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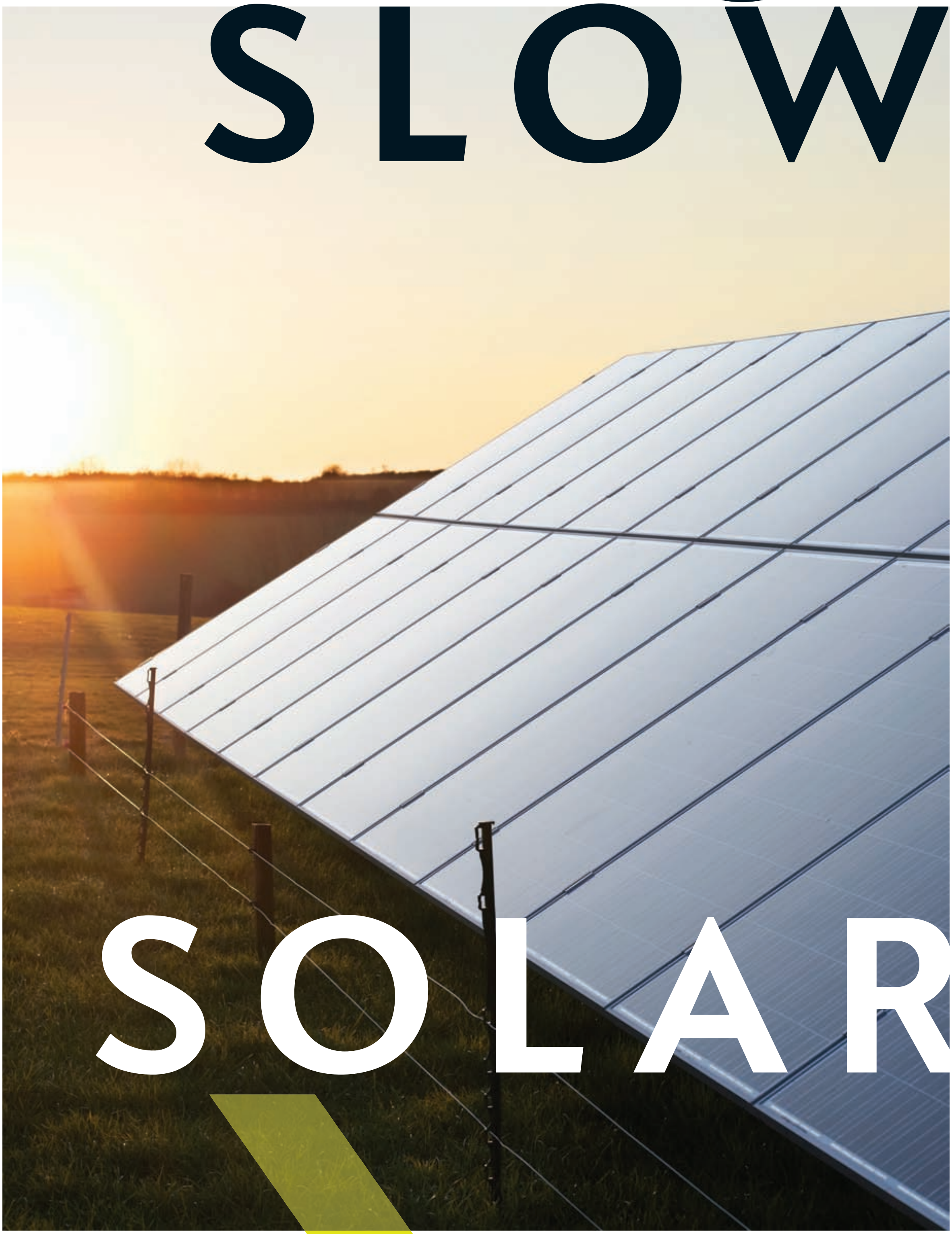

