Rocky Mountain Visions: A Review Essay*

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Why should I review a book whose American edition sold out before its publication date, a book called by its dust-jacket boosters a "conceptual milestone," "the design manual for the 21st century," the wisdom of "three of the world's best brains," and "the bible" for the next industrial revolution?[1] I am not a keen book reviewer but such an astonishing lack of historical perspective and such marketing hubris devoid of any sense of proportion, emblematic as they may be of the times we live in, impel me to pen a modest essay recalling useful lessons from the past and offering cautionary observations about the present and the future.

The book introduces four central strategies of natural, as opposed to conventional, capitalism: radically increased resource productivity; biomimicry (reducing waste through recycling); service and flow economy (a shift from purchasing goods to renting services); and investing in natural capital, that is in ecosystems, in order not just to ensure the supplies of valuable goods but to sustain the provision of irreplaceable environmental services ("capitalism as if living systems mattered"). What is so stunning about these maxims? What in all of this is so paradigmatically pathbreaking, so breathtaking, that a comparison with Adam Smith came immediately to the mind of another reviewer; what is so irresistibly biblical about these visions that "come not a moment too soon" to tell us all how to live?

Those readers familiar with writings by Amory and L. Hunter Lovins will find very little here that they have not seen before. Although Paul Hawken, a businessman and the author of the "classic book" (the dust jacket, again) and the eponymous PBS series (*Growing a Business*), is listed as the first author, the book is unmistakeably the latest entry in the line of the Lovinses' grand prescriptions for paradisiacal futures. Actually, large parts of the book are simply recycled, with only slight alteration, from their re-

*Review of Paul Hawken, Amory Lovins, and L. Hunter Lovins, *Natural Capitalism: The Next Industrial Revolution*. Boston: Little, Brown and Company, 1999. xix + 396 p. $26.95.

cent writings, particularly from *Factor Four*, which the co-CEOs of the Rocky Mountain Institute (RMI) coauthored with Ernst von Weizsäcker.[2]

As a witness to Amory Lovins's transformations during the past three decades—from zealous critic of nuclear energy to militant advocate of "soft-path" energies to his most recent incarnation as a guru of corporate consulting coming to save the planet through natural capitalism—I have felt like a tourist trudging along a particularly well-worn path. That is because all the outward changes have been much less important than the underlying constants in his writings. He always writes well, and he steadfastedly advocates smarter techniques, higher efficiency, cleaner environments, and less pollution: who could disagree? In addition, there is the money—and nothing sells better to a population addicted to double-digit increases of stock market indexes than the promise to "make a lot of money on the side" while doing socially and environmentally admirable deeds.[3]

My attitude toward these visions and promises has not changed either: it has always been a mixture of strong approval on one hand and recurrent exasperation and resolute disagreement on the other—reactions potentiated by this book. Both the Lovinses and Hawken say many things with which I wholeheartedly agree; and parts of their and my writings and speeches, although informed by different backgrounds, are readily interchangeable. I share their calls for technical rationality, higher efficiency, lower environmental impacts, and more considerate farming—but I cannot foresee such easy walks and such stunning rewards in so short a time as they claim or imply. My quarrel is not with their goals but with the excessive promises, repeated exaggerations, wishful thinking, and righteous insistence that theirs is the only enlightened way.

Our fundamental differences lie in the awareness of history and in the readiness to prescribe grand solutions. I am constantly aware of the presence and importance of the past (natural for someone coming from Kafka's city), and hence I marvel how even the most "revolutionary" ideas grow so unmistakeably from tangled thickets of old thought, and how little our individual contributions matter when one looks at incremental and cumulative progress in science, engineering, and human wellbeing. And having lived for 27 years in a vassal state of the Soviet Empire has made me distrustful of any normative solutions revealed in point-by-point instruction sheets by "best brains." (Comrade Stalin, as I well recall from my grade-school days, had one too!)

