Mapping Global Energy: Realities and Issues for the 21st Century

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Chapter 2

Our Energy Past: 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. On Earth, and through history, fire has been the genie of endless invention. Humans have been makers and users 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.

Onset of this modern era, meanwhile, was extraordinary, breathtaking. How long did hominids burn wood as their dominant fuel? Archeologists now believe fire was first harnessed over a quarter of a million years ago or more—prior to the first true humans, which 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 itself. 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 progressively 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 16th century were expanding rapidly, due to a great phase of population growth and agricultural productivity. Such expansion meant more construction, thus growth in brick- and glass-making, as well as other energy-intensive industries, like brewing, dyeing, salt refining, and soap making. Colonial exploration and conflict with Spain had brought about an arm's race and the threat of war. England thus found itself also 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) used in 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" 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, from surface mines, 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 two things in its favor:

it was plentiful in known and easily accessible areas, and it burned with a flame as hot or hotter than charcoal, supreme fuel of the day. By the early years of Elizabeth's reign (1550s and 60s), the price of firewood had reached 2-5 times that of coal, with charcoal even more costly. The stage was therefore set for a large-scale changeover in fuels. This progressed rapidly, as coal was taken up by a range of industries, in London particularly, and in households as well. London's populace, a mere 70,000 or so in 1550, grew to nearly 350,000 by 1650. Coal, then, rose in import just as London stepped into eminence and the Scientific Revolution got underway, a fortuity of no small consequence. British natural philosophy (as science was then called), as it progressed into the 18th century, was both theoretical and practical in its work, engaged in experiments, but also in the making of instruments and machines.(3)

Steam 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 improved by Thomas Newcomen in 1712, to draw water out of coal mines, which had proliferated by this time, exhausting many of the shallowest seams and were thus forced to go deeper where water drainage became a problem. By this time, better quality coal was mined in many areas, but the water predicament had grown serious—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 had become 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 resulting in far more power. British capitalism harnessed Watts' steam 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.(4)

In many standard histories, the rise of coal is made to seem ordained. This was far from the case. Coal's uptake was neither accidental nor cast from above. It had to substitute for an existing resource: required was the replacement of 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 also 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 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 have been different, for a time anyway.

Coal constituted an affordable and widespread source, available in many nations (England, France, Germany, Italy, Holland, Russia, the U.S. all have deposits), therefore reliable in supply. Its advantages over wood were plain: it burned for a longer time, did not have to be prepared like charcoal, and yielded more work per unit of volume. It was easier to transport and store, and lasted indefinitely (did not rot). It gave off a more noxious smoke than wood, 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.

Coal thus succeeded as the first energy resource of the modern era due to a combination of market forces, practical advantage, acceptable environmental risk, and fortuitous timing. Whether the Industrial Revolution would have been possible without it is open to endless debate. Certain, however, is the fact that inventive enterprise 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 factors. 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—think of the new factories, mills, stores, and offices remaining open into the evenings; the 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 (from coal), for example—but they had drawbacks. They were expensive, explosive, or low in quality (kerosene burned with a dull, smelly flame).(5)

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—naptha, lamp oil, paraffin, waxes, lubricants, tar, showing that petroleum represented "a raw material from which…very valuable products" may be made.

The 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 of 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, oil did much to save the Sperm Whale from extinction. Within a mere 15 years, annual output from the Pennsylvanian fields was ten million barrels (42 million gallons). Petroleum wedged its way into industrial life, aided by science, technology, and economics. It did not compete so directly with coal, which continued to underlie The Machine Age in nearly every domain. But then, in the 1890s, something new appeared to change all this.

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 had competitors. Both steam and electric autos existed, but were limited, ultimately, in crucial ways. "Steamers" needed warming up, frequent cleaning, and could only go about 25-30 miles before needing water. Electric cars were silent, simple (no shifting of gears), clean, and dependable, but also slow (<20 mph was typical) and, given battery technology, had a range of under 15 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 non-existent, 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 production 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 played a role. The final result was that 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.(6)

Again, the process was neither instantaneous 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., then the Middle East and Indonesia. Petroleum brought with it, very soon, a shift in the geopolitical order of energy security. And there were other bumps. 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 little 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 found itself 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 uses and (for oil) fuels, leading to new products, new vehicles, new industries, new modes of social existence, and thus 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 equation still further: shortage + socio-economic 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, so that it can be eventually used 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, or applicability.

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 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. This was not true in the past—coal and oil were hardly vast improvements in this domain. But today the environmental criterion is critical. It is critical because concerns over pollution, public health, ecological damage, and climate change are driving a large part of the demand for change. Only if we add this criterion can we fully explain the situation that is urging alternative sources like renewables, hydrogen, 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 no energy advantages over oil; hydrogen and fusion are not yet practical. Economics remain a question for all of these sources.