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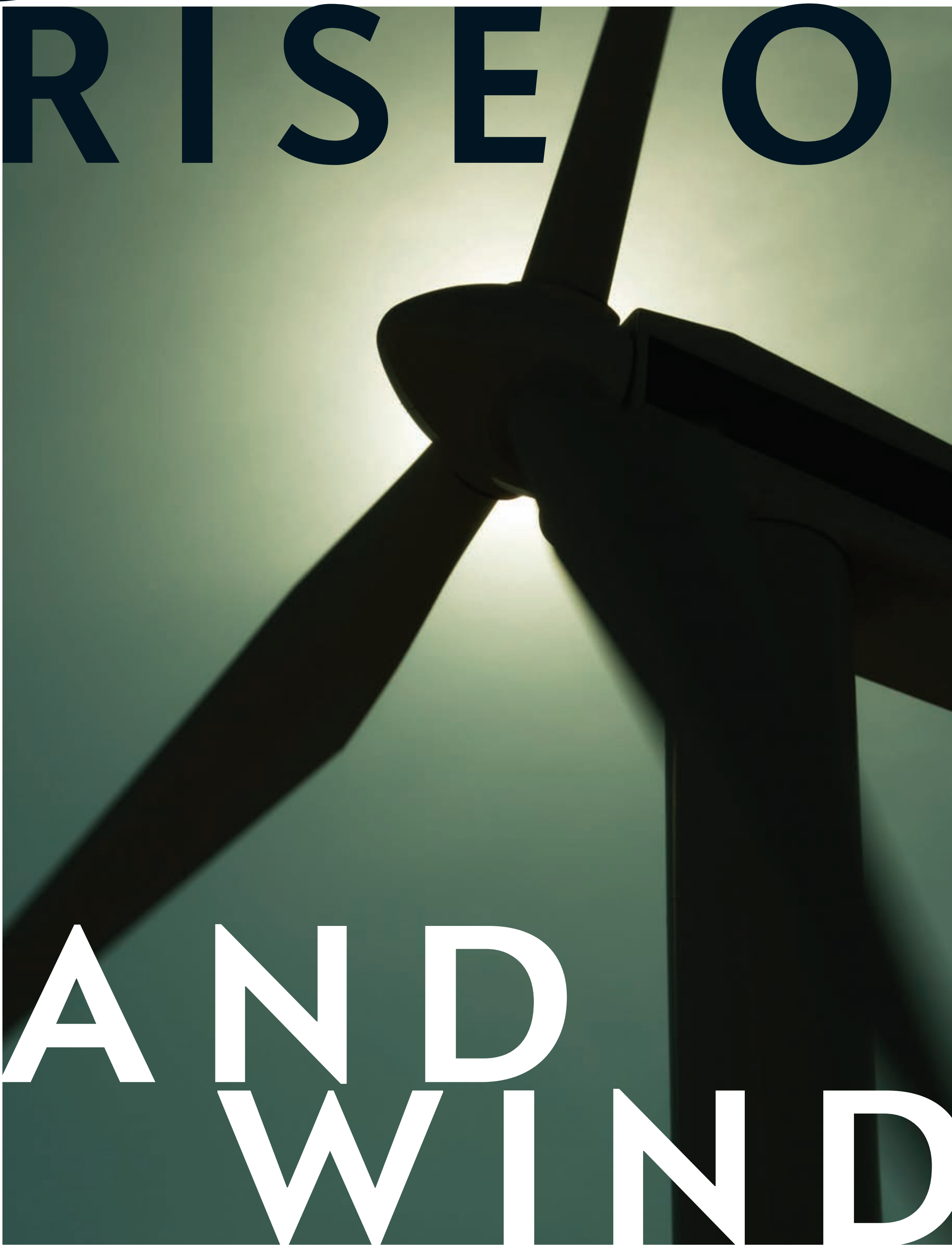

transition to renewable energy is wishful thinking *By Vaclav Smil*

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RENEWABLE ENERGY SOURCES COULD TAKE THE WORLD BY STORM.

That is what well-known advocate Amory Lovins envisaged in 1976. He claimed that by the year 2000, 33 percent of America's energy would come from many small, decentralized renewable sources. Decades later, in July 2008, environmentalist Al Gore claimed that completely repowering the country's electricity supply in a single decade would be "achievable, affordable and transformative." And in November 2009 Mark Jacobson and Mark Delucchi published "A Path to Sustainable Energy by 2030" in *Scientific American,* presenting a plan for converting the global energy supply entirely to renewables in just two decades.