De omnibus dubitandum: I may have strong preferences based on what I think is fairly good evidence—but inevitable uncertainties and ignorance make me anxious about what might go wrong and hence cautious about the course I would advocate for others to follow. I know that there are no actions without unintended consequences, that the propensity for catastrophe is conserved in every civilization, and that both as individuals and as

nations we have immense capacity for self-delusion, denial, and irrational choices in the name of rationality. And I much prefer gradual workings of evolutionary change to sweeping calls for new revolutions, no matter how sleekly merchandised they may be.[4]

In contrast, the Lovinses have never shown any qualms about prescribing for all of humanity. Theirs is a linear world where, after the break with the unbearably irrational past, *everything* will get better if only we march under their supremely rational techno-banner, which is now not merely soft and green but has a "lot of money" on the side. Just read the scenario opening the book:

> [C]ities have become peaceful and serene. . . . Living standards for all people have dramatically improved, particularly for the poor and those in developing countries. Involuntary unemployment no longer exists, and income taxes have largely been eliminated. . . . there are few if any active landfills; worldwide forest cover is increasing. . . . The frayed social nets of Western countries have been repaired. . . . A progressive and active union movement has taken the lead to work with business, environmentalists, and government. . . . Is this the vision of a utopia? In fact, the changes described here could come about in the decades to come. . . . (pp. 1–2)

Here we have no cautious reformers: our trio has perfect solutions for everything, and the cures are nearly instant. After millennia of miseries and troubles, misguided humanity has finally found its true saviors who could stick its dumb muzzle into the trough of perpetual happiness in a matter of mere decades. Of course, there is nothing new about the idea of social salvation through a technical fix, only the ingredients keep changing: in this case fuel cells and Hypercars are to become the guarantors of human contentment. Nor is it the first time energy conversions have been singled out to play such an omni-catalytic role: during the 1950s it was to be the too-cheap-to-be-metered nuclear electricity, and after the OPEC oil shocks of the 1970s we were promised rapid energy self-sufficiency and untold social rewards through wind generators on rooftops and biogas digesters in backyards.[5]

The precept of natural capitalism also resembles those earlier grand schemes because of its supposed infallibility: in the current American parlance, it has no downside. No Murphy's law stalks the trio's super-efficient nirvana, no unintended consequences will follow if the world does as they say. While many doubting, fallible agnostics wait for the accumulated evidence before venturing a verdict on complex affairs, the authors are true, unwavering believers-with-a-mission who know they are right. Often they are—often they are not, and, given the deplorable state of scientific literacy, too many people could be easily misled by their facile affirmations.

And so, leaving their opening fairy tale aside, when the authors state that "One of the keys to the most beneficial employment of people, money and the environment is radical increases in resource productivity" (p. 9), I can only respond: of course, well said—and I could have yanked out scores of such citations and displayed them approvingly. But when the book claims, citing the declaration of the Factor Ten Club, that "within one generation, nations can achieve a ten-fold increase in the efficiency with which they use energy, natural resources and other materials" (p. 11),[6] then I must respond: what a ridiculous exaggeration. Every scientist or engineer should be a professional skeptic and doubt unprecedented claims: the authors should have questioned the Factor Ten statement—not called it "prophetic."

If it were to happen, the factor ten improvement in a single generation would mean a magical disappearance of population size as a factor in economic development and in global environmental degradation. The only interesting matter would then be how to organize this miracle. Five billion people (more than four-fifths of humanity) in Asia, Africa, and Latin America now claim only about one-third of the world's resources—but wringing ten times as many useful services out of their current fuel, electricity, mineral, wood, and water consumption would make them developed by any definition: China's standard of living would be lifted above that of today's Japan; India would be better off than Argentina.

North America and the European Union, content with maintaining today's high standard of living, would have no need for 90 percent of their current resource use, a shift resulting in plummeting global commodity prices. Poor countries could then snap up these give-away commodities (capacity to produce them will not disappear) and, using them with ten times higher efficiency than they do today, they could support another 7 billion people enjoying a high standard of living—and all of this with no increase in the global use of energy and materials! Who would care if the global population total were to grow by another 2 or 3 billion before stabilizing?

The United States would consume less energy in the year 2020 than India uses today.[7] China, with nearly 1.5 billion people in 2020, could reap the world's largest food harvest by applying less fertilizer than does France today.[8] Conversely, with a constant rate of energy and material consumption, a country would have at its disposal ten times as much light, heating, cooling, and transport capacity, or it could grow ten times as much food with the same amount of fertilizers or enclose ten times as much living space with the same amount of materials.[9] The authors must know that none of this can happen in one generation. But I am not sure whether they are as ignorant of the precedents of their "four central strategies of natural capitalism" as their ahistorically exuberant "introduction" of these great principles suggests—or whether they are just resorting to a marketing hyperbole that seems to be the norm these days.

