Energy in the 21st Century

Excerpts from Post Carbon Institute's Energy Primer[1]

We are now facing a transformational moment in our energy story. As we leave the age of seemingly cheap and plentiful fossil fuels and enter an era of extreme energy, the ever-rising financial, social, and environmental costs of fossil fuels can no longer be ignored. The essential problem is not just that we are tapping the wrong energy sources (though we are), or that we are wasteful and inefficient (though we are), but that we are overpowered, and we are overpowering nature.

– Richard Heinberg, from the Introduction to ENERGY: Overdevelopment and the Delusion of Endless Growth

The Energy Picture

In order to make the right choices and investments, we must have a more comprehensive understanding of our energy predicament, including:

- The true costs, potential benefits, and limitations of all energy options, including renewables;
- The impact of each form of energy production on human societies and nature; and
- The true relationship between energy, our economic system, and the environment.

It's tempting to take the micro-view and look for ways to target each of our energy problems with a technical fix. Can't we improve the energy efficiency of vehicles, insulate our buildings, and develop renewable energy sources? Yes, of course. Can't we regulate the fossil fuel industry better, and allow the vast, recently unlocked North American reserves of shale gas and shale oil to be produced responsibly? Possibly. We could do all of those things, and many more besides, to lessen the current energy economy's impacts on natural and human communities—and still there would remain serious obstacles ahead. Why? Let's move out from the details of our dilemma and take in the big picture.

What is Energy?

Though we cannot hold a jar of pure energy in our hands or describe its shape or color, it is nevertheless the basis of everything. Without energy, nothing could happen; matter itself could not exist in any meaningful sense. But because energy as such is so elusive, physicists and engineers define it not in terms of what it is, but what it does—as "the ability to do work," or "the capacity to move or change matter."

In traditional societies, most useful energy came from the sunlight annually captured by food crops and forests; people exerted energy through muscle power and obtained heat from firewood. Modern industrial societies obtain enormously greater amounts of energy from fossil fuels, nuclear power, and hydroelectric dams, and they exert energy through a vast array of machinery. Industrial energy

[1] http://energy-reality.org/primer/

production is essential to every aspect of modern life, but no matter how far our technology for capturing or using energy advances, energy itself always remains the same.

In the nineteenth century, physicists formulated two fundamental laws of energy that appear to be true for all times and places. These are known as the First and Second Laws of Thermodynamics. The First Law is known as the law of conservation. It states that energy cannot be created or destroyed, only transformed. Think of energy as a singular reality that manifests itself in various forms—nuclear, mechanical, chemical, thermal, electromagnetic, and gravitational—and that can be converted from one form to another.

The Second Law states that in every energy conversion, some energy is dissipated (typically as heat). When the gas gauge in a car moves from “full” to “empty,” it may appear that the energy that is chemically stored in gasoline is being consumed. But all the energy that was originally present in the gasoline still exists. In reality, the stored energy is merely being released and doing some work as it moves from a condition of higher concentration to one of lower concentration. It is converted from chemical storage (via the atomic electromagnetic bonds within hydrocarbon molecules) to mechanical motion and heat (as combustion within the engine’s cylinders pushes the car forward and also increases the rate of motion of molecules in the cylinder and the surrounding environment).

We might be able to get some work out of the “wasted” heat being given off by the burning of gasoline in the car engine; but heat tends to radiate quickly into the general environment, so we would have to use that heat both immediately and close to the engine. If we could gather up all the heat and mechanical energy that was released by burning the tankful of gasoline, it could do just as much work for us yet again; but the act of re-concentrating and storing it would require more energy than we could regather. Thus, in effect, available energy is always being lost.

The Second Law is known as the law of entropy (entropy is a measure of the amount of energy no longer practically capable of conversion into work). The Second Law tells us that the entropy within an isolated system inevitably increases over time. Energy that is sufficiently concentrated (relative to background energy levels) so that it can do work for us is called a source. There are two kinds of energy sources: flows (examples include sunlight, winds, and rivers) and stocks (a word that in this context refers to energy chemically stored in substances such as wood or fossil fuels). Flows tend to be variable, whereas stocks deplete.

