Wind turbines, despite being substantially cheaper than solar technology in windy areas, may have a more limited future in an economically and envi-

Despite a one-third reduction in energy intensity in the United States since 1973, total domestic energy use has risen 20 percent.

The intermittent characteristic of wind and solar energy could make those energies bridges to conventional energy.

ronmentally conscious world because of siting constraints.

The *Petroleum Economist's* headline for 1998 projects, "Ever Greater Use of New Technology,"[250] will also characterize future years, decades, centuries, and millennia under market conditions. If the "ultimate resource" of human ingenuity is allowed free rein, energy in its many and changing forms will be more plentiful and affordable for future generations than it is now, although never "too cheap to meter" as was once forecast for nuclear power. For the nearer and more foreseeable term, all signs point toward conventional energies' continuing to ride the technological wave, increasing the prospects that when energy substitutions occur, the winning technologies will be different from what is imagined (and subsidized by government) today. Such discontinuities will occur not because conventional energies failed but because their substitutes blossomed.

Notes to Policy Analysis No. 341

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12. See endnote 5 for citations on reserve revisions.

13. See the technology articles in *American Oil and Gas Reporter* 41, nos. 4 and 7 (April and July 1998).

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15. Arthur Andersen and Co., *Oil & Gas Reserve Disclosures* (Houston, Tex.: Arthur Andersen, 1985), p. S-41; and Arthur Andersen and Co., *Oil & Gas Reserve Disclosures* (Houston, Tex.: Arthur Andersen, 1997), p. 10.

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17. See Simon, part 1.

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than just increasing extraction percentages and locating new reservoirs of a "fixed" (in a mathematical, not an economic, sense) biogenic supply of decayed plants and animals. Some scientists suspect that oil and gas may have abiogenic origins deep in the earth. Carbon, some suspect, can move upward from the earth's crust to replenish the near-surface supplies of petroleum and gas accessible by the drill bit. If so, substantial upward revisions would need to be made to the resource base, replacing estimates in the hundreds of years with estimates in the thousands of years, or even making probable resource estimates obsolete. See Thomas Gold, "An Unexplored Habitat for Life in the Universe," *American Scientist*, September–October 1997, pp. 408–11. Empirical support for that hypothesis is described in "Gas Traces Found, Siljan Well Aims for 24,600 Ft.," *Oil and Gas Journal*, February 2, 1987, p. 18.

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71. Arlon Tussing and Bob Tippee, *The Natural Gas Industry* (Tulsa: PennWell Books, 1995), p. 54.

72. Makansi, pp. 27–28.

73. Enron Corp., *The Natural Gas Advantage: Strategies for Electric Utilities in the 1990s* (Houston: Enron, 1992), pp. 2–8.

74. This could be true if for no other reason than the "act of God" limitations of wind and solar—intermittent stillness for wind and darkness and intermittent cloudiness for solar.

75. World Association of Nuclear Operators, "1998 Performance Indicators for the U.S. Nuclear Utility Industry," http://www.nei.org/library/tmiframe.html.

76. EIA, *Annual Energy Review 1997*, pp. 7, 241, 243.

77. Nuclear Energy Institute, *Strategic Plan for Building New Nuclear Power Plants* (Washington: Nuclear Energy Institute, 1998), pp. III-4 and III-5.

78. EIA, *Annual Energy Outlook 1998*, p. 54.

79. Nuclear Energy Institute, *Nuclear Energy*, fourth quarter 1994; and Nuclear Energy Institute, *Nuclear Energy Insight 1996*, February 1996, pp. 1–2.

80. "EPRI Unveils New Reactor Design Standardization to Improve Safety," *Electric Power Alert*, July 1, 1998, pp. 27–28. A natural gas combined-cycle plant of the same size can still be built in two-thirds of this time.

81. As the Department of Energy has noted, "Without [the Price-Anderson Act of 1957], the nuclear power industry would not have developed or grown." U.S. Department of Energy, *United States Energy Policy: 1980–1988* (Washington: DOE, 1988), p. 105.

82. For a description of the environmental and economic features of a modern coal plant available to the international market, see Cat Jones, "Shinchi Leads Way for Large Advanced Coal-Fired Units," *Electric Power International*, September 1997, pp. 36–41.

83. Deren Zhu and Yuzhuo Zhang, "Major Trends of New Technologies for Coal Mining and Utilization beyond 2000—Technical Scenario of the Chinese Coal Industry," *Proceedings: 17th Congress of the World Energy Council* (London: World Energy Council, 1998), vol. 5, p. 93.

84. EIA, *International Energy Outlook 1998*, p. 78.

85. DRI, *Energy Choices in a Competitive Era*, p. 4-3.

86. Chinese and Indian energy planners provide an example of energy exploitation. They made wind and solar investments that had high capacity ratings but produced little energy. See EIA, *International Energy Outlook 1998*, pp. 103–4.