In any case, a few reminders are in order. Doing more with less is an admonition that resonates through millennia of both Western and Eastern thought. Medieval monastic orders were excellent embodiments of nearly all of the tenets of natural capitalism. All energies were soft (monks' muscles, donkeys, oxen, here and there a small waterwheel); production of all food and often also of all cloth and all wooden and metallic necessities or adornments of life was local, artisanal, and utterly decentralized. Nothing was packaged, everything was recycled, and monks owned nothing; they were merely renting the order's bleak cells, hard beds, and coarse cloth in return for copying missals, singing *a cappella*, curdling cheese, and weeding vegetables.[10]

And if they were Franciscans, then, following the precepts of their sainted founder from Assisi, they were the protectors of that most valuable of all natural capital, the biodiversity bequeathed to us by evolution: "brother wolf," ilex groves, soaring falcons, wild flowers, and "little brethren the birds" were as dear to their hearts as were lepers and beggars.[11] Ancient Romans would not be surprised: where human mores are concerned, *nihil novum sub sole*.

More recently—once the great machine of Western modernization began spinning its innovations—generations of engineers spent their professional lives wringing every bit of efficiency from their contraptions and mimicking nature in their devices and structures.[12] Entire nations, guided by the invisible hand rather than by any bibles, have been relentlessly following the path of reduced waste and higher productivity. Given the ubiquitous waste that accompanies common fuel and electricity conversions, the quest for higher energy efficiency has been the very essence of secular technical progress. Quantitative historical perspectives are sorely needed here, and I will offer just a few examples concerning energy and materials.

The best charcoal-fueled late-nineteenth-century iron blast furnaces needed only about one-tenth as much fuel as their medieval counterparts: a factor ten efficiency gain, but it took about 500 years.[13] Today's best commercial ammonia synthesis needs less than one-quarter of the energy required by BASF's first Ludwigshafen plant in 1913: factor four in less than a century.[14] While Edison's carbonized paper loops converted a mere 0.2 percent of electricity into light in his first bulbs, fluorescent tubes introduced in the late 1930s were about 7 percent efficient: factor 35 in just two generations.[15]

While energy efficiencies of animate prime movers and biomass combustion improved only slowly during antiquity and throughout the Middle Ages, impressive examples of cutting down on the use of materials and doing more with less go back more than two millennia. The Parthenon's architraves (447 BC) weigh about 2.7 t/m^3 and their free span was less than 2.5 m; the Pantheon's bricks (27 BC) and light concrete average just 1.7 t/m^3

but the building's coffered vault spans almost 44 m: a nearly 30-fold increase in mass/space spanning factor in about 400 years.[16] Again, the modern systematized quest for better performance speeded up many such rates. For example, in 1750 the iron and wood of Newcomen's steam engines weighed well above 500 grams per watt of their capacity; by 1900 iron, steel, and aluminum making up the best internal combustion engines weighed just 1 g/W: a mass decline factor of 600 in 150 years.[17]

Declines in the use of materials have been historically so large that they can be easily seen even in aggregate national statistics: when measured as mass per unit of GDP, the use of water, timber, steel, or copper in the US economy has been dropping steadily since before the Lovinses were born.[18] And what has been no less noteworthy about these trends is that the rates of decline often appear to be entirely autonomous. Perhaps most remarkably, the energy intensity of the US economy—how much energy is used per inflation-adjusted dollar of national product—fell at exactly the same compounded rate during the crisis-fraught 1930s as it did during the e.com-bewitched 1990s (about −1.2 percent per year).[19]

A book filled with such examples could be as long as *Natural Capitalism* because that potent mixture of systematized curiosity- and profit-motivated innovation has been driving human advancement particularly rapidly for the past 200–300 years. Cumulative technical and managerial innovations, incremental learning, and diffusion brought most of these improvements regardless of prevailing commodity prices, government interventions, or the presence or absence of consulting gurus—or of any epochal "introductions" by best brains. A "revolutionary strategy" of "radically increased resource productivity" formulated by the trio is in fact a key evolutionary trend of human history. That some gains within this multifaceted process are now realized faster than ever is only as expected: huge accumulating investment in our scientific understanding, instant communication of new findings, and globally fungible capital had better make some difference!

But what about the premise that traditional capitalism does not value the largest stock of the Earth's capital locked in ecosystems and in numerous services they provide? Should not this omission be fixed, as the book advocates, by taking a proper account of these costs, so that production will eventually generate little or no waste and investment will not merely sustain but also expand those precious stores of natural capital?

