OUR ENERGY PAST 2

Does It Hold Any Lessons?

Today, the idea of progress in a single line without goal or limit seems perhaps the most parochial notion of a very parochial century.

LEWIS MUMFORD, *Technics and Civilization*

FIRE MAKER

Here is a humbling truth: despite all our advancement and wealth, the fundamental forms of energy today echo those at the dawn of society. What did humanity begin with? Fire from wood, for heating and cooking; sun for drying and warmth; wind and water for power and movement; animals for physical labor. What do we have today, so many millennia later? Fire—from coal, oil, natural gas, nuclear fuels, and biomass (plant material). Sun—for solar power and heating, and, in many parts of the world, for drying and warming still. Wind—for electricity, mechanical work (mills), and movement (sails). Flowing water—for electricity and work (again, mills). And yes, animals too—in their inorganic form, as machines.

Above all, we remain a world lit, built, and moved by fire. In myth, Prometheus was punished for bringing this power to humanity, whom Zeus wished to keep barbarous. But once fire was in its hands, humanity became the genie of invention, the maker and user of thermal energy first and last, *homo ignipotens*. It is fire that brings electricity and modern civilization into most of our lives, that powers our technology and our modes of transport. Indeed, discovering new forms of fire making defines a hallmark—perhaps *the* hallmark—of the modern energy era.

The onset of this modern era, meanwhile, was extraordinary, breathtaking. How long did hominids burn wood as their only fuel? Archeologists now believe fire was first harnessed over a quarter of a million years ago—prior to the first true humans, who appeared about 160,000 years BCE.[1] *Homo ignipotens*, in other words, long preceded *homo sapiens*. Eons were overthrown, then, when coal entered the scene after 1600 and became by 1850 the fuel of modernity. And if this change required a blink of the archeological eye, the next transition was yet more sudden. Between 1900 and the end of World War II, petroleum took the mantle from coal until by 1970 it was dominant. Since the death of Shakespeare, therefore, the West (as modern energy leader) has undergone not one but *two* revolutions in fire making. How did this happen? What were the primary factors involved? The answers are complex, but a few elements seem clear and suggest application to our own time.

THE STORY OF COAL: CRISIS, ADVANTAGE, AND FORTUITY

British towns of the sixteenth century were expanding rapidly, due to a great phase of population growth and agricultural productivity. Such expansion meant more building, thus growth in brick and glass making, the smelting and refining of ores, as well as other fire-hungry industries, like brewing, dyeing, and salt and soap making. Colonial exploration and conflict with Spain had brought about an arms race and the threat of war. England found itself swept up in a surge of ship building and weapons forging, which brought vast new demand for lumber and fuel. Nearly a thousand oaks were needed to build a single warship. Almost an equal number was required each month to generate charcoal (derived from the partial burning of wood in the absence of oxygen, to produce a nearly pure carbon fuel) for the forges then turning out canons, muskets, swords, armor, nails, and more. As the cities and navy grew, forests shrank at a frightening pace. Already in 1543, Parliament passed a Preservation of Woods Act in order to safeguard remaining timber. A period of scarcity ensued, a "wood famine," that caused prices to soar.[2]

Coal, meanwhile, had been mined at the surface in limited amounts for centuries along the River Tyne, in northeast England. During the late Middle Ages, it was used as ballast in ships, as well as fuel in lime kilns, and was known as "sea coal" to distinguish it from "char-coal." A resurgence of use began in Tudor times, toward the end of the 1400s, when brick making became a new industry in England to meet the demand for gigantic country homes and in-town mansions of the gentry.

Yet, coal's true ascent surely came with the deforestation crisis. It was not prized by blacksmiths and kiln owners—much of the coal used at this time was of lower quality (high sulfur and ash content) and could produce unwanted side effects, such as increased brittleness in finished iron. But coal had three things in its favor: it was plentiful in easily accessible areas; it could be transported rapidly by water to any port (wood had to move slowly and cumbrously over poor roads, and charcoal would pulverize and so had to be made close to its site of use); and it burned with a flame as hot or hotter than charcoal, the supreme fuel of the day. By the early years of Elizabeth's reign (1550s and '60s), the price of firewood had reached several times that of coal, with charcoal even more costly, and as the country entered the 1600s, its population, commerce, and industry at unprecedented levels, wood and charcoal prices grew a full order of magnitude further, well beyond that of any other common commodity. When the Great Fire of 1666 destroyed the greater part of old medieval London, cremating over 13,000 houses and 85 churches, there was little debate about what fuel might be employed to make the millions of bricks that would be needed to rebuild.