Yet from 1990 to 2012 the world's energy from fossil fuels barely changed, down from 88 to 87 percent. In 2011 renewables generated less than 10 percent of the U.S. energy supply, and most of that came from "old" renewables, such as hydroelectric plants and burning wood waste from lumbering operations. After more than 20 years of highly subsidized development, new renewables such as wind and solar and modern biofuels such as corn ethanol have claimed only 3.35 percent of the country's energy supply.

The slow pace of this energy transition is not surprising. In fact, it is expected. In the U.S. and around the world, each widespread transition from one dominant fuel to another has taken 50 to 60 years. First came a change from wood to coal. Then from coal to oil. The U.S. is going through a third major energy transition right now, from coal and oil to natural gas. Between 2001 to 2012 America's coal consumption fell by 20 percent, and crude oil was down by 7 percent; at the same time, the consumption of natural gas rose by 14 percent. Yet even though natural gas is abundant, clean and affordable, it will be another decade or two before gas use overwhelms

IN BRIEF

The major global energy transitions—from wood to coal to oil—have each taken 50 to 60 years. The current move to natural gas will also take a long time.

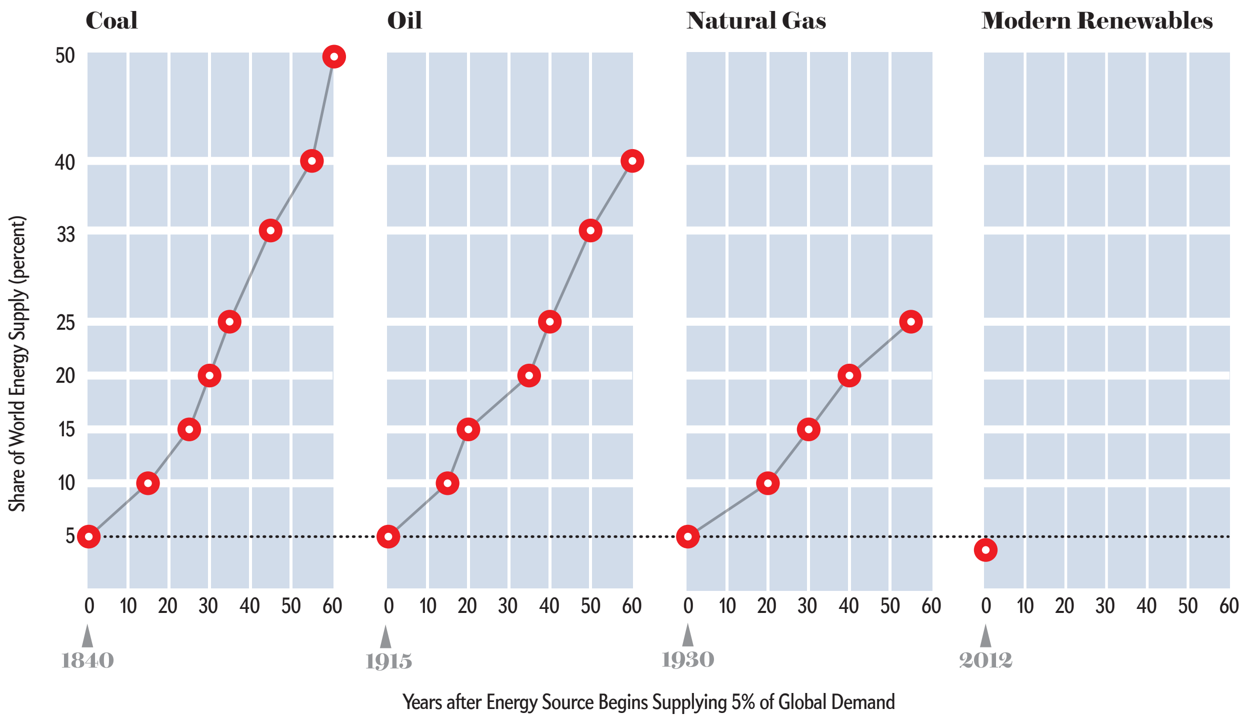
There is no reason to believe that a change to renewable energy sources will be exceptionally fast. In rich countries, "old" renewables such as hydroelectricity are maxed out, so growth will have to come from new renewables such as wind, solar and biofuels, which provided only 3.35 percent of the U.S. supply in 2011.