Once again, labels may be new—common use of the term environmental services dates only to the 1970s—but there is nothing new about advocating new accounting schemes for a better valuation of resources or about reinvesting repeatedly in natural capital. Supposedly superior accounting systems proposed during the twentieth century include Frederick Soddy's new economics; the US Technocracy of the 1930s, which was to run the world by an energy, rather than a money, standard; and Howard Odum's

EMERGY.[20] Much like natural capitalism, the first two schemes were to bring great social transformations by doing away with poverty and unemployment and by spreading affluence, while Odum's questionable concept of accounting for every good and service in terms of embodied solar energy was explicitly designed to save the biosphere.

And centuries, even millennia, of continuous production from crop fields would have been impossible without appropriate reinvestment into natural capital: every farmer who ever rotated crops or plowed straw and manure into soil to replenish its organic content and to improve its tilth and water-holding capacity has been such an investor.[21] And while tropical deforestation gets the headlines, extensive increase of forest cover in some temperate regions of the world, including eastern North America, has been curiously unreported: European increases have been particularly rapid.[22]

Since the 1950s some industrial activities have internalized their environmental burdens to a surprisingly high degree. US coal, one of the Lovinses' great villains, is a good example. Its price now includes the producers' contributions to a fund for black lung disease as well as the cost of land reclamation after the mining is over; all large power plants have electrostatic precipitators (eliminating more than 99.5 percent of particulate matter), most of them have much costlier flue gas desulfurization (SO_2 emissions have been declining since the 1970s, and those from large stations shrank by another 30 percent during the 1990s); and reductions of NO_x emissions and further controls of smaller particulates are underway.[23]

Of course I, too, would like to see thousands more environmental burdens appropriately internalized, but the task is not one of simple bureaucratic fiats: these are fascinating but exceedingly tricky matters that have no easy resolution. If, obviously, "there are some resources that no amount of money can buy" (p. 147)—and if these include nearly all of the essential functions evolved during the nearly 4 billion years of the biospheric complexification—how are we to value them in order to make businesses focus on sustaining and renewing this invaluable capital?

Even much simpler challenges are exceedingly hard. If we are to internalize the true cost of gasoline-run cars (my fervent wish), what price are we to put on additional photochemical smog–induced asthma attacks: $50 or $500 per event, the price of an emergency check-up or of a child's and parents' momentary (or even anticipated) anguish?[24] Indeed, how do we decide in the first place which shares of new attacks in particular cities are due to the smog and which to the mysteriously global higher incidence of the disease?[25] If we decide to include in gasoline's price the cost of the 1991 Gulf War and the share of the Pentagon's budget that has been spent since then on aircraft carriers and prepositioned planes and troops in Saudi Arabia and Kuwait, we must remember that the American ships, jets, and troops were, and are, in the Gulf also because Iraq was, and is, bent on

developing nuclear weapons, and that most of the Middle Eastern oil is actually bought by Europe and Japan; how do we split all that?

And if we want to burden the combustion of fossil fuels with the future possible cost of fossil fuel–induced global warming, we would face a very different discounting choice with a slow warming, say an average of 1.5 °C over a century, than with a rapid one (perhaps in excess of 3 °C in 50 years).[26] This list could go on and on—and there is no indisputable science to inform such decisions, no correct way to apportion, or to discount, the costs. Hence, do not look for a biospherically integrated price sheet stuck on the window of a new car for sale in the year 2005.

Natural Capitalism skates over such matters. Its prescribed solution is a massive taxation of everything the authors consider a burden on the environment: all electricity nonrenewably generated, all fossil fuels, chlorine, air traffic, all roads, pesticides, synthetic fertilizers, piped-in water, timber, all wastes. "Thermal insulation and superwindows in such a world will have a bigger payout than Microsoft stock. You will be able to make Warren Buffet[t] returns by simple investment in hardware-store technologies" (p. 167). The book says nothing about who will decide what the levels of these myriads of taxes will be, and how one can impose them globally to save the biosphere. If China, the world's largest CO_2 emitter from coal combustion, will not tax its coal why should Japan tax its much cleaner natural gas; if Indonesia will burn all of its immense and rich biodiversity, then how futile to protect a tiny patch of poor Mediterranean scrubland.

And what about those people who cannot do without such "evils" as piped water and synthetic fertilizers? The book advocates gathering rain water from roofs to giant vats (as a certain doctor does in Austin, Texas), and it implies that we can be fed from organic farming. How does one replicate that gathering feat as a tenant on the fifteenth floor of a Hong Kong or Osaka housing estate? And, yes, heavy taxes on nitrogen fertilizers may dramatically reduce their application in Iowa—and overweight Americans may simply have less corn to feed their steer and pigs and hence, perhaps, a less meaty diet and actually be better for it.