The stage was therefore set for a large-scale changeover in energy sources. This progressed rapidly, as coal was taken up by a range of industries, in London particularly, and eventually in households as well. London's populace, a mere 70,000 or so in 1550, grew to nearly 350,000 by 1650 and, despite the Great Fire, to over 530,000 by the 1690s. Coal, then, rose in import just as London stepped into full urban eminence as Europe's largest metropolis and the first home of the Scientific Revolution. Indeed, coal proved not merely a source of heat but an origin of innovation. To reduce its unwanted effects on everything from bread to metal with various impurities, users were forced to improve existing ovens and furnaces to prevent direct contact with coal gases, and to invent a new type of fuel, coke, adapted from making charcoal (partial burning of coal in an oxygen-poor environment to drive off the unwanted volatile material). By the late 1600s, use of coal had helped spur a broad set of commercial innovations that were part of the rise of modern science. British natural philosophy (as science was then called) was both theoretical and practical in its work, engaged in experiments, but also in the making of instruments and machines.[3]

Steam soon came to define one such area of invention. Viewed as the moving power of water in vapor form, it was first harnessed successfully by Thomas Savery in 1698, and brought to practicality by Thomas Newcomen in 1712, to draw water out of coal mines. These had proliferated by this time, exhausting many of the shallower seams and were thus forced to go deeper where water drainage became a serious problem. The success of Newcomen's engine proved crucial. A few decades later, when James Watt began work to improve the engine in the 1770s, the drainage problem had been largely solved, and London stood as a city of soot-blackened stoves and chimneys. Watt's innovations were nonetheless epochal, allowing the engine to work without interruption, at higher rates and efficiencies, thus with far more power. British capitalism harnessed Watt's engine in dozens of potent ways—in mills and mines, factories, and soon the railroad and steamship—transforming England into "the workshop of Europe" by the early 1800s. Through such uses, steam became "the power of civilization," and coal the fuel of economic, military, technological, and industrial expansion.

In many standard histories, the rise of coal is made to seem inevitable. This was far from the case. Coal's uptake was neither accidental nor ordained above. It had to substitute for an existing resource, which means it had to replace an entire infrastructural system—types of stoves/boilers designed for firewood and charcoal; wood cutters and other human suppliers; delivery and storage methods; pricing structures; middlemen; and public habit. A new system of extraction, preparation, transportation, and use had to be created. In hindsight, too, we can see that the great turnover from a fuelwood society to a coal society was predicated on historical events, including intellectual and political ones. Had England given up its colonial ambitions, its longing for a naval empire, things might well have been different, for a time anyway.

Coal proved an affordable and widespread source, available in many nations (England, France, Germany, Italy, the Netherlands, Russia, and the U.S. all have deposits), therefore reliable in supply. Its advantages over wood were plain; it burned longer, needed no special preparation like charcoal, and yielded more work per unit volume. It was easier to transport and store, and lasted indefinitely (it did not rot). It gave off a more noxious smoke, but this could be partly "controlled" by higher chimney stacks and by the silent requirement that people simply adapt—we should perhaps recall that this was also the era when tobacco was viewed as healthful. Though dangerous to mine, and toxic to nearby areas, coal came with effects that were acceptable to most, even in line with the dangers of other operations, like the tin and copper mines of Cornwall.

Success for the first energy resource of the modern era was thus due to a combination of market forces, practical advantage, acceptable risk, and fortuitous timing. The inventive enterprise we commonly call the Industrial Revolution seized hold of coal's capabilities, rendering the new energy source a basis for machines of every kind, deeply integrating its use into all aspects of commercial, residential, and official life--an integration that had to be replaced, in turn, once petroleum arrived.

PETROLEUM: A NEW LIQUIDITY

Here, the pivotal country was the U.S., and both urbanization and scarcity were again involved. Yet the need was different and the advantages, at first, narrower. As a modern fuel, petroleum had a modest beginning, as a lighter of lamps.