Energy-fueled Population Growth

Humanity’s current population explosion is an aberration. During the vast majority of human history, population levels were low and quite stable. Demographer Joel Cohen estimates that from the time our species emerged until roughly twelve thousand years ago, when local agriculture appeared, the population growth rate was less than 1/500th of 1 percent. After the widespread adoption of farming the growth rate ticked up by a factor of ten or more, but for thousands of years thereafter remained at around 1/50th of 1 percent. It took all of human history until the early eighteen hundreds for global population to reach one billion. Then the population doubled—a second billon was added—in just a century or so. Adding the next billion humans to the planet took only thirty years. The next billion, fourteen years. The next, twelve years. After another dozen years, in 1999, world population reached six billion, and the seven billion mark was passed in 2011.

When charted graphically, the human demographic explosion takes the familiar "hockey stick" shape of a classic exponential growth curve. Many factors contributed to demographic expansion, including: the global agricultural revolution in the sixteen hundreds when new foods were shared between continents; the dispersal of scientific and public health knowledge; and increasing urbanization. But central to the runaway population growth of the past two centuries is the incredible windfall of energy that fossil fuels presented to humanity. The ability to command energy, especially highly energy-dense fuels like coal, precipitated the Industrial Revolution and allowed its descendant, the techno-industrial growth culture, to flourish. Food could now be produced in far larger quantities, and local scarcity could be overcome through global transport networks.

Leading ecologists agree that humanity has already surpassed Earth's ecological carrying capacity. Exploiting the onetime reserve of fossil energy has allowed us to temporarily escape the constraints that kept early human population levels in check. Today's global extinction crisis, massive poverty and malnutrition, rising social inequity, and unraveling ecosystems around the globe suggest that the age of abundance is nearly over. As economist Lisi Krall tells her students, "The defining fact of this historical moment is the reality of exponential growth. With exponential growth, if you do the same things as your parents, you'll get entirely different results." Confronting the population problem is the preeminent challenge of our time.

Net Energy

A business may have high gross receipts and still go broke; it is the net, the profit after costs are subtracted, that determines viability. For any potential energy resource, the fundamentals are the same. How much energy is available after subtracting the energy costs to extract, process, and deliver the resource? To know how much energy from a particular source can actually be deployed by society, we must factor in both the production costs and the system costs—that is, the energy required to make energy available to the end user. With gasoline, for instance, this calculation would include energy costs related to oil exploration, drilling, refining, transportation, and the infrastructure that supports each step of the process. With coal-derived electricity, the calculation would include the life cycle from mine to power plant to electric grid.

Experts who study this use the terms "net energy ratio" or "energy returned on energy invested" (EROEI). Decades ago when the most accessible reserves were drilled, an oil company might produce 100 barrels of oil or more for each barrel's worth of energy invested. Declining oil field productivity has brought the average net energy ratio for conventional oil down to approximately 20:1 globally, with more remote or hard-to-refine oil significantly worse. For fossil energy generally, the trend is downward despite technological advances in exploration and drilling. For biofuels, the net energy ratio is lower still. Some studies suggest that corn-derived ethanol actually has a negative net energy ratio—that is, more energy than a gallon of ethanol can deliver is used to produce a gallon of ethanol. Sugarcane-based ethanol has a superior net energy ratio, but it is still low compared to fossil fuels.

Any produced energy resource can be analyzed for its net energy ratio, although the process raises a difficult question: What are the boundaries of consideration? For example, when tallying the energy required to build a solar photovoltaic panel, what should be included in the accounting? The energy needed to mine the bauxite for the aluminum frame? The energy needed to manufacture the heavy equipment that did the mining? The energy needed to construct the factory that produced the panel? Where the boundaries are drawn affects the final net energy ratios.