But without synthetic nitrogen fertilizers China could feed only half its current 1.25 billion people, and while savings in nitrogen applications are both possible and highly desirable, we can never make their use 90 percent efficient. No factor of ten here. Contrary to what the authors imply, biospheric cycles operate with considerable unavoidable inefficiencies. The bacteria-run nitrogen cycle is particularly leaky because of natural nitrification, leaching, denitrification, and volatilization, and were the Chinese to boost the element's average uptake efficiency by 50 percent (from almost 50 percent to 75 percent) they would do exceedingly well.[27]

Natural Capitalism also propagates two standard modes of Lovinsian discourse: toss out a quotable, captivating sentence, deduce an epochal con-

sequence from it, and move on to another sound bite; or make a sweeping proposal and declare that it can be turned easily into reality, without acknowledging much evidence to the contrary. Over the years many engineers, scientists, and economists have been exasperated by this peculiar kind of discourse-by-declaration. Two glaring examples from the book suffice.

"Some 15 percent of global food is already grown in cities. In China, urban farming in back gardens, on little plots, and on rooftops provides 85-plus percent of urban vegetables—more in Beijing and Shanghai—plus large amounts of meat and treecrops" (p. 200). This is patent nonsense. Growing 15 percent of the world's food in cities would be equivalent to harvesting about 400 million tons of grain, or almost 20 percent more than the entire US cereal crop.[28] Even assuming, wrongly, that all of the world's vegetables would be grown in suburban fields (obviously not the same as "in cities"), the proportion would be a mere 2 percent.[29] Moreover, by saying "already" the authors seem to imply that this preposterously high share might grow, while in reality the periurban yields are increasingly endangered by high levels of ozone generated by photochemical smog.[30]

"By now, most readers are probably wondering why, if such big energy savings are both feasible and profitable, they haven't all been exploited" (p. 254). Readers would wonder less if they were told about the extensive economic and technical literature which shows that people are often not interested in mundane energy conservation because they have an excessive demand on the rate of return,[31] and which also demonstrates that achieved savings are commonly much more modest than initially believed. For example, the true costs of utility-subsidized electricity conservation are often significantly higher than the costs reported by utilities and these costs, in turn, are much higher than those suggested by the technical potential totals cited by the Lovinses.[32] Moreover, a great deal of evidence shows that energy efficiency does not necessarily save energy.[33]

But this has long been the RMI practice: while they keep preaching the gospel of the super-efficient world, many devotees of efficiency and optimization know that in many cases gaps between technical potential and actually accepted, durable, and reliable everyday performance will not be maximally narrowed because of often-unanticipated technical glitches, social inertia, basic human inconsistency, and personal priorities and preoccupations.

And if all of this is about "making sense, making money" (to use the title of Norman Myers's review of *Natural Capitalism* in *Nature*[34]), why are people not making sense and money right now? They are surely free to do so, for example, without having to wait for the appearance of customized Hypercars ordered by e-mail (so-called ultra-light hybrids, promised for 2005 or so). They could have been making money by virtue of the much lower capital, fuel, and maintenance costs of driving Honda Civics, rather than

Chevy Suburbans, ever since those little, frugal, nimble vehicles appeared in the mid-1970s.

Instead, people vastly prefer those monstrous trucks and vans and "sport-utility" machines costing commonly twice as much but being less than half as fuel-efficient as Civics: here we have the factor four in reverse, alive and well at every intersection in North America. Opportunities for savings are always there, always potentially large, but they are not taken for any number of reasons, not least because people are neither predictably nor consistently rational.

How should I close this essay? Nothing is so salutary when looking ahead as taking a look back. In 1976 Amory Lovins published his signature piece in *Foreign Affairs*, in which he argued for an accelerated demise of centralized energy production and for the takeover of the world energy supply by soft—that is, decentralized, small, and renewable—conversions.[35] Two years later, in a follow-up review, he plotted two very similar graph lines predicting fractional market penetration of these soft techniques in the US commercial energy market and concluded that their slope "does not appear unreasonably steep in view of the simplicity, short lead times, and diversity" of soft conversions.[36]

Those lines predicted that in the year 2000 the United States would draw about 35 percent of its commercial energy from soft energies. Another two years later, in 1980, I listened, both bemused and irked, when at an international energy conference the Lovinses concluded their sales sermon about the inevitability of soft energies during the coming generation by saying: "It must be that way."[37] The year 2000 is here, and renewable energies supply about 7.5 percent of US primary energy. But half of this is hydroelectricity generated by water compounded by large dams, definitely no species of small, decentralized soft-energy production.[38] Biomass (mostly combustion of wood waste by lumber and pulp and paper industries and some fuel alcohol), wind, and solar energy provide just over 3 percent of all US energy use, or about one-tenth of Amory Lovins's "not unreasonable" projection. Being off by more than 90 percent—factor ten in reverse—hardly qualifies as a triumphant vision of an inevitable future.