By the mid 1800s, the Industrial Revolution and the selective prosperity it brought created a burgeoning demand for artificial lighting—new mines, factories, mills, stores, and offices remaining open into the evenings; an explosion of theaters, restaurants, bars, and other "after hours" entertainment in the growing cities; the homes of the expanding middle class. Before the 1850s, whale oil had been the fuel of choice. But whales were being harvested at too great a rate, and whalers had to sail much farther to get their catch, pushing prices ever higher. Other sources existed, to be sure—"town gas" and kerosene (both from coal)—but they had drawbacks. They were expensive, explosive, or low in quality (kerosene burned with a dull, smelly flame).[4]

A small group of entrepreneurs, led by the intrepid George Bissell, saw an opportunity in "rock oil." This flamed more brightly and with little odor. It was also abundant, even leaking from the ground in western Pennsylvania, where it had been used locally for medicine. The next step—and it was a crucial one—was to get the imprimatur of science. Enter the great Yale geologist and chemist Benjamin Silliman, Jr., contracted by Bissell's group to analyze crude oil samples from Pennsylvania. Using distillation, Silliman generated a stunning variety of substances—naphtha, lamp oil, paraffin, waxes, lubricants, tar, showing that petroleum represented a raw material from which "very valuable products" may be made.

Silliman's endorsement brought legitimacy, investment, and (after a bumpy start) the first successful well in 1859. This established the new resource in great quantity and set off a true boom in drilling and discovery. The price of "rock oil" fell, capturing the lighting market and (the final rub) swelling demand beyond all expectation. Whale oil became a commodity of the past—thus, in a curious twist, petroleum did much to save the sperm whale from extinction. Within a mere fifteen years, annual output from the Pennsylvania fields was 10 million barrels (420 million gallons). Petroleum at this stage did not compete so directly with coal, which continued to underlie the Machine Age in nearly every domain except lighting. No true, full-scale energy transition had yet taken place. But then, in the 1890s, something new appeared to alter everything.

As with steam, the internal combustion engine (or ICE, as it is often known) had been an object of invention and experiment for some time. Indeed, the idea of taking the piston-cylinder mechanism and giving it an interior source of power was but a matter of logic. Early attempts, between 1840 and 1870, sought mainly to mimic steam-based equipment and did not fare well, particularly since coal-gas, with its low burning temperature and restricted power output, was the fuel. The introduction of liquid petroleum made the difference. Such a fuel had huge advantages, recalling those of coal compared to wood, but were even greater. As a liquid, oil was even easier to transport and store, could be delivered via gravity, and generated far more heat per unit weight than coal itself. Improved liquid fuel engines of the late 1880s and early 1890s advanced the success of oil, even as oil ensured that the ICE would soon dominate motor transport.

Early on, however, petroleum still had competitors. Cars powered by both steam and electricity existed, but were ultimately limited in crucial ways. "Steamers" needed warming up, frequent cleaning, and could only go about twenty-five to thirty miles before re-watering. Electric battery cars were silent, simple (no shifting of gears), clean, and dependable, but also slow (<20 mph was typical) and had a range of under fifteen miles. This was fine when the only good roads were in cities, and private cars were used for commuting and short trips about town. Once, however, the road system expanded to interurban and rural travel, the superior power and range of the ICE became major advantages. Moreover, infrastructure for electricity was nearly nonexistent, that for oil half a century old by 1910. Other factors were economic; discovery of oil in Texas greatly lowered gasoline prices after 1912, while Ford's assembly line brought ICE cars within the budgetary reach of millions. Technological improvements, such as Charles Kettering's electric starter (which did away with the hand crank), also helped greatly. In little more than a generation, by 1930, the spread of trucks, tanks, jeeps, airplanes, oil-powered ships, and above all, cars secured the Hydrocarbon Age.

Again, the process was neither immediate nor smooth. Nearly all the advanced countries of Europe had coal resources, while almost none had oil. They were therefore forced to import it, mainly from the U.S. at first. Petroleum brought with it, very soon, a shift in the geopolitical order of energy security. And there were other bumps. As with wood, large portions of the coal society had to be replaced. An entire new system of storage tanks, pipelines, tankers, gas stations had to be developed. But the advantages, again, were overwhelming. No less a voice than Winston Churchill took up the cause on the eve of the Great War, securing the changeover to oil for the entire British navy. By the 1920s, a new type of fire making had begun to power the industrial West.

WHAT CAN WE LEARN?