87. Roger Fouquet and Peter Pearson, "A Thousand Years of Energy Use in the United Kingdom," *Energy Journal* 19, no. 4 (1998): 7.

88. Carlo LaPorta, "Renewable Energy: Recent Commercial Performance in the USA as an Index of Future Prospects," in *Global Warming: The Greenpeace Report*, ed. Jeremy Leggett (Oxford: Oxford University Press, 1990), pp. 235, 242–43.

89. Flavin and Lenssen, p. 189.

90. Paul Druger and Carel Otte, eds., *Geothermal Energy: Resources, Production, Stimulation* (Stanford, Calif.: Stanford University Press, 1973), pp. 21–58.

91. "Shell Gets Serious about Alternative Power," *Petroleum Economist*, December 1997, p. 38; and Kimberly Music, "Shell Pledges to Focus on Renewable Energy," *Oil Daily*, October 17, 1997, p. 1.

92. John Browne, *Climate Change: The New Agenda* (London: British Petroleum Company, 1997).

93. Enron Corp., "Enron Forms Enron Renewable Energy Corp.; Acquires Zond Corporation, Leading Developer of Wind Energy Power," Press release, January 6, 1997.

94. Total international energy investment, estimated by the World Energy Council to be $1 trillion annually, would make planned investments in wind, solar, geothermal, and biopower minuscule. Commercial energy financing only, estimated to be around $150 billion in 1995 alone, would put nonhydro renewable investment at a fraction

of 1 percent, comparable to the world market share of wind, solar, and geothermal combined. Martin Daniel, "Finance for Energy," *FT Energy World*, Summer 1997, p. 5; and EIA, *International Energy Annual 1996*, p. 20.

95. Shell International Limited, "Shell Invests US$0.5 Billion in Renewables," Press release, October 16, 1997; and Sam Fletcher, "Shell to Spend $1 Billion on 3 Deep Gulf Fields," *Oil Daily*, March 20, 1998, p. 1.

96. Quoted in Amal Nag, "Big Oil's Push into Solar Irks Independents," *Wall Street Journal*, December 8, 1980, p. 31.

97. Charles Burck, "Solar Comes Out of the Shadows," *Fortune*, September 24, 1979, p. 75.

98. Paul Gipe, "Removal and Restoration Costs: Who Will Pay?" *Wind Stats Newsletter*, Spring 1997, p. 1. See also Bradley, "Renewable Energy," pp. 20–22.

99. John Berger, *Charging Ahead: The Business of Renewable Energy and What It Means for America* (New York: Henry Holt, 1997), pp. 4–5. This book provides an in-depth look at the personal hardships, financial precariousness, shifting government subsidies, and occasional environmental degradation associated with unconventional energy development in this period.

100. Flavin and Lenssen, pp. 176–77. Biopower can be carbon neutral if its inputs are replanted to create sinks (a "closed loop" system), leaving cost and quantity as the major issues.

101. EIA, *Renewable Energy Annual 1995* (Washington: U.S. Department of Energy, 1995), p. 78; and Bradley, "Renewable Energy," pp. 33–34.

102. Ibid., pp. 26–28.

103. See, for example, Rebecca Stanfield, "Lethal Loophole: A Comprehensive Report on America's Dirtiest Power Plants and the Loophole That Allows Them to Pollute" United States Public Interest Research Group, Washington, June 1998, p. 11.

104. Kenneth Lay, "The Energy Industry in the Next Century: Opportunities and Constraints," in *Energy after 2000*, ed. Irwin Stelzer (Seville, Spain: Fundacion Repsol, 1998), p. 23.

105. Expenditures of the Department of Energy, since its creation, on wind and solar energy have averaged, respectively, nearly 4 cents and 23 cents per kWh produced. Other renewable and fossil-fuel technologies for electricity generation have averaged less than 1 cent per kWh. Bradley, "Renewable Energy," pp. 55, 63.

106. M. L. Legerton et al., "Exchange of Availability/Performance Data and Information on Renewable Energy Plant: Wind Power Plants," Paper presented to the 17th Congress of the World Energy Council, September 15, 1998, pp. 5–6. This cost estimate is exclusive of major tax preferences.

107. Bradley, "Renewable Energy," pp. 7–12.

108. Adolf Huitti, "Challenges of the Power Plant Market," in *World Energy* (New York: McGraw-Hill, 1998), p. 55.

109. Alliance to Save Energy et al., *Energy Innovations: A Prosperous Path to a Clean Environment* (Washington: ASE, June 1997), p. 37. See also Adam Serchuk and Robert Means, "Natural Gas: Bridge to a Renewable Energy Future," REPP Issue Brief, May 1997. The Department of Energy in its most recent 20-year forecast states, "Low fossil fuel prices are expected to continue to hamper the development of renewable energy sources." EIA, *International Energy Outlook 1998*, p. 5.