Such considerations, however, are outweighed—perhaps balanced is a better word—by environmental benefits. And if we look at the matter more holistically, we can see that enviro-benefits *do* translate into economic terms, for these alternatives don't come with the costs of petroleum pollution and military intervention in the Middle East and do promise at least the possibility of new industries, jobs, even life-styles. 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, for progress in energy, also comes back to the laws of thermodynamics and a few of their implications. Energy, these laws tell us (as noted in the last chapter), is about transformation, using some type of resource to effect useful, physical change. To become useful, resources like oil, natural gas, sunlight, or vegetal matter must be first converted into some kind of finished fuel or product, what is known as an "energy carrier." Common examples are refined fuels (gasoline, diesel, biofuels), processed natural gas (ready for burning), and electricity. Energy carriers are what we often use to do actual work. Their end-use occurs by 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, moreover, 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 this involve backing out of the driveway or turning on a light to pay the electric bill. 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 Savory'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%.(7) Some common efficiency levels today include: 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%.(8)

Focus on 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—i.e. 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. Another way of putting this is to say that 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.(9)

Does this mean there will soon be a wholesale changeover to EVs, especially in the U.S., which relies on petroleum for 90% of its transportation and could thus solve its "foreign oil problem"? Probably not. First, battery technology is not quite there yet: low-cost, light-weight versions that can be mass produced cheaply are not yet available and require major innovations be made before they appear. EVs that use current technology to yield similar performance to a gas-powered car remain expensive (in 2008, the Tesla Roadster and Fisker Karma, representing state-of-art EV capabilities, each cost over $80K). Second, there are in the neighborhood of 155-160 million passenger cars on U.S. roads(11), about 170,000 gas stations, and a gigantic network of oil refineries, pipelines, tankers, auto makers, and subsidiary industries, employing a labor force of millions, backed by Congressmen and Senators from relevant districts and states. It took about 30 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 universe, which is far larger and more complex in scale, would disappear so much 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 allies) 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 known, the convenient, the comfortable.

Consider hybrid cars, whose American sales have gone from zero to a over a million in ten years (1998-2008), with all auto manufacturers now offering models (many as SUV hybrids).(12) Such growth may appear impressive, and it is. But it represents a mere 0.6% percent 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 high gas prices, climate change, and a new social context where car choices can become statements with ethical and practical status. 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. Meanwhile, a decade to penetrate less than 1% of the market hardly seems like a barn storm.

There is enormous 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 built gas-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 unending global anxiety, conflict, and even war. By such reckoning, it seems irrational at best to continue to expand the realm of the ICE. And yet, the petroleum-fed engine has also created the entire universe of modern transport, a universe of untold power and capability, freedom and flexibility, wholly unimaginable a century ago, erected in the historical breath between 1900 and 1950, and with a momentum and functionality that go 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. This raises the question, then, of whether the world is headed in such a direction.

De-Carbonization: Not a New Idea, Nor a Matter of Destiny

In fact, we are frequently told that the future of our energy landscape is now determined. It must be, and *will* be, a continual reduction in carbon-rich (read: fossil) fuels. Global warming, pollution, national security concerns, the presumed exhaustion of oil reserves, and more will drive this move—toward 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 proposed, in detailed form, some time ago, in 1979. That year, Ceasare 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 longterm pattern of energy change in industrial economies.(13) The Marchetti-Nakcenovic theory showed each energy source rising, peaking, and then falling as a series of partly overlapping, symmetrical curves, one replacing another, like waves crashing upon a beach—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). Plots of actual energy use seemed to bear the model out 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)(14) 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 C per million Btus or dollar of gross domestic product). The line on this graph literally tumbled for the century spanning 1860 to 1980. It fell most steeply after 1950, when oil took over from coal. Decarbonization thus seemed a type of destiny. Rather than a prediction or theory, it was a simple perception of energy history, an evolution as firm and irreversible as ape to hominid.

The Marchetti-Nakenovic 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 de-carbonization a bit differently—as a progression from *solid* fuels (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."(15) 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 final 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 socio-economic overlay: Heffner described a movement away from big, centralized modes of energy use toward "increasingly sustainable…decentralized, less capital-intensive technologies." In a fit of over-enthusiasm, Hefner even 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 with providence.