Are there lessons to be gleaned from these potted histories? There may well be. In each case a new fuel gained ground due to scarcity in another. Market forces—supply, demand, and cost—were essential. But the power of need, expressed as demand, drove all. Technology was vital too: King Coal was lifted to its throne by the piston of the steam engine, petroleum by internal combustion. In each case, energy advantage spawned an ever-widening array of invention, use, and (for oil) fuels, leading to new products, new vehicles, new industries, new modes of social existence, and an ever-deepening integration into modern reality. Thus, in total: two episodes of resource scarcity and "unsustainability," two periods of economic struggle, two engines that remade the world. Or, to simplify the relationship still further: shortage + socioeconomic instability + technology → new alternative (change).

Do we then have the final formula for the process of energy change? This would be welcome, indeed. More likely, we have a set of basic ingredients and conditions that have worked to create transformation. These include:

1. a major situation (economic, political, etc.) creating a perceived need for change;
2. an alternative resource that can be made abundant and reliable, usable on a large scale;
3. energy advantages to this resource/option—for example, higher efficiency or energy content, flexibility of use, perceptions of safety, reduced ill effects;
4. economic advantages, so that the new option can create and penetrate markets, win over the public (hearts and wallets), urge the building of infrastructure;
5. forms of technology to make the new resource practical, even superior, in performance, cost, applicability; and
6. promoters or paladins, as well as investors, that bring it to the notice of those able to develop and market it to the rest of us.

These conditions all seem essential. Are they sufficient, together, for a new energy source or era to develop? This is difficult to say. They definitely help explain some of the success and limits for more recent sources like nuclear energy, which, in real terms, satisfies most conditions but not those regarding a situation of necessity (electricity was not in a crisis state), economics (nuclear-generated electricity was cheap but nuclear power plants were very expensive to build), perceptions of safety, and consensual sponsorship.

But the case of nuclear energy also suggests that something is missing from our list. In our world today, new energy options must also bring environmental advantages—indeed, advantages here are now perceived to be wholly critical. This was not true in the past—coal and oil were hardly vast improvements in this domain. Only if we add this criterion today, however, can we fully explain the situation that is urging alternative sources like renewables, hydrogen, and fusion. None of these alternatives satisfy all six points above: wind and solar have reliability problems (they operate only some of the time); biofuels have less energy content than oil; hydrogen and fusion are not yet practical; nearly all of these sources remain expensive.

Yet such considerations are now outweighed—perhaps "balanced" is a better word—by environmental benefits. Our world is not driven toward change by scarcity or the happy discovery of some new and marvelous energy source. Motives have much more to do with geopolitics, volatile prices, and concerns over pollution, public health, ecological damage, and climate change. Indeed, the transition we have entered in the twenty-first century could be the first in which social benefits take precedence over energy advantages. And if we look at the matter more holistically, we can see that enviro-benefits *do* translate into energy and economic terms, for the newer alternatives don't come with the costs of coal/petroleum pollution (which we now understand), military intervention in the Middle East, and other effects, and do promise at least the possibility of new industries, jobs, even lifestyles. The past may not, entirely, be a key to the present in all this. There are elements in our energy landscape today that render our list above a helpful but incomplete guide to the future.

THE QUESTION OF CONVERSION: WHAT IS GAINED AND LOST

Need for change also comes back to the laws of thermodynamics and their implications. Energy, these laws tell us, is about transformation, which involves a chain of conversions. First, to become useful, resources like oil, natural gas, sunlight, or bio-matter must be converted into some kind of finished fuel or product, what is known as an "energy carrier." Common examples are gasoline, diesel, biofuels, processed natural gas (ready for burning), and electricity. Next, energy carriers are employed to do actual work through another set of conversions, involving motors, engines, boilers, and appliances.