110. In 1996 wind and solar plants operated at 22 percent and 31 percent capacity factors, respectively. EIA, *Renewable Energy Annual 1997* (Washington: Government Printing Office, 1998), p. 12.

111. The lower energy loss of natural gas transportation relative to electricity transmission dictates that gas power plants be located close to their market. Wind and solar farms, on the other hand, often have to be away from their market centers and must have their transmission lines sized at peak output despite their low average capacity factor. Ballonoff, p. 47.

112. U.S. Department of Energy and Electric Power Research Institute (EPRI), *Renewable Energy Technology Characterizations* (Pleasant Hill, Calif.: EPRI, 1997), p. 2-1.

113. Ibid.

114. The biopower cost estimate is the bottom of the range for existing plants given by DOE and EPRI and a current estimate by the EIA. Ibid.; and Roger Diedrich, industry analyst, EIA, conversation with the author, September 1, 1998. For wind and solar estimates, see Pfeifenberger et al., p. 4. See also Bradley, "Renewable Energy," p. 11, for wind power; and Solarex, "Everything You Always Wanted to Know about Solar Power," Company pamphlet, March 1997, p. 3, for solar power. The 6 cents per kWh for wind at ideal U.S. sites with scale economies is exclusive not

only of the 10-year federal tax credit (approximately 1.7 cents per kWh today) but also of accelerated depreciation (a 5-year rather than a 20-year write-off of capital costs).

115. Flavin and Lenssen, pp. 101–2; and Nelson Hay, ed., *Guide to New Natural Gas Utilization Technologies* (Atlanta: Fairmont, 1985), pp. 323–31.

116. Cler and Lenssen, pp. 13, 28; Gerald Cler and Michael Shepard, "Distributed Generation: Good Things Are Coming in Small Packages," *Tech Update*, November 1996, pp. 14–16; and "Utilities Benefit in DOE Grants for Fuel Cells," *Gas Daily*, August 23, 1996, p. 6.

117. Cler and Lenssen, p. 27.

118. Battery storage devices to hold electricity from ten seconds to two hours cost between $400 and $1,000 per kilowatt. DOE and EPRI, p. A-4. Battery costs alone are as much as or more than the installment cost of distributed oil and gas generation, making the competitive viability of intermittent energies decades away at best.

119. Yves Smeers and Adonis Yatchew, "Introduction, Distributed Resources: Toward a New Paradigm of the Electricity Business," *Energy Journal*, Special Issue, 1998, p. vii. See also Robert Swanekamp, "Distributed Generation: Options Advance, But toward What Pot of Gold?" *Power*, September–October 1997, pp. 43–52.

120. Nancy Rader and William Short, "Competitive Retail Markets: Tenuous Ground for Renewable Energy," *Electricity Journal*, April 1998, pp. 72–80.

121. EIA, *Annual Energy Outlook 1998*, p. 57.

122. Of the 17 states that had announced a restructuring of their electric industry as of early 1998, 8 had a renewable quota requirement, 3 had financial subsidies in addition to a quota requirement, and 5 had financial incentives for renewables only. For a list of those states and programs, see Bentham Paulos, "Legislative Help Grows at State and Federal Level," *Windpower Monthly*, April 1998, pp. 52, 54.

123. American Automobile Manufacturers Association, *Motor Vehicle Facts & Figures, 1997* (Washington: AAMA, 1997), p. 44.

124. American Petroleum Institute, *How Much We Pay for Gasoline: 1997 Annual Review* (Washington: API, April 1998), p. i.

125. Ibid., pp. ii–iii; and EIA, *Monthly Energy Review*, February 1999, p. 114. In a free-market system, electronic road billing would replace pump taxation as the primary incremental cost of driving, outside of vehicle costs and (free-market) fuel costs. See generally, Gabriel Roth, *Roads in a Market Economy* (United Kingdom: Avebury Technical, 1996).

126. See, for example, a spot check of 25 liquid products at a Philadelphia grocery store in Interfaith Coalition on Energy, "The Cost of a Gallon of Gasoline," *Comfort & Light Newsletter*, Spring 1998, p. 2.

127. A recent advertisement by Mobil described the goal of new-generation refineries as producing "a new breed of fuels that burn cleaner and more efficiently, lubricants that last longer and chemicals that are recyclable" from advanced compositional modeling and molecular engineering (membrane and catalyst technologies). Mobil, "Technology: Transforming Tomorrow's Refineries," *New York Times*, September 17, 1998, p. A31.

128. W. Michael Cox and Richard Alm, "Time Well Spent: The Declining Real Cost of Living in America," in Federal Reserve Bank of Dallas, *1997 Annual Report* (Dallas: Federal Reserve Bank of Dallas, 1998), p. 11.