But, the author argues, certain policies could hasten the rise of renewables. These include funding research into many technologies, ending unneeded subsidies, making sure prices reflect the environmental and health costs imposed by energy sources, and improving energy efficiency worldwide.

PRECEDING PAGES: OLI KELLETT *Getty Images (solar panels);* MARTIN SOEBY *Gallery Stock (turbine)*

Many Years Needed to Take Over the Energy World

Each major energy source that has dominated world supply has taken 50 to 60 years to rise to the top spot. Coal reached 5 percent of global supply in 1840 (*bottom left*) and gradually took over from wood, reaching 50 percent some 60 years later, around 1900. Subsequent transitions to oil and natural gas have followed a similar pattern in reaching benchmark levels of supply (*vertical axis*), rising steadily after they achieve 5 percent. Oil has not yet reached 50 percent and may never. Natural gas is still partway along the path and is taking longer to ascend. The so-called modern renewable energy sources—wind, solar, geothermal and liquid biofuels—have hit only about 3.4 percent; unless a disruptive technology or revolutionary policy speeds up change, they, too, may be destined for a long transition.



coal consumption, which still generates more than a third of U.S. electricity.

Renewables are not taking off any faster than the other new fuels once did, and there is no technical or financial reason to believe they will rise any quicker, in part because energy demand is soaring globally, making it hard for natural gas, much less renewables, to just keep up.

Change can take place faster in some countries, but the global move to renewables will proceed slowly, particularly as the current shift to natural gas plays out. Of course, it is always possible that a disruptive technology or a revolutionary policy could speed up change. But energy transitions take a long time.

FROM WOOD TO COAL TO OIL

TODAY'S GREAT HOPE for a quick and sweeping transition to renewable energy is fueled mostly by wishful thinking and a misunderstanding of recent history. Most people think that the world's energy consumption during the 19th century—the era of rapid industrialization—was dominated by coal, that the 20th century was the era of oil and that our current century will belong to renewable energy. The first two impressions are wrong; the last one remains questionable.

Even with the rise of industrial machines, the 19th century was not run on coal. It ran on wood, charcoal and crop residues (mostly cereal straw), which provided 85 percent of all energy worldwide—roughly 2.4 yottajoules (YJ, 1×10^{24} joules). Coal began to supply more than 5 percent of all fuel energy around 1840 but by 1900 still supplied only about half of demand. The rise from 5 to 50 percent took 50 to 60 years. Fairly good U.S. statistics point to 1885 as the year when energy supplied by fossil fuels (mostly coal, some crude oil and a very small volume of natural gas) had surpassed energy provided by wood and charcoal. The tipping point occurred in 1875 in France and 1901 in Japan but not until 1930 in the U.S.S.R., 1965 in China and the late 1970s in India.

Likewise, in the 20th century the biggest energy source was not oil but indeed coal. Bituminous coals and lignites reached the highest share of global fuel consumption, at about 55 percent, during the 1910s. But crude oil, already in use then, did not surpass coal until 1964.

SOURCES: BP STATISTICAL REVIEW OF WORLD ENERGY; UNITED NATION STATISTICS DIVISION

Graphic by Jen Christiansen

And yet because coal's declining relative importance was accompanied by a steady increase in global energy demand, in raw terms coal—not crude oil—ended up as the 20th century's most important fuel: coal contributed roughly 5.3 YJ of energy, compared with 4 YJ for oil. Only two major economies have accomplished the third fossil-fuel transition; natural gas surpassed crude oil consumption in the U.S.S.R. in 1984 and in the U.K. in 1999.

One way I have demonstrated that transitions are gradual and prolonged is by plotting the rate of an energy source's ascendance. I begin to count a fuel when it has reached 5 percent of the total supply and then see when it reaches a measure of dominance.