The world does not run by blueprints, not even if they come with soothing qualifiers of "soft" or "natural." The world does not follow any prescribed linear path, and taxation of everything is surely not salvation of everything. The world of impressively higher efficiency may actually be, as is ours today compared to the one of a millennium or a century ago, one of much greater waste: unintended consequences are not eliminated by wishful thinking.

The US economy, we are told, should simply rid itself of $2 trillion of waste that is "a built-in feature of an outmoded industrial system." The trio provides a long list of things to be eliminated, ranging from hidden social

costs of driving, guarding sea lanes bringing oil, and bad dietary choices, to current insurance systems, illegal drugs, lawsuits, complex tax codes, and all government waste. The list reads like part of a naive sermon: humanity shedding its cherished modern vices just because the three supremely rational utopians tell it to do so. Too bad that we are not told how the trio will make society virtuous within a generation when countless religious visionaries, social and economic reformers, and political dictators (from benevolent to brutal) have failed to prevent or eliminate even lesser vices throughout recorded history. Unrevealed modalities of this great purge aside, would not ridding the country of nearly a third of its gross domestic product in a matter of years have some very far-reaching side effects, including many unforeseeable and unpleasant consequences?

And so to you, younger readers—who, after finishing *Natural Capitalism*, are eagerly anticipating a world filled with gas-reforming plants at every wellhead so the continent could be flooded with hydrogen-feeding myriads of silent fuel cells, where only healthy food choices come from bucolic roof patches that use no synthetic fertilizer, where nobody sues anybody else for the sake of maximized efficiency, where factories that produce Wal-Mart junk ooze no waste, where government does not waste a penny, and where super-sleek F-16-like indestructible composite-fiber hypercars (sorry, Hypercars™, or I'd get sued) that weigh less than you do, create no environmental burdens and act like power plants while you sleep—my only counsel is: beware! Turning once more to those durable Romans, I will quote Pliny the Younger who, writing nineteen centuries ago, put it best: "It is better to believe the world than individuals. For individuals can deceive and be deceived, whereas no one ever fooled the world."

Notes

1 All quotes from the book's dust jacket.

2 Ernst von Weizsäcker, Amory B. Lovins, and L. Hunter Lovins, *Factor Four: Doubling Wealth, Halving Resource Use* (London: Earthscan, 1997). This collection of examples of more-efficient economic activities, although still too wide-eyed, is much more realistic than the new book. For more on *Factor Four*, see Vaclav Smil, "Nature's services, human follies: A review essay," *Population and Development Review* 24 (1998):613–623.

3 The quote comes from President Clinton's speech to a Democratic National Committee dinner: ". . . if you read it, you will be convinced that whatever you're doing and however well you're doing it, you could make a lot of money on the side by getting into alternative sources of energy and energy conservation. This is a huge deal." Cited in: "Nat Cap *Buzz*," *Rocky Mountain Institute Newsletter* 15 (Fall 1999): 3.

4 On closer examination it turns out that few technical revolutions are worthy of that term. Certainly not the Neolithic Revolution, although school children will probably be brainwashed forever with Gordon Childe's mistaken idea that our species transformed itself in a matter of a few generations from gatherers to farmers. Overwhelming archaeological evidence reveals instead the evolutionary character of the change and a prolonged coexistence of the two modes of subsistence.

And definitely not the Industrial Revolution, which, too, was a complex, protracted affair rather than a rapid shift of economic forces. For example, almost all of England's coalfields operating in 1900 were opened up between 1540 and 1640; and the country still had more shoemakers than coal miners, and more blacksmiths than ironworkers in 1851: R. Cameron, "A new view of European industrialization," *The Economic History Review* 38 (1985): 1–23.