129. Ibid.

130. See, for example, *New York Times* reprint, "Ford Motor Co. Plans to Reduce Average Price on '99 Cars, Trucks," *Houston Chronicle*, August 11, 1998, p. 4C.

131. Cox and Alm, p. 11.

132. Arthur Cummins, "Diesel Vehicles, in Greener Mode, May Stage Comeback," *Wall Street Journal*, April 9, 1998, p. B4. Mainstream environmentalists overrate the environmental potential of diesel relative to gasoline, citing the lower CO_2 emissions of the former. Carbon dioxide, as will be discussed, is not a pollutant, compared with other emissions that are greater with diesel technology.

133. "Diesel Will Continue to be Heavy-Duty Fuel of Choice," p. 9.

134. Robert L. Bradley Jr., *Oil, Gas, and Government: The U.S. Experience*, (Lanham, Md.: Rowman & Littlefield, 1996), pp. 1744–45.

135. Public Law 96-294, 94 Stat. 611 (1980).

136. EIA, *Annual Energy Review 1997*, pp. 37, 251.

137. American Petroleum Institute, "Alternative Fuels," p. 2.

138. Auto/Oil Air Quality Improvement Research Program, *Final Report*, January 1997, pp. 4, 26–27.

139. Complained Daniel Becker of the Sierra Club, "Ford's announcement about making cars for which there is not fuel is a cynical ploy to avoid violating a law." Quoted in Keith Bradsher, "Ford to Raise Output Sharply of Vehicles That Use Ethanol," *New York Times*, June 4, 1997, p. A1.

140. EIA, *Renewable Energy Annual 1997*, p. 13.

141. National Academy of Sciences, *Policy Implications of Greenhouse Warming* (Washington: National Academy Press, 1992), p. 342.

142. Cannon, p. 2. Farm equipment uses diesel fuel.

143. Public Law 105-78, 112 Stat. 107 at 502 (1998).

144. See, for example, Matthew Wald, "It Burns More Cleanly, but Ethanol Still Raises Air-Quality Concerns," *New York Times*, August 3, 1992, p. D1.

145. *Methanol: Fuel of the Future, Hearing before the Subcommittee on Fossil and Synthetic Fuels*, 99th Cong., 1st sess. (Washington: Government Printing Office, 1986), pp. 43, 80, 114.

146. Ibid., pp. 52–53; and "Methanol: Alcohol-Based Fuel Has Powerful Ally," *Houston Post*, September 17, 1989, p. A-14.

147. Charles Imbrecht, Statement, in *Alternative Automotive Fuels: Hearings before the Subcommittee on Energy and Power of the House Committee on Energy and Commerce*, 100th Cong., 1st sess. (Washington: Government Printing Office, 1988), pp. 336–46.

148. American Petroleum Institute, "Methanol Vehicles," GSA Response no. 464, August 23, 1991, p. 1. Methanol-flexible vehicles would register 40 percent less fuel economy than vehicles using CARB Phase 2 reformulated gasoline.

149. Matthew Trask, "Methanol Power Experiment Called a Failure," *California Energy Markets*, December 23, 1993, p. 2.

150. CEC, *California Oxygenate Outlook* (Sacramento: CEC, 1993), pp. 19, 65; and CEC, *The California Energy Plan 1997* (Sacramento: CEC, 1998), pp. 18–19, 32–33. The CEC's first step in abandoning methanol was to state in a December 1995 study that natural gas was overtaking methanol as the alternate fuel of choice in California and elsewhere in the country.

151. Cannon, p. 3-4.

152. Flavin and Lenssen, p. 200.

153. American Petroleum Institute, "Alternative Fuels: Myths and Facts," August 8, 1995, p. 4.

154. Andrea Adelson, "Not One of Your Big Jump-Starts," *New York Times*, May 7, 1997, p. C1; Rebecca Blumenstein, "Electric Car Drives Factory Innovations," *Wall Street Journal*, February 27, 1997, B1; and Rebecca Blumenstein, "GM to Put New Batteries in Electric Cars to Increase Per-Charge Driving Range," *Wall Street Journal*, November 10, 1997, p. A13. As of 1996, the cumulative private and public investment in electric vehicles was nearly $1 billion, "roughly equal to half of the National Science Foundation's entire research budget." Richard de Neufville et al., "The Electric Car Unplugged," *Technology Review*, January 1996, p. 32.

155. Peter Passell, "Economic Scene," *New York Times*, August 29, 1996, p. C2.

156. Quoted in American Petroleum Institute, "Alternative Fuels," p. 3.

157. Neufville et al., p. 33.

158. Quoted in Dan Carney, "Once on Fast Track to Future, Electric Cars Take Wrong Turn," *Houston Post*, December 12, 1993, p. A17.