The three successive changeovers have intriguing similarities [*see box on preceding page*]. Coal (replacing wood) reached 5 percent of the global market around 1840, 10 percent by 1855, 15 percent by 1865, 20 percent by 1870, 25 percent by 1875, 33 percent by 1885, 40 percent by 1895 and 50 percent by 1900. The sequence of years needed to reach these milestones was 15-25-30-35-45-55-60. The intervals for oil replacing coal, which began at the 5 percent level in 1915, were virtually identical.

Natural gas reached 5 percent of the global fuel market by about 1930. It has reached 10, 15, 20 and 25 percent of supply over a sequence of 20-30-40-55 years and is now on its way to reaching 33 percent of the total. If we compare the number sequences, we see that natural gas has taken significantly longer to reach 25 percent of the overall market, roughly 55 years compared with 35 years for coal and 40 years for oil.

The most important way to speed up the gradual transition to renewables is to lower overall energy use through efficiency gains. The faster global demand rises, the more difficult it is to supply a large fraction of it.

A mere three sequences do not dictate the tempo of future global energy transitions. And a real breakthrough in safe and inexpensive nuclear power or a truly cheap way to efficiently store massive amounts of energy generated by wind and solar could hasten another change. But the similar pacing of three global transitions over two centuries is remarkable, particularly because the fuels required very different production techniques, distribution channels and machinery to convert them into usable power—whether diesel engines for trains or furnaces for homes. Worldwide the enormous investment and infrastructure needed for any new energy source to capture a large share of the market require two to three generations: 50 to 75 years.

A CHALLENGING SWITCH TO RENEWABLES

THUS FAR renewable energy technologies are on the same slow course. In 2011 renewables generated 9.39 percent of the U.S.'s energy: 9.135 quadrillion BTU of the total 97.301 quadrillion BTU consumed (equivalent to about 103 quintillion joules). Traditional renewables supplied 6.01 percent: hydroelectric plants 3.25 percent, wood (mostly waste from lumbering operations) 2.04 percent, with the small remainder from biomass and geothermal. "New" renewables were still negligible: liquid biofuels at 2.0 percent, wind 1.19 percent and solar 0.16 percent.

The total of 3.35 percent for the new renewables is an important number. Virtually all future growth in the U.S. renewable energy supply will have to come from these sources because the old ones, especially hydro, have very limited potential to grow further.

A transition to renewable energy is particularly challenging for several reasons. The first is scale. In 2012 the global use of fossil energies was about 450 exajoules (1×10^{18} joules), 20 times greater than during the 1890s, when coal was overtaking wood. Simply generating this much energy with any new source is daunting, and a significant share of it will have to come from the U.S., which now consumes close to a fifth of the world's total.

Another factor is the intermittent nature of wind and solar energy. Modern societies need a reliable, uninterrupted supply of electricity, with an increasing share demanded at night to power air conditioning and the electronic infrastructures of megacities, ranging from subways to Internet servers. Coal and nuclear plants provide the "base load" of power in the U.S.—the share of electricity that is produced steadily around the clock. Hydroelectric and natural gas–fired plants, which can be switched on and off quickly, typically supply the added power needed to meet the short but high peaks in demand that arise well above base load during certain hours.

Wind and solar can contribute to the base load, but they alone cannot supply all of it, because the wind does not always blow, the sun is down at night and that supply cannot be predicted reliably. In countries such as Germany, where renewables have already grown substantially, wind and solar may supply anywhere from a negligible amount to roughly half of all demand during certain sunny and windy hours. These large fluctuations require backup from other power plants, typically coal- or gas-fired, or increased electricity imports. In Germany, all this variability can cause serious disruptions in electricity flow for some neighboring countries.

SCIENTIFIC AMERICAN ONLINE Will the world run out of oil? See a video at ScientificAmerican.com/jan2014/smil

If electric utilities had an inexpensive way to store massive amounts of excess power generated by wind and solar when demand is low, which could later be tapped to meet peak demand, then the new renewables would expand much more quickly. Unfortunately, decades of development have provided only one good, large-scale solution: pumping water up to an elevated reservoir so it can flow back through a turbine to generate electricity. Not many localities have the elevation change or space to make this work, and the process entails net energy loss.