5 Hopes pinned on decentralized, small-scale, renewable energy conversions during the 1970s owed a great deal to an uncritical countercultural embrace of Schumacher's dubious advocacy of worth measured by size: E. F. Schumacher, *Small Is Beautiful: Economics as if People Mattered* (New York: Harper & Row, 1973). Amory Lovins's labeling of such conversions as soft, a thoroughly misleading but very captivating term (after all, it is the marketing, not the substance that sells!), and his vastly exaggerated claims for the speed of their commercial penetration, only raised more false hopes. For a contemporaneous critique of this small-is-beautiful renewable "solution" see Vaclav Smil, "Renewable energies: How much and how renewable?" *The Bulletin of the Atomic Scientists* 35(1979): 12–19. For a recent review of renewable energy performance in the United States, see Robert L. Bradley, Jr., *Renewable Energy: Not Cheap, Not "Green"* (Washington, DC: Cato Institute, 1997).

6 A group of 16 scientists, economists, government officials, and business people from Europe, the United States, Japan, Canada, and India convened in Carnoules, France in 1994 "to discuss their belief that human activities were at risk from the ecological and social impact of materials and energy use" (p. 11). The Factor Ten Club, as the participants called themselves, issued a declaration that contained the claim just quoted.

7 The United States consumed energy equal to about 2.3 billion tons of oil in 1999, or 8.5 t/capita; India used 300 million tons: British Petroleum Amoco, *Statistical Review of World Energy 1999* (London: BP Amoco, 2000) >http://www.bpamoco.com/worldenergy<

8 In 1997 China applied 23.6 million tons of nitrogen in synthetic compounds, France 2.3 million tons: Food and Agriculture Organization, *FAOSTAT Agriculture Data* (Rome: FAO, 2000) >http://apps.fao.org<

9 Of course, a brand new super-efficient building can easily use less than one-tenth the energy of an old, shoddily built structure—but a country's entire building inventory will not be replaced or retrofitted, or plastered over with photovoltaic collectors, in two decades. Similar limits to structural shifts are true for transportation and, given the fact that energy use in many processes is nearing thermodynamic limits, also for some sectors of industrial production.

10 And medieval monasticism's quest for self-sufficiency made important contributions to innovations that eventually resulted in Western technical supremacy: Lynn Townsend White, *Medieval Religion and Technology: Collected Essays* (Berkeley, CA: University of California Press, 1978); George Basalla, *The Evolution of Technology* (Cambridge: Cambridge University Press, 1988).

11 Roger D. Sorrell, *St. Francis of Assisi and Nature: Tradition and Innovation in Western Christian Attitudes toward the Environment* (New York: Oxford University Press, 1988).

12 Among many fascinating accounts of this quest in different industries I would particularly recommend those dealing with the early history of commercial electricity: David E. Nye, *Electrifying America: Social Meanings of a New Technology, 1880–1940* (Cambridge, MA: The MIT Press, 1990); Margaret Cheney, *Tesla, Man Out of Time* (Englewood Cliffs, NJ: Prentice-Hall, 1981); Matthew Josephson, *Edison: A Biography* (New York: McGraw-Hill, 1959).

13 And coke-fueled blast furnaces have become even more efficient even faster: their energy consumption is now about 1/15 of what it was in 1800: Vaclav Smil, *Energy in World History* (Boulder, CO: Westview Press, 1994), p. 180.

14 Vaclav Smil, *Greening the Earth* (Cambridge, MA: The MIT Press, 2000).

15 See Smil, cited in note 13, p. 231.

16 The Parthenon is marble from Pentelikon. The Pantheon is a bold, beautiful, and clever combination of bricks and concrete (perhaps the greatest of Roman material inventions)—and the concrete gets lighter (made with tufa, travertine limestone, and pumice) as the coffered vault converges on the stunning central eye. Too few people realize that

this span was never surpassed by preindustrial builders: Michelangelo's double dome of San Pietro spans 41.75 m, Brunelleschi's Santa Maria del Fiore just a smidgen over 42 m.

17 And today's best gas turbines have carried this declining mass/power trend by yet another order of magnitude since the late 1930s: Smil, cited in note 13, pp. 177 and 231.

18 Iddo K. Wernick and Jesse H. Ausubel, "National materials flows and the environment," *Annual Review of Energy and the Environment* 20 (1995): 463–492. Of course, the use of silicon, aluminum, titanium, and plastics has been rising.