159. Timothy Henderson and Michael Rusin, *Electric Vehicles: Their Technical and Economic Status* (Washington: American Petroleum Institute, 1994), chapter 2.

160. Michael McKenna, "Electric Avenue," *National Review*, May 29, 1995, p. 38.

161. K. H. Jones and Jonathan Adler, "Time to Reopen the Clean Air Act: Clearing Away the Regulatory Smog," Cato Institute Policy Analysis no. 233, July 11, 1995, p. 18.

162. Cited in "Science Panel Knocks Hybrid-Electric Cars," *Oil Daily*, April 20, 1998, p. 1.

163. Internationally, "operating experience with cars using [compressed natural gas] is fairly extensive, going back to the 1920s in Italy." Robert Saunders and Rene Moreno, "Natural Gas as a Transportation Fuel," in *Natural Gas: Its Role and Potential in Economic Development*, ed. Walter Vergara (Boulder, Colo.: Westview, 1990), p. 251.

164. Reported one leading company in the effort: "[Natural gas vehicle conversions in the 1970s] died due to . . . oil carry over into the fuel systems and the difficulties of trying to get a mechanically ignitioned carbureted engine to run on dual fuels acceptably." Eric Heim, "Pacific Gas &

Electric," in *Utility Strategies for Marketing Compressed Natural Gas: Proceedings* (Arlington, Va.: Natural Gas Vehicle Coalition, 1991).

165. CEC, *Fuels Report 1995*, p. 53.

166. "NGVs Seen as Average, or Worse, in FedEx Test," *Gas Daily*, April 17, 1995, p. 3. The test was done for 1992-model vehicles.

167. Natural Gas Vehicle Coalition et al., *NGV Industry Strategy*, May 1995, p. 16.

168. EIA, *Annual Energy Outlook 1998*, p. 46. The premium without subsidies is an estimate from Harry Chernoff, senior economist, Science Applications International Corporation, communication with the author, October 13, 1998.

169. Within the alternative-fuel-capable family, methanol (M85) has a 5 percent market share with 21,000 vehicles, ethanol a 3 percent share with 11,000 vehicles, and electricity a 1 percent share with 5,000 vehicles. EIA, *Alternatives to Traditional Transportation Fuels 1996* (Washington: Government Printing Office, 1997), p. 16.

170. *Report of the National Fuels and Energy Study Group*, pp. 297–98.

171. Cannon, pp. 9–10; Joseph Norbeck et al., *Hydrogen Fuel for Surface Transportation* (Warrendale, Pa: Society of Automotive Engineers, 1996), pp. 397–406.

172. C. E. Thomas et al., "Market Penetration Scenarios for Fuel Cell Vehicles," *International Journal of Hydrogen Energy* 23, no. 10 (1998): 949.

173. Ibid.

174. Ibid., p. 957.

175. Ibid., p. 949. The authors add, "Government alone has the charter to develop those technologies that will benefit society, including reduced environmental impact and reduced dependence on imported fossil fuels."

176. Ibid., p. 963. This assumes that, on the basis of a 1995 actual 200 million fleet, the total U.S. fleet could be as high as 250 million vehicles in this period.

177. Alliance to Save Energy et al., p. 76.

178. Keith Naughton, "Detroit's Impossible Dream?" *Business Week*, March 2, 1998, p. 68.

179. Steve Plotkin, communication with the author, July 27, 1998.

180. Matthew Wald, "In a Step toward a Better Car, Company Uses Fuel Cell to Get Energy from Gasoline," *New York Times*, October 21, 1997, p. A10.

181. Rebecca Blumenstein, "Auto Industry Reaches Surprising Consensus: It Needs New Engines," *Wall Street Journal*, January 5, 1998, p. A1.

182. California Environmental Protection Agency, "Proposed Amendments to California Exhaust, Evaporative, and Onboard Refueling Vapor Recovery Emission Standards and Test Procedures for Passenger Cars, Light-Duty Trucks and Medium-Duty Vehicles," November 5, 1997, p. 11.

183. "The Third Age of Fuel," *The Economist*, October 25, 1997, p. 16. Optimistic forecasts for hydrogen vehicles have a long—and wrong—history. For example, a study by Frost and Sullivan in 1989 predicted "significant movement" away from fossil fuels to hydrogen by the year 2000. J. E. Sinor Consultants, *The Clean Fuels Report* (Niwot, Colo.: J. E. Sinor, 1990), pp. 102–3.

184. American Automobile Manufacturers Association, *World Motor Vehicle Data* (Washington: AAMA, 1997), pp. 3, 8.

185. EIA, *Annual Energy Review 1997*, pp. 177, 211.

186. A current challenge for reformulated gasoline is the alleged contamination of drinking water by a popular oxygenate, methyl tertiary butyl ether (MTBE), a problem currently being debated in the state. If the problem is found to be more associated with leaking from underground gasoline tanks than with the fuel additive itself, the problem will be self-correcting under existing regulation.