By the early 2000s, however, it was clear that these types of models—and perhaps the ordained march toward de-carbonization—were questionable. Contrary to forecasts, oil use did not fall (as it seemed to be doing during the early 1980s, due to high prices, recession, and lower demand): after the price collapse of 1986, consumption began to climb again, and rose all through the 1990s into the 2000s, when high prices and economic crisis returned. This historical revenge of the liquids, moreover, was matched by the return of coal, presumed fuel of an earlier cycle. By 2003, with natural gas prices rising and industrialization in coal-rich Asia in full swing, coal had become the most rapidly expanding fuel (and could well remain so for decades), while hydrogen was not yet even on 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 two-fold. First, both the Marchetti-Nakicenovic and Heffner models of universal energy history were both parochial and ahistorical: they were confined to assumptions about rich, western nations, and they overlooked the coming truth, then on the horizon (now a fact), that developing nations 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 global oil use through the 90s and early 2000s was led by the U.S., where 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. The modern era of fire-making, after all, still does not yet belong to a huge portion of the people in poorer nations. At the time of this writing, an estimated 1.4-1.6 human beings are living without power.(16) 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 confined to the dark.

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 a dark 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 are more complex, and undetermined, than most models or assumptions accept. "Natural sine curves" aren't able to account for, or even accurately describe, what has happened in the last half-century (indeed, I have heard that Dr. Nakicenovic has decided to disavow his original theory). Decarbonization isn't assured or predestined, at least in the near- and mid-term. Certainly, over the span of the next hundred years, we will see the return of a decarbonizing trend, probably for good. But the next 30-50 years may well prove the most crucial in terms of global pollution and climate change.

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 in the 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 1000 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. The models of Marcetti-Nakicenovic and Heffner are not a guide for them to do this, but do provide clues. Those who claim that the world can achieve a decarbonized reality in short order are grandly misleading their audience. Yet they are right about one thing. Energy use is not destiny, whether molecular or mathematical, but a result of the interaction between dynamic markets, government policy, science/ technology, and the public. If we do seek such a shift, 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 itself been an unending scene of transformation. The eras of coal and oil were themselves anything but static when traced in detail. There has never ceased to be a drive to improve existing technologies and discover new ones, plus new and more diverse applications, new capacities to do and to make. Coal began in the fireplace and the forge, but then made glass and bricks and brewed beer, each business utilizing its own type of boiler. From there it went on to power the steam engine, applied in a myriad 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 with uses for coal—or 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 provided, 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 for us a promised land of limitless power. A few possibilities—solar energy, fusion, the "hydrogen economy"—have certainly been promoted in such terms. Indeed, there is a utopian aroma that hovers around many questions routinely 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 messiah 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 crucial, yet the total portfolio making up that

95% had tripled: natural gas, nuclear power, hydroelectricity, wind power, solar energy, geothermal energy, and biofuels had all been added to the mix. Some of these sources, true enough, remained a small part of the whole—renewables (not counting hydro) still accounted for under 2% of global energy use in 2007. Yet on a nation-by-nation basis, they had become major, integrated options for many countries: geothermal power, for example, at over 15% of energy use in New Zealand, Iceland, the Philippines, Kenya; wind power supplying 7% of electricity in Germany, 10% in Spain.

Now consider land transport. As recently as 1970, only one type of car regularly trod the roadways: the gasoline engine dominated all. Today, there are diesel, flex-fuel, hybrid, all-electric, and compressed natural gas cars (many of these in India), with others like plug-in hybrids and fuel-cell vehicles, in the wings. None of the new species of auto is likely to swallow the global market whole; neither are all of them doomed to so-called "niche" buyers. It is certainly possible that some of these vehicles represent transitions: hybrids, by their very nature, may be a bridge to new types more reliant on electricity. The total variety of car types may even 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. Culture, indeed, can be a vital factor.

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…(17; p. 384).

I cite this example not to imply that Americans become Danes (or, god forbid, vice versa), but to stress 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 an expansive and highly developed welfare state. Cogeneration is a natural fit for, and also an expression of, such a society of shared services. The point is that throwing over one such system for another is not a simple matter of trading technologies, substituting machinery. It involves altering socio-economic reality. Of course it can be done—has been done, and must be done again—but it can't be achieved overnight. Think of what would be required for Denmark to switch to individualized solar heating systems.

Energy use in the past and present is cultural, and 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 advancing all other options. If tamed to lower, more controlled rates of use, with emissions greatly reduced, these sources could be vital for a very long time. Similarly, large power plants or other massive infrastructure are not, by definition, antithetical to a "greener" future. Small may be beautiful, but populations and cities are huge and growing. By 2030, over half of humanity will live in urban areas. It seems unlikely that the new mega-metropoli will be able to subsist on wind turbines 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, which cannot yet be answered. The final point that history may offer is that over-reliance on, and prophetic desire for, any single fuel or technology is likely to be all too mortal. It is our ideas that power our technology. An hourglass is fragile because so narrow at the pinch.