A society that depends on inexpensive energy to maintain a high standard of living and constant growth faces a predicament—it cannot maintain itself over the long run without high net energy fuels. Oil, natural gas, and coal have provided a huge, high-quality energy subsidy to the modern world. That subsidy, which has enabled human population and wealth to grow exponentially, is based on finite resources and cannot continue indefinitely. Renewable energy sources, excluding hydropower, are generally more diffuse and have lower net energy ratios than fossil fuels. If high net energy sources are in decline, and no reasonable replacements are available, the result may be a painful restructuring as society rearranges economic activity to fit a diminishing energy supply.

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Energy-fueled Economic Growth

World economic activity has historically grown slowly. From the Middle Ages to until the early eighteen hundreds, average per capita income rose only about 50 percent. But since the advent of the Industrial Revolution the pace has picked up, with global per capita income rising more than eightfold in just the last two hundred years.

Energy consumption has also risen dramatically, from under 20 gigajoules (GJ)[2] per person per year in the pre-industrial era to over 75 GJ per person today (and more than 300 GJ per person in the United States). During this period, energy consumption and economic activity have stoked each other in a self-reinforcing feedback loop. Once the fossil fuel tap was opened for the modern world in eighteenth-century Britain, the high-energy content of coal (and, later, oil) enabled unprecedented productivity—spurring more consumption, more demand for energy, and better technology to get at yet more fossil fuels.

Despite the clear link between energy and economic growth, economists have interpreted and normalized growth as resulting from factors such as “market efficiency” and “labor productivity,” which

[2] One joule is defined as the work required to produce one watt of power for one second. A gigajoule is a billion joules

(it is assumed) can be counted upon to produce more and more growth, ad infinitum. Policy makers have therefore built dependence on growth into the design of our economic system. Investors demand constant growth and high rates of return. Future growth is assumed to wipe away the debts taken on today by governments, businesses, and households. Most Americans are even betting their retirement savings, sitting in mutual funds on Wall Street, on continued growth.

As the global bonanza of cheap fossil fuels winds down, what will happen to economic growth? Certainly it's possible to get more benefit per joule through smarter use of energy, but using energy efficiency to "decouple" economic growth from energy consumption can only go so far. After the easy efficiencies are found, further efficiency measures often require greater cost for less benefit; and while greater efficiency may reduce costs at first, it can have the effect of spurring yet more consumption.

It's intuitively clear that it takes energy to do things, and modern civilization has exploited high-energy-content fossil fuels to dramatically reshape the living conditions and experiences of billions of people. (Altering the climate and destroying natural ecosystems around the globe were unintended consequences.) In the future, humanity will need to cope with both more expensive energy and less energy available per capita. Maintaining an acceptable level of productivity—let alone growth—may constitute one of society's foremost social, political, technical, and economic challenges.

Energy Density

Different fuels contain more or less potential energy per unit of weight or volume, and even within fuel types, such as wood or coal, the heat value varies. Anthracite packs more energy than bituminous coal, and putting oak rather than pine in the woodstove before bedtime makes a big difference in how warm the house will feel on a winter morning. The fossil fuel age has been such a bonanza because oil and coal are extremely energy-dense fuels. They have benefited from the long work of geological processes to concentrate the carbon molecules from ancient plant and animal matter.

On average, coal has approximately twice the energy density of wood. Liquid fuels refined from petroleum including gasoline, kerosene, diesel, and heating oil all contain more than three times the energy value of wood. It is no accident that when human societies have had the opportunity to transition from locally harvested biomass to concentrated fossil energy fuels they have chosen to do so.

The miraculous quality of fossil fuel energy density is easy to understand if one imagines trying to push an automobile for twenty miles. Given enough time, and some help from athletic friends, it would be possible to push a 3,000-pound car that distance. But it would require a tremendous amount of effort. And yet a mere gallon of gasoline (which, despite recent price increases, still costs far less in the United States than an equivalent amount of good coffee) can easily power a car that far in the time it takes to drink a mocha latte. The fact that renewable energy is, in general, more diffuse than fossil fuel presents the primary challenge to transitioning from the current energy economy to a renewables-powered future.