187. CEC, *California Energy Plan 1997*, p. 30.

188. Ibid., p. 29.

189. Robert Bradley Jr., "California DSM: A Pyrrhic Victory for Energy Efficiency?" *Public Utilities Fortnightly*, October 1, 1995, p. 41.

190. Ibid., p. 12. The "sustainable changes" refer to open-access transmission under which customers can purchase their own electricity and outsource their entire energy function to energy service companies.

191. Paul Wuebben, Statement, in *Alternative Fuels: Hearing before the House Subcommittee on Energy and Commerce*, 103d Cong., 1st sess. (Washington: Government Printing Office, 1994), p. 7.

192. Bradley, *Oil, Gas, and Government*, pp. 569–75.

193. Ibid., p. 579.

194. Quoted in Ted Wett, "Synfuel's Future Hinges on Capital, Cooperation," *Oil and Gas Journal*, June 16, 1980, p. 55.

195. Peter Nulty, "The Tortuous Road to Synfuels," *Fortune*, September 8, 1980, p. 64.

196. Robert Bradley, *Energy Choices and Market Decision Making* (Houston: Institute for Energy Research, 1993), pp. 16–17.

197. "FERC Law Judge Holds That Settlements Negotiated by Pipeline Purchasers of SNG Plant Output with Dakota Gasification and DOE Were Imprudent," *Foster Report*, no. 2062, January 4, 1996, pp. 1–3.

198. Christopher Flavin and Seth Dunn, *Rising Sun, Gathering Winds: Policies to Stabilize the Climate and Strengthen Economies* (Washington: Worldwatch Institute, 1997), pp. 20-21.

199. U.S. Department of Energy, *United States Energy Policy: 1980/1988*, p. 109.

200. Sierra Club, Letter to the Honorable Tim Wirth, July 27, 1988, reprinted in *National Energy Policy Act of 1988 and Global Warming: Hearings before the Senate Committee on Energy and Natural Resources*, 100th Cong., 2d sess. (Washington: Government Printing Office, 1989), p. 481.

201. "Environmentalists Blast Nuclear Funding in Clinton Budget Proposal," *Electric Power Alert*, February 11, 1998, pp. 32–33.

202. PG&E Corporation, *1997 Environmental Report* (San Francisco: PG&E, 1998), p. 6.

203. National Academy of Sciences, p. 691. See also Fred Singer, "Control of Atmospheric CO_2 through Ocean Fertilization: An Alternative to Emission Controls," in *Global Warming: The Continuing Debate*, ed. Roger Bate (Cambridge: European Science and Environment Forum, 1998), pp. 118–26.

204. Paul Ehrlich,"An Ecologist's Perspective on Nuclear Power," Federal Academy of Science Public Issue Report, May–June 1975, p. 5.

205. Quoted in Paul Ciotti, "Fear of Fusion: What If It Works?" *Los Angeles Times*, April 19, 1989, p. 5-1.

206. Paul Ehrlich et al., "No Middle Way on the Environment," *Atlantic Monthly*, December 1997, p. 101.

207. Quoted in Jonathan Adler, *Environmentalism at the Crossroads* (Washington: Capital Research Center, 1995), p. 116.

208. "To replace one 650-megawatt coal-burning power station, you would need to set up a line, almost 100 kilometers long, of 900 windmills of the type that EDF is going to build in Morocco in the Tetouan region, or you could construct a 100-kilometer-long, 30-meter-wide highway of solar panels. And we should not forget that between now and 2020, world needs for energy supplies will increase to 4,600 times this power level." Francois Ailleret, "The Nuclear Option," in *McGraw-Hill's World Energy* (New York: McGraw-Hill, 1998), p. 94.

209. Quoted in Abba Anderson, "US Electricar: An Inside View," *California Energy Markets*, April 28, 1995, p. 6. US Electricar's story is not unlike that of Luz and Kenetech on the renewable energy front: "fat travel budgets to promote the company internationally, soaring warranty costs due to faulty equipment and unrealized sales." Oscar Suris, "Morgan's Drive with Electricar Runs Out of Gas," *Wall Street Journal*, March 23, 1995, pp. B1, B6.

210. See Irwin Stelzer and Robert Patton, *The Department of Energy: An Agency That Cannot Be Reinvented* (Washington: American Enterprise Institute, 1996), pp. 28–40.

211. Mark Mills, *A Stunning Regulatory Burden: EPA Designating CO_2 as a Pollutant* (Chevy Chase, Md.: Mills McCarthy & Associates, 1998), p. 4.