A main aspect to this energy conversion chain, as the second law teaches, is that losses occur at each step. These losses are far from trivial. In most cases, well over *half* of the original energy content in the primary source is gone by the time any useful work is done, whether turning on a light or backing out of the driveway. Conversions are often measured in terms of "efficiency," defined as the amount of usable energy as a percentage of the total energy content available. Thomas Savery's original steam pump for drawing water out of coal mines was less than 1% efficient. Watt's epochal engine raised this considerably, to about 2%.[5] Some common efficiency levels today include: industrial boilers, 75%–86%; natural gas power plants (converting heat into power), 40%–50%; coal-fired power plants, 30%–45%; the average car, 15%–18% (gasoline into motion); the incandescent light bulb, 2%–5%.[6]

Consider the car for a moment. Refining crude oil into gasoline retains about 85% of the original energy content. The car's engine and drive train are able to convert only about 20% of this—17% of the original energy in petroleum—into actual power delivered to the wheels. The great majority of chemical energy in the fuel is lost to waste heat and friction, especially by the engine. Thus, the "well-to-wheel" efficiency of the average car is about 17%; not very impressive, to say the least. Similar calculations have been done for other types of autos, notably electric vehicles (EVs). In this case, starting with the energy content in coal or natural gas, which supply electricity to recharge the vehicle's batteries, we find "mine/well-to-wheel" efficiencies are 2–4 times that of the gas-powered car. The biggest improvement happens in the engine—electric motors are able to convert 75% of the chemical energy in batteries to mechanical energy powering the car's wheels.[7]

Does this mean there will soon be a wholesale changeover to EVs, especially in the U.S., which could thereby solve its "foreign oil problem"? Probably not. First, battery technology is not quite there; low-cost, light-weight versions that have a life span equal to that of the car itself and can be mass-produced cheaply are not yet available and need major innovations before they appear. In 2009, EVs able to yield similar performance and driving distance to a gas-powered car remained expensive (the Tesla Roadster and Fisker Karma, representing state-of-art EV capabilities, each cost over $80 thousand). Second, there are 155–160 million passenger cars on U.S. roads,[8] about 170,000 gas stations, and a gigantic network of oil refineries, tankers, and pipelines, not to speak of automakers and subsidiary industries, employing a labor force of millions, backed by congressmen and senators from relevant districts and states. It took about thirty years to sweep horse-drawn vehicles out of the urban environment, and another two decades to do this in rural areas. It would seem naïve to suppose that the ICE, whose total universe is far more extensive, would vanish more quickly. Then there is the reality (minor, to be sure) of the global petroleum market in which the U.S. plays such a central role, well beyond the Middle East, with many relationships and responsibilities to consider. And there is something else, too—call it public comfort. Whatever the energy or economic advantages, any new kind of vehicle will begin with an exotic and therefore limited appeal. To become fully accepted, it will need to cross a psychological barrier, a type of passivity, defined by the force of the familiar and the caution toward the 1.0 or "beta" version of such an important piece of equipment. Recall that it required a full decade (1998–2008) and an oil shock as well for hybrid sales in America to go from zero to a over a million total.[9] Such growth, moreover, represents a mere 0.6% of the total U.S. fleet of private autos. Hybrids—a half-step to EVs—have now entered a comfort zone in the public mind, urged by a period of rising gasoline prices and a new social context where car choices become statements with ethical status. Most carmakers therefore see advanced hybrid versions becoming far more prevalent than EVs in the next few decades. But other new vehicle types, such as plug-ins or full EVs, will need their own gestation periods too, even if hybrids have paved the way.

There is inertia built in to our existing systems of energy production and use, not least when it comes to consumer choice. Judged on a pure efficiency basis, we should never have continued to build gasoline-powered vehicles—they are powerful, yes, and can be made a thing of beauty, even fetishism, but they remain among the most wasteful machines on Earth. Today, as we've noted, there are 700–800 million cars globally, with tens of millions more every year, and they burn up a resource that is not only exceedingly precious but the object of great global anxiety, conflict, and even war. By such reckoning, it seems irrational (a diplomatic word) to expand the realm of the ICE still further. And yet, the petroleum-fed engine defines the core of modern transport, a cosmos of untold capability, diversity, and flexibility, wholly unimaginable a century ago, erected in the historical breath between 1900 and 1950, and with a functionality that goes far beyond "well-to-wheel" considerations. To replace the ICE—while keeping everything beneficial about this transport universe intact—will require ingenuity, experiment, luck, and time. Will it happen, then? Most certainly—indeed it has already begun, as hybrids and the first EVs make plain. This raises the question, then, of whether it points in a more general direction.

DE-CARBONIZATION: NOT A NEW IDEA, NOR A MATTER OF DESTINY

In fact, we are frequently told that the future of our entire energy landscape is now determined. It must be, and *will* be, a continual reduction in carbon-rich (read, fossil) fuels: decarbonization.