Peak Oil and Resource Depletion

Every individual gas or oil well, every oil field, and every oil-producing country experiences a similar lifecycle. After a well is drilled, extraction ramps up to its maximum sustained output and eventually begins to decline as the reservoir is depleted. Then we search for the next well, which is generally a little harder to find, a little more expensive to produce. The price of any fossil energy determines what reserves are economically recoverable, and technological innovations can temporarily reverse the decline or extend well life. But as with any finite, nonrenewable resource—coal, natural gas, uranium, etc.—depletion is inevitable at some point.

In recent years, a large body of literature has begun exploring the many ramifications of "peak oil"—the moment when aggregate global oil production reaches its apex. The late American geologist M. King Hubbert predicted in the mid-1950s that U.S. oil production would reach the top of its production curve around 1970 and then begin to decline. That assessment was remarkably prescient: America's production of crude did peak in 1970 and has been generally declining since, despite the addition of new sources on the Alaska North Slope and in the Gulf of Mexico. The United States, the first great power of the oil age, was also the first nation to explore, exploit, and begin to deplete its conventional oil reserves.

Oil of course is a global commodity. From a global perspective, reaching Hubbert's peak means that roughly half of the world's total oil resources are still in the ground, waiting to be tapped. Practically, however, the second half of the global oil resource is more difficult to access, making it less profitable (in terms of net energy) and more environmentally destructive than the earlier-exploited reserves.

The exact timing of the global oil production peak will only be recognizable in hindsight. Some energy experts predict that the peak will occur sometime during the first two decades of the twenty-first century. Others project continued growth in oil extraction through 2050. Based on data published by the International Energy Agency, global conventional oil production has been essentially flat since 2004, despite record-high prices, and likely peaked in 2006. Increased production of unconventional oil (deepwater oil, tar sands, oil shale, and shale oil) is officially projected to help meet growth in demand in the near future, but some energy experts insist that new production from these sources will be unable to make up for accelerating declines in production from conventional oil fields. Whether peak oil has occurred, is imminent, or remains years or decades off makes little difference to the salient fact: The era of abundant, inexpensive oil is closing, and all the systems for modern life designed around that earlier reality are bound to be affected.

Embodied Energy

Every material artifact—a carrot bought at the grocery store, the cooler where it was displayed, the supermarket building, the car driven there, and the road network it travels—requires a certain amount of energy in its manufacture, maintenance, and eventual disposal. The methods used to analyze the total embodied energy of manufactured objects vary, but in general, studies over the decades have used life-cycle analysis to quantify embodied energy in computers, household appliances, automobiles, and other common products.

The embodied energy in our physical infrastructure—from water mains and buildings to superhighways and airports—is immense, and thus infrastructure is one of the most important areas where energy use (and associated greenhouse gas pollution) could be reduced. In addition to building smaller, or building less, we can also build differently. Wood, for example, has the lowest embodied energy of common building materials; plastic has approximately six times as much embodied energy by weight, glass 16 times as much, steel 24 times as much, and aluminum a whopping 126 times as much embodied energy as wood. Erecting the scaffolding of civilization took a great deal of energy, and maintaining and expanding it takes more all the time. This vast amount of embodied energy, along with psychological and financial investments in the current energy distribution system, is a key obstacle to fundamental changes in that system.

Another useful metaphor that communicates the idea of embodied energy across a product's life cycle is the "energy train." Take for example that ubiquitous artifact of modern civilization, the mobile phone. To its owner, a cell phone is simply a handy gadget that offers convenience and a feeling of connection. But the phone does not exist in isolation—it isn't a single locomotive chugging down the tracks; rather, it pulls a train of cars behind it, all of which have ecological and energetic costs. Those metaphorical railroad cars are filled with packaging to ship