212. "[Higher CO_2 produces] a positive net transfer of organic carbon from dead vegetative tissue to living vegetative tissue [to] . . . increas[e] the planet's abundance of living plants. And with that increase in plant abundance should come an impetus for increasing the species richness or biodiversity." Sherwood Idso, *CO_2 and the Biosphere: The Incredible Legacy of the Industrial Revolution* (St. Paul: University of Minnesota Press, 1995), p. 30. See also, generally, Sylvan Wittwer, *Food, Climate, and Carbon Dioxide* (New York: Lewis, 1995).

213. IPCC, *Climate Change 1995: The Science of Climate Change*, pp. 3–4; and Molly O'Meara, "The Risks of Disrupting Climate," *World*Watch*, November–December 1997, p. 12.

214. For example, "skeptic" scientists Richard Lindzen, Fred Singer, and Patrick Michaels estimate a warming of .3°C, .5°C, and 1–1.5°C, respectively. Richard Lindzen, Massachusetts Institute of Technology, communication with the author, June 15, 1998; Fred Singer, Science and Environmental Policy Project, communica-

tion with the author, December 8, 1998; and Patrick Michaels, *Sound and Fury: The Science and Politics of Global Warming* (Washington: Cato Institute, 1992), p. 187.

215. Richard Kerr, "Greenhouse Forecasting Still Cloudy," *Science*, May 16, 1997, pp. 1040–42; Fred Pearce, "Greenhouse Wars," *New Scientist,* July 19, 1997, pp. 38–43; and James Hansen, "Climate Forcings in the Industrial Era," *Proceedings of the National Academy of Sciences*, October 1998, pp. 12753–58.

216. S. Fan et al., "A Large Terrestrial Sink in North America Implied by Atmospheric and Oceanic Carbon Dioxide Data and Models," *Science*, October 16, 1998, pp. 442–46.

217. "[The NCAR] 2°C warming is very similar to a number of GCMs that have recently repeated their sensitivity simulations." Jeff Kiehl, head, Climate Modeling Section, National Center for Atmospheric Research, communication with the author, August 14, 1998.

218. IPCC, *Climate Change*, pp. xxx, 138–39; IPCC, *Climate Change 1995: The Science of Climate Change*, pp. 5–6; and *World Climate Report,* January 5, 1998, pp. 1–2. Steven Schneider's statement in 1990 that model forecasts of temperature could as easily be revised upward as downward has been proven wrong to date—the revisions of the IPCC and most models have been downward. Steven Schneider, "The Science of Climate-Modeling and a Perspective on the Global-Warming Debate," *Global Warming: The Greenpeace Report*, p. 60.

219. Patrick Michaels, "Long Hot Year: Latest Science Debunks Global Warming Hysteria," Cato Institute Policy Analysis no. 329, December 31, 1998, pp. 2, 5.

220. John Houghton, *Global Warming: The Complete Briefing* (Cambridge: Cambridge University Press, 1997), p. 85; and Gerald North, "Global Climate Change," in *The Impact of Global Warming on Texas*, ed. Gerald North (Austin: University of Texas Press, 1995), p. 7.

221. James Hansen et al., "A Common-Sense Climate Index: Is Climate Changing Noticeably?" *Proceedings of the National Academy of Sciences,* April 1998, p. 4113.

222. Ibid., pp. 4118–20.

223. Warming estimates would be reduced by either a negative, a neutral, or a weak positive water vapor feedback in climate models. For a negative-to-neutral feedback hypothesis, see Richard Lindzen, "Can Increasing Carbon Dioxide Cause Climate Change?" *Proceedings of the National Academy of Sciences*, August 1997, pp. 8335–42. For evidence of a weak positive feedback, see R. W. Spencer and W. D. Braswell, "How Dry Is the Tropical Free Troposphere? Implications for Global Warming Theory," *Bulletin of the American Meteorological Society*, July 1997, pp. 1097–1106.

224. IPCC, *Climate Change 1995: The Science of Climate Change*, pp. 27, 144–45, 172, 294. See also David Eastering et al., "Maximum and Minimum Temperature Trends for the Globe," *Science*, July 18, 1997, pp. 364–67; and Thomas Karl et al., "Trends in High-Frequency Climate Variability in the Twentieth Century," *Nature*, September 21, 1995, pp. 217–20.

225. "A Heated Controversy," *The Economist*, August 15, 1998, pp. 66–68.

226. IPCC, *Climate Change 1995: The Science of Climate Change*, pp. 29–30, 173.

227. Ibid., p. 7.

228. Council of Economic Advisers, *Administration Economic Analysis: The Kyoto Protocol and the President's Policies to Address Climate Change*, July 1998, p. 11, http://www.whitehouse.gov/WH/New/html/Kyoto.pdf.