19 Calculated from data in Sam H. Schurr and Bruce C. Netschert, *Energy in the American Economy 1850–1975: An Economic Study of Its History and Prospects* (Baltimore, MD: Johns Hopkins University Press, 1960); Angus Maddison, *Monitoring the World Economy, 1820–1992* (Paris: OECD, 1995); US Energy Information Administration, *Annual Energy Review 1999* (Washington, DC: EIA, 2000). That rate of sustained decline would save about 20 percent of energy use in one generation, far less than the "prophetic" 90 percent drop endorsed by the trio.

20 Juan Martínez-Alier, *Ecological Economics: Energy, Environment, and Society* (Oxford: Basil Blackwell, 1987); Frederick Soddy, *Wealth, Virtual Wealth and Debt: The Solution of the Economic Paradox* (London: Allen & Unwin, 1933); Technocracy, Inc., *The Energy Certificate* (Savannah, OH: Technocracy, Inc., 1938); Howard T. Odum, *Environmental Accounting: EMERGY and Environmental Decision Making* (New York: John Wiley, 1996).

21 Continuing importance of this practice is described in Vaclav Smil, "Crop residues: Agriculture's largest harvest," *BioScience* 49 (1999): 299–308.

22 Since 1960 the area of European forests grew by about 12 percent, and the French total was up by almost 30 percent, impressive gains in just two generations: FAO, cited in note 8.

23 Robert L. Bradley, Jr., *The Increasing Sustainability of Conventional Energy* (Washington, DC: Cato Institute, 1999); US Energy Information Administration, cited in note 19.

24 One example of this challenge is that various assumptions in estimating annual mortality and morbidity benefits from meeting the air quality standards in the Los Angeles Basin ended up with totals ranging from as little as $2.4 billion to as much $20 billion: J. V. Hall et al., "Valuing the health benefits of clean air," *Science* 255 (1992): 812–816. Clearly, an order-of-magnitude difference provides a poor guide for good public policy.

25 Among recent reports see W. O. C. M. Cookson and M. F. Moffatt, "Asthma: An epidemic in the absence of infection?" *Science* 275 (1997): 41–42.

26 For the latest published consensus range offered by the Intergovernmental Panel on Climate Change see *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change* (New York: Cambridge University Press, 1996).

27 The authors appear to be entirely ignorant of the fundamental role of synthetic nitrogen fertilizers in the very existence of at least one-third of humanity: see Smil, cited in note 14, and for a shorter exposé: Vaclav Smil, "Population growth and nitrogen: An exploration of a critical existential link," *Population and Development Review* 17 (1991): 569–601. Nor do the authors appreciate a large land-sparing effect of synthetic fertilizers: without them all densely populated countries would have to cultivate much larger areas of land, further reducing their biodiversity: Dennis T. Avery, "Saving nature's legacy through better farming," *Issues in Science and Technology* 14 (1997): 59–64.

28 Total global food harvest is now about 2.8 billion tons of dry matter in cereals, leguminous and sugar crops, tubers, fruits, and vegetables; cereals account for about two-thirds: FAO, cited in note 8.

29 Global vegetable harvest is now about 60 million (dry matter) tons a year: FAO, cited in note 8. Next time I am in Beijing I must correct my oversight of many trips over the past 20 years and find those rooftop gardens producing plenty of food.

30 William L. Chameides et al., "Growth of continental-scale metro-agro-plexes, regional ozone pollution, and world food production," *Science* 264 (1994): 74–77.

31 "Money to burn," *The Economist*, 6 January 1990, p. 65.

32 Paul L. Joskow and Donald B. Marron, "What does a negawatt really cost? Evidence from utility conservation programs," *The Energy Journal* 13 (1992): 41–74.

33 One of the best recent reviews of this topic is Horace Herring, *Does Energy Efficiency Save Energy? The Economists Debate* (Milton Keynes: The Open University, 1998). Also available at >http://www-tec.open.ac.uk/eeru<

34 Norman Myers, "Making sense, making money," *Nature* 402 (1999): 13–14.

35 Amory B. Lovins, "Energy strategy: The road not taken?" *Foreign Affairs* 55 (1976): 65–96.

36 Amory B. Lovins, "Soft energy technologies," *Annual Review of Energy* 3 (1978): 477–517.

37 For a printed version of that presentation see Amory B. Lovins and L. Hunter Lovins, "If I had a hammer," in Robert A. Bohm et al. (eds.), *World Energy Production and Productivity: Proceedings of the International Energy Symposium* (Cambridge, MA: Ballinger Publishing, 1981), pp. 123–146. For my brief response in the same volume see pp. 151–152.

38 US Energy Information Administration, cited in note 19.