Notes

1. Regarding the first use of fire, see the brief article by Michael Balter, "Earliest Signs of Human-Controlled Fire Uncovered in Israel," *Science*, April 30, 2004, p. 663-664. The oldest remains of *Homo sapiens* are discussed by Ann Gibbons in this same journal. See Gibbons, Ann, "Oldest Members of *Homo Sapiens* Discovered in Africa," *Science*, June 13 2003, p. 1641.

2. Hatcher, John, 1993, *The History of the British Coal Industry, Volume 1: Before 1700, Towards the Age of Coal* (London: Oxford University Press). Galloway, Robert, 2007, *A History of Coal Mining in Great Britain*. Reprint of the original 1882 edition published by Newton Abbot (Whitefish, MT: Kessinger Publishing). Galloway, J., Keene, D., and M. Murphy, 1996, "Fueling the City: Production and Distribution of Firewood and Fuel in London's Region, 1290-1400," *Economic History Review* 49, p. 455-496.

3. Hatcher (1993), Galloway (2007). See also: TeBrake, William, 1975. "Air Pollution and Fuel Crises in Preindustrial London, 1250-1650," *Technology and Culture*, 16, p. 337-359.

4. Cardwell, Donald, 2001, *Wheels, Clocks, and Rockets: A History of Technology* (New York: Norton). Another excellent source on early steam power is Sieferle, R.P., 2001, *The Subterranean Forest: Energy Systems and the Industrial Revolution* (Conway, NH: White Horse Press).

5. This discussion of the early history of petroleum draws on two sources: Yergin, D., 1993, *The Prize: The Epic Quest for Oil, Money, and Power* (New York: Free Press); see p. 21-34. Also useful for the early history of oil exploration is Owen, E.W., 1975, *Trek of the Oil Finders* (Tulsa: American Association of Petroleum Geologists).

6. See Kimes, B.R., 2004, *Pioneers, Engineers, and Scoundrels: The Dawn of the Automobile in America* (Warrendale, PA: SAE International).

7. The designs, workings, and efficiencies of early steam pumps and engines are discussed in Derry, T.K. and T.I. Williams, 1960, *A Short History of Technology* (London: Oxford University Press).

8. These efficiency ranges have been adopted from several sources: Boyle, G., Everett, B. and J. Ramage, 2003, *Energy Systems and Sustainability* (London: Oxford University Press); Smil, V., 2008, *Energy in Nature and Society* (Cambridge, MA: MIT Press); Williams, D., 2006, "Advanced System Controls and Energy Savings for Industrial Boilers," online article published by Northeast Midwest Institute (Washington, D.C.), at: www.nemw.org/iecec98.htm .

9. While there are many discussions available that talk about efficiencies of internal combustion engines, I have drawn on the straightforward and well-illustrated example offered by the U.S. Department of Energy at http://www.fueleconomy.gov/FEG/atv.shtml

10. For an article on the Tesla Roadster, about which there has been much media interest, see the article by Keith Naughton, "An Electric Dream," *Newsweek*, October 29, 2007. Online at: http://www.newsweek.com/id/55405

11. This figure, updated through 2006, is derived from the U.S. Bureau of Transportation Statistics (Research and Innovative Technology Administration), as part of its online National Transportation Statistics report. Available at: http://www.bts.gov/publications/national_transportation_statistics/html/table_01_11.html. I have added to the total for passenger cars rough sales figures of around 16 million for 2007 and 13 million for 2008, while also considering the annual "retirement" of several million or more vehicles. S ee article by Reuters, "Toyota US new car sales unlikely to hit 14 million – report," October 3, 2008, online at: http://www.reuters.com/article/rbssConsumerGoodsAndRetailNews/idUSN0334837620081003.

12. Annual sales figures and models are published regularly by the Electric Driver Transportation Association, online at: http://www.electricdrive.org/index.php?tg=articles&topics=7

13. Marchetti, C. and N. Nakicenovic, 1979, *The Dynamics of Energy Systems and the Lgositic Substitution Model* (Laxenburg, Austria: International Institute for Applied Systems Analysis).

14. See Nakicenovic, N., 1993, *Decarbonization: Doing More with Less*. (Laxenburg, Austria: International Institute for Applied Systems Analysis). Starting about this time and continuing throughout the 1990s, the author spoke in terms of a "methane economy" that would form the essential bridge to the non-fossil future.

15. Heffner, R.A. III, 1993, *Age of Energy Gases*. Monograph published by the GHK Company (Oklahoma City, OK). Various versions and presentations of this publication are available through the GHK website: http://www.ghkco.com/publication_news/

16. IEA, 2008, *World Energy Outlook 2008* (Paris: International Energy Agency).

17. Nye, D., 1992, *Electrifying America: Social Meanings of a New Technology, 1880-1940*. (Cambridge, MA: MIT Press).