The alternative solution is to build an extensive array of wind and solar plants across a large region—on the scale of a major nation or half of a continent—and connect them with transmission lines, maximizing the chance that a subset of the plants will always be providing power to the grid. Better and longer transmission lines are technically possible, but they are expensive to build and often face stiff local opposition: not surprisingly, the approval of new lines in both the U.S. and Germany is proceeding at a slow pace.

Ultimately mass adoption of renewable energy would require a fundamental reshaping of our modern energy infrastructure. For electricity, it would entail a shift from a relatively small number of very large thermal or hydropower plants to a much greater number of small, distributed wind and solar systems. For liquid fuels, it would require moving from extraction of high-power-density oil to production of lower-power-density biofuels. In many ways, a transition to renewables is more demanding than the prior shifts from coal to oil and then to natural gas.

The final factor leading to a prolonged shift is the size and cost of existing infrastructure. Even if we were given free renewable energy, it would be economically unthinkable for nations, corporations or municipalities to abandon the enormous investments they have made in the fossil-fuel system, from coal mines, oil wells, gas pipelines and refineries to millions of local filling stations—infrastructure that is worth at least $20 trillion across the world. According to my calculations, China alone spent half a trillion dollars to add almost 300 gigawatts of new coal-fired generating capacity between 2001 and 2010—more than the fossil-fuel generating capacity in Germany, France, the U.K., Italy and Spain combined—and it expects those plants to operate for at least 30 years. No country will walk away from such investments.

WHAT TO DO?

LET ME BE CLEAR. There are many environmental reasons to reduce dependence on fossil fuels, even beyond the quest for reduced greenhouse gas emissions. Burning fossil fuels emits sulfur and nitrogen oxides that lead to acid rain and photochemical smog, black carbon that adds to global warming, and heavy metals that harm human health. Reliance on fossil fuels also causes water pollution and ruins land. A switch to nonfossil energy is environmentally desirable, although some of the alternatives also have significant environmental impacts.

How to get there as effectively as possible is the real question. Knowing that the transition will take many decades makes a number of policy choices clear. Energy and environmental policies in the U.S. and the world have been dismal. Instead of short-term fads promoted by wishful thinking, we need long-term policies based on realistic expectations, and we should be making no-regret choices rather than hasty, poorly conceived commitments.

One way to do this is to avoid picking energy winners. Governments cannot foresee which promising research and development activities will make it first to the free market, and hence they should not keep picking apparent winners only to abandon them soon for the next fashionable option (remember fast breeder reactors or fuel-cell cars running on hydrogen?). Spending on a variety of research activities is the best strategy: Who would have guessed in 1980 that during the next three decades the best return on federal investment in energy innovation would come not from work on nuclear reactors or photovoltaic cells but from work on horizontal drilling and hydraulic fracturing ("fracking") of shale deposits?

Governments also should not offer large subsidies or loan guarantees to companies that are jumping onto the latest energy bandwagon, exemplified by Solyndra, a manufacturer of photovoltaic solar systems, which received $535 million from the U.S. government before promptly going bankrupt. Subsidies can accelerate the advance of nascent energy conversions, but they should be guided by realistic appraisals, and they require steady commitment, not flitting from one exaggerated "solution" to another.

At the same time, prices of all forms of energy should reflect, as much as possible, the real costs, which include both the immediate and the long-term environmental and health impacts of creating that energy. The impacts range from greenhouse gases and black carbon from burning fossil fuels, to soil erosion, nitrogen runoff and water depletion caused by growing corn for ethanol, to the cost of a high-voltage supergrid to link far-flung wind and solar farms. This reality check can reveal long-term advantages of energy sources.

The most important way to speed up the gradual transition to renewables is to lower overall energy use. The faster demand rises, the harder it is to supply a large fraction of it. Recent studies have shown that there are no insurmountable technical problems to reducing energy use by a third, both in the affluent world and in rapidly modernizing countries, notably through efficiency gains. As we reduce demand, we can retire the old fossil sources. People and politicians in wealthy nations must also accept the fact that during the past half a century the price of energy, though rising, has been extraordinarily low in historic terms. Rich countries should pay more to properly account for energy's environmental and health consequences.

Energy transitions on a national or global scale are inherently protracted affairs. The unfolding shift from fossil fuels to renewable energy sources will be no exception. It will require generations of perseverance. SA

MORE TO EXPLORE

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