229. T. M. L. Wigley, "The Kyoto Protocol: CO_2, CH_4, and Climate Implications," *Geophysical Research Letters,* July 1, 1998, pp. 2285–88.

230. Jerry Mahlman, director, Geophysical Fluid Dynamics Laboratory, Princeton University, quoted in David Malakoff, "Thirty Kyotos Needed to Control Warming," *Science*, December 19, 1997, p. 2048.

231. Wigley, p. 2287.

232. In the United States in 1990, 83 percent of greenhouse emissions were from fossil-fuel consumption. EIA, *Impacts of the Kyoto Protocol on U.S. Energy Markets and Economic Activity* (Washington: U.S. Department of Energy, 1998), p. xiii.

233. Ibid. Sink creation and a weighting of the six greenhouse gases for the United States would lower the obligation to 3 percent below 1990 levels according to the Clinton administration. *The Kyoto Protocol and Its Economic Implications, Hearing before the Subcommittee on Energy and Power of the House Committee on Commerce,* 105th Cong., 2d sess. (Washington: Government Printing Office, 1998), pp. 58–59.

234. Peter VanDoren, "The Costs of Reducing Carbon Emissions: An Examination of

Administration Forecasts," Cato Institute Briefing Paper no. 44, March 11, 1999, p. 8.

235. Ibid.

236. Amory Lovins and L. H. Lovins, *Climate: Making Sense and Making Money* (Old Snowmass, Colo.: Rocky Mountain Institute, 1997), p. 2.

237. Interlaboratory Working Group on Energy-Efficient and Low-Carbon Technologies, *Scenarios of U.S. Carbon Reductions: Potential Impacts of Energy-Efficient and Low Carbon Technologies by 2010 and Beyond* (Oak Ridge National Laboratory, Lawrence Berkeley National Laboratory, Pacific Northwest National Laboratory, National Renewable Energy Laboratory, and Argonne National Laboratory, September 1997).

238. Council of Economic Advisers.

239. Ronald Sutherland, "A Critique of the 'Five Lab' Study," American Petroleum Institute, Washington, June 1998.

240. EIA, *Monthly Energy Review*, June 1998, p. 16.

241. The low estimate is from the Department of Energy. *Annual Energy Outlook 1998*, p. 52. The high estimate is from Michael Maloney and Robert McCormick, *Customer Choice, Customer Value: Lessons for the Electric Industry* (Washington: Citizens for a Sound Economy, 1996), p. x.

242. Economists Maloney and McCormick estimate that electricity generation could increase as much as 25 percent without any new capacity, which would lower rates for end-users between 13 percent and 25 percent. In the long run, rates could fall by more than 40 percent with a similar increase in output, both from fully utilized existing plants and new (gas-fired) capacity generating electricity at 3 cents per kWh. Maloney and McCormick, pp. viii–x.

243. The "effective international trading" assumption was stated by Janet Yellen, chair, Council of Economic Advisers, in *The Kyoto Protocol and Its Economic Implications*, p. 35.

244. J. W. Anderson, "Two New Reports Project Much Higher Climate Costs Than White House Estimates," Resources for the Future, June 11, 1998, www.weathervane.rff.org/negtable/accfd.html.

245. "G-8 Members Take Swing at U.S. Plan for Greenhouse Emissions Trading," *Electric Power Alert*, April 22, 1998, p. 26; and Michael Toman and Jean-Charles Hourcade, "International Workshop Addresses Emissions Trading among 'Annex B' Countries," Resources for the Future, Weathervane Web site, August 11, 1998. See also the full-page advertisement protesting the "U.S. unrestricted trading plan," described as a "loophole that will undermine the Kyoto global warming treaty," by 10 environmental organizations, including the Sierra Club, Friends of the Earth, the National Wildlife Federation, and Ozone Action. *New York Times*, June 11, 1998, p. C28.

246. William Niskanen, "Too Much, Too Soon: Is a Global Warming Treaty a Rush to Judgment?" *Jobs & Capital*, Fall 1997, pp. 17–18.

247. Gro Harlem Brundtland, *Our Common Future* (Geneva: World Commission on Environment and Development, 1987), p. 28. Economic growth has become a plank in mainstream sustainable development theory to eliminate poverty pollution. See President's Council on Sustainable Development, *Sustainable Development* (Washington: Government Printing Office, 1996), p. iv. Al Gore, *Earth in the Balance* (New York: Plume, 1992), p. xv, also prioritizes economic growth.

248. The World Resources Institute et al., *World Resources 1998–99* (New York: Oxford University Press, 1998), pp. 65–66, 80–81.

249. Simon, p. 162; and Mark Mills, "Healthy Choices in Technologies," Study for the Western Fuels Association, April 1997.

250. "Ever Greater Use of New Technology," *Petroleum Economist*, December 1997, pp. 8–17.

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