Whether we embrace such a vision for the coming century—or, to more impatient types, the next decade or two—it is not new. It was predicted, in detailed form, as early as 1979. That year, Cesare Marchetti and Nebojsa Nakicenovic, two theorists at the International Institute for Applied Systems Analysis in Austria, published a book entitled *The Dynamics of Energy Systems*, laying out a mathematical model for the long-term pattern of energy change in industrial economies.[10] The

Marchetti-Nakicenovic theory showed each energy source rising, peaking, and then falling as a series of partly overlapping, symmetrical curves, one replacing another, like waves smoothly running upon a shore—oil ascending as coal declines, then cresting and collapsing as it is replaced by natural gas, which then gives way to some future source (solar energy and fusion were mentioned). Moreover, plots of actual energy use seemed to bear the model out, all the way through the 1980s, demonstrating a clear trend toward less carbon-rich fuels, especially when hydropower and nuclear were added in. Indeed, the authors included (and later updated) an actual graph of "carbon intensity"—defined as the amount of carbon per unit of energy consumed or unit of economic output (e.g. tons of carbon per million Btus or dollar of GDP). The line on this graph tumbled for the century spanning 1860 to 1980. It fell most steeply after 1950, when oil took over from coal. Decarbonization thus seemed a script of destiny. Rather than a theory, it was a simple perception of energy history, an evolution as firm and irreversible as ape to hominid.

The Marchetti-Nakicenovic model, with its pleasing curves, got a new look in the 1990s when taken up by Robert A. Hefner III, an entrepreneur of the petroleum industry. Hefner saw the trend toward decarbonization a bit differently—as a progression from *solids* (wood and coal), to *liquids* (mainly oil), and finally to *gases* (natural gas and hydrogen), a progression that would lead not to solar energy or fusion but to an "age of energy gases."[11] Each phase change in this grand narrative involved a lowering in the number of carbon atoms and an increase in hydrogen, with H_2 itself the end member. Overall, it meant higher energy content, higher efficiencies, and lower emissions—a "cleaning up" of our dominant sources, if you will. There was also a socioeconomic overlay: Heffner described a movement away from big, centralized modes of energy use toward "increasingly sustainable . . . decentralized, less capital-intensive technologies." Perhaps in a fit of overenthusiasm, he also claimed that his graph revealed "natural sine curves," proving that energy markets, like *mysterium cosmographae*, must be left entirely free and unregulated. Government mustn't mess or putter with Providence.

By the early 2000s, however, it was clear that these types of models—and perhaps the ordained march toward decarbonization—were questionable. Oil use did not fall as it was supposed to, and as it seemed to be doing in the early 1980s; after the price collapse of 1986, consumption began to climb again, rising all through the 1990s into the 2000s, until Himalayan prices and economic crisis returned in 2008. This revenge of the liquids, moreover, was matched by the return of coal, presumed solid of an earlier cycle. By 2003, with natural gas more expensive than ever and industrialization in coal-rich Asia going fortissimo, coal had become the most rapidly expanding fuel worldwide, while hydrogen remained utterly off the graph. The 140-year trend of decarbonization, for the time being, was over. In the first decade of the new century, humanity was *re*-carbonizing.

The "lesson" here is twofold. First, the Marchetti-Nakicenovic and Heffner models of universal energy history were both parochial and ahistorical; they overlooked that nations like China would soon be industrializing on a scale never before seen (and barely imagined) and would quickly take over the future of carbon fuels, starting, as the West did, with those they have in most abundance. Second, the models of decarbonization ignored the dynamics of the market. The return of cheap oil in the '90s and the advent of high prices for natural gas in the 2000s had real impacts on patterns of fuel choice and demand. Truth to tell, the climb in oil use was led by the U.S., whose consumption grew nearly 50% between 1986 and 2004. But from 2003, the developing world took over as the center of fossil fuel consumption, and this seems unlikely to change—there is vast pent-up demand in the fact that the modern era of fire making, after all, still does not yet belong to a huge portion of the people in poorer nations, where an estimated 1.4–1.6 billion live with no electricity.[12] The famous claim, attributed to Thomas Edison, that "we will make electricity so cheap only the rich will burn candles" becomes today a trenchant irony, with so many of the world's poor still without power.

This reality is an enormous disadvantage to the global community. Imagine if all of these power-less people could be given the amenities that even basic electrical facilities offer—modern schools; hospitals and health care; better food and sanitation; a wider range of employment; computer technology—all contributing to a potent increase in what economists call "human capital." How the world might benefit from such investment in humanity! And yet we see the problem, and the conflict, right away. Such benefit, that is, could have another side indeed, were it to continue bringing a leap in carbon-related pollution and emissions—something that remains a distinct possibility.

Our energy past, present, and future extend beyond the easy reach of modeling. Human ingenuity and behavior, as well as geopolitics, are unlikely to step in line with "natural sine curves." Decarbonization isn't assured or predestined, at least in the near and mid term; we will have to work at it. A hope we might all share, as citizens of our only *orbis terrarum*, is that nations without modern energy, in their urge to acquire it, might avoid following so closely in the soot-laden footprints of their industrialized counterparts. There is no fate either that says the developing world, with its vast populations and burgeoning need, *must* collapse the stages of Western energy use and all its impacts into a few blackened decades.

These nations have nearly 1,000 times the population that the West did when Drake drilled the first oil well. For the sake of global public health, security, and much else, we should wish these countries to move towards a broader, more flexible blend of sources. Those who say that this can happen quickly are grandly mistaken. Yet they are right about one thing. If we do seek such a move, we ourselves must make it happen.

THE MEANING OF ENERGY PROGRESS

So how to define the idea of "energy progress"? In truth, modern energy has been an unending scene of transformation. The eras of coal and oil were themselves anything but static. There has never ceased to be a drive to improve existing technologies and discover new ones, plus new and more diverse applications. Coal began in the fireplace and the forge, but soon came to make glass and bricks and brew beer, each business utilizing its own type of boiler. From there it went on to power the steam engine, applied in a myriad of evolving innovations for industry and transport. Still it was far from done: coal vastly expanded the making of steel and cement, the flesh and bone of modern cities, then lit and powered them with electricity. More recently, it has been used itself as a source for natural gas and for generating liquid fuels too. Innovation, research, serendipity, and capitalistic enterprise have all worked their will. There was never any final satisfaction—nor for oil, whose multiform employment, from fuels to plastics, is even greater.

Nonetheless, a certain psychological imprint from the past remains. Because of what coal and oil each became, we are perhaps to be forgiven for indulging the hope that there will come again, in the years ahead, some other great mono-source to open a promised land of near-limitless power. Certain possibilities—solar energy, fusion, the hydrogen economy—have been promoted in such terms. Indeed, there is a utopian aroma lingering around many questions posed about our energy future: "What will power our civilization in 2050?" "What will the car of tomorrow run on?" "There is more than enough solar energy striking the Earth at every moment to run the world—when will we put it to use?" The dream is that, in time, some Great Solution will arrive, to absolve us of all our energy woes, worries, and responsibilities. As we've noted several times, however, things have been headed in a very different direction.

In 1930, the globe relied on coal, oil, and traditional biomass for over 95% of its energy use. By 1990, these fuels remained pivotal, yet the total portfolio making up that 95% now also included natural gas, nuclear power, hydroelectricity, wind power, solar energy, geothermal energy, and biofuels. Some of these sources, true enough, remained a small part of the whole. Yet on a nation-by-nation basis, they had become major, integrated options: hydropower in many countries; geothermal at over 15% of energy use in New Zealand, Iceland, the Philippines, and Kenya; wind supplying 7% of electricity in Germany, 10% in Spain, more in Denmark. Now think of land transport. As recently as 1970, only one type of car trod the roadways; the gasoline engine ruled all. Today, there are diesel, flex-fuel, hybrid, all-electric, and natural gas cars, with others like plug-in hybrids, compressed air, and fuel-cell vehicles in the wings. None of the new species is likely to swallow the global market whole; neither are all likely to survive. It is certainly possible that some represent transitions; hybrids, by their very nature, offer a bridge to full EVs, but could themselves advance and become central. The total variety of car types may narrow over time, to several superior options. But this still represents great diversity over the past.

The future, I wager, belongs to energy pluralism. When we look at the totality of need—electricity, transport, industry, commerce, homes, agriculture—what we see developed over the past half-century is energy diversification, the exploration and expansion of new technological options. This has allowed for much localization, but of a complex type. Such localization, that is, depends not only on the country's natural resources, but its politics, wealth, and culture, all of which are dynamic, subject to change. Culture, indeed, can be a vital factor—if defined not only as traditional patterns and proclivities but adaptations of a rather anthropological sort. Taking Denmark as an intriguing instance, we might consider this contrast offered by David Nye in his excellent book *Electrifying America*:

> Most Danish communities have built large power stations that use steam turbines to generate electricity and then pump the resulting boiling water through underground pipes to heat businesses and homes. This "cogeneration" is cheaper and less polluting than having inefficient furnaces in every home, and it has the secondary effect of binding the community more tightly together . . . In contrast, the combination of American individualism and a reliance on the market place to determine the shape of development produced the dominance of private utilities.[13]

Does this suggest that Americans should become Danes or, God forbid, vice versa? But the point is that forms of energy use are deeply woven into the structure, outlook, and even identity of a society. The "Danish technological style," as Nye calls it, also emerges from close-knit living, a lack of heavy industry, and one of the world's most expansive social welfare states. Cogeneration (also known as combined heat and power, or

CHP) is a natural fit for, and also an expression of, such a society of shared services. Throwing over one such system for another is not a simple matter of trading technologies, substituting machinery. It involves altering socioeconomic reality. Of course it can be done—has been done, and must be done again—but it can't be achieved without changes of mind, space, and lifestyle.

But such changes can go in a number of directions, especially when left to their own devices. Take the case of Danish bathrooms. Since the 1990s, households in Denmark have launched a renovation boom for this space. A large portion of the populace, turning away from simple Scandinavian styles previously the norm, have added more toilets, double sinks, vanities, spa-like tubs, independent showers with surround spray, and more, during an era of growing affluence and longer work hours. Social researchers Maj-Britt Quitzau and Inge Røpke help us comprehend the larger meaning here. It is an example, they say, proving "the complexity of drivers and other aspects involved in the construction of new normality."

> [This involved] the increasing importance of the home as a core identity project and a symbol of the unity of the family . . . the convenience of more grooming capacity during the busy family's rush hours, the perceived need for retreat and indulgence in a hectic everyday life, and the increased focus on body care and fitness. The case also illustrates that when people have the economic possibilities for increasing consumption, they will [be guided by] ideas that are closely integrated with their prevailing everyday concerns.[14]

Energy behavior involving daily consumer preferences is not a mere matter of "private choice" alone, but is guided by pressures and possibilities that social reality creates. A far more demanding work life, with both parents busy outside the home, coupled with rising incomes and new standards for a healthful, controlled appearance, together helped transform the Danish bathroom into a site of cleansing need and sanctuary. But the effect has been big increases in energy and water use nationwide. Missing, imply the authors, is a norm that understands the bathroom as an environmental nexus—a core, no less than the kitchen, of energy flow and use (lights, hot water, hair dryers, etc.). Such a norm would obviously have to compete to succeed. It might even have to displace, or "shame," the desire for touches of luxury. But this is exactly the point; changing energy reality means changing aspects of mind as well as machine.

Energy use in the past and present is personal, social, and cultural all at the same time, thus so is its progress. Sustainability for every part of the globe is the ultimate goal (nearly all agree on this), but defined in flexible fashion. The grand trend toward energy diversity, meanwhile, will have its own limits. We can't go on expanding the number of sources, or the types of cars and power plants, forever. Sustainability will depend upon further advancing some of the choices we already have, developing certain new ones, and creating an adaptable portfolio able to address not one or two but many challenges, from rising transport demand to national security. Moreover, this idea, "sustainability," should not be understood in a doctrinaire way, as ruling out fossil fuels, for example, or large-scale power systems. Viewing fossil energy as a barbed impediment to the future would be a grave error. Oil, gas, and coal are what run the world today, and they are therefore required to advance all other options. Small may be beautiful, but populations and cities are huge and growing. By 2030, over half of humanity will live in urban areas. It is hard to imagine the new mega-metropoli running on solar and wind power alone.

In the meantime, however, Robert Heffner is right. We will pass beyond the Hydrocarbon Age—not by chance but by need and necessity. Whether the world does this together or in competitive fashion is a critical question that cannot yet be answered. The final point history may offer is that over reliance on, and prophetic desire for, any single fuel or technology will prove misguided. It is our ideas that power our technology. An hourglass is fragile because so narrow at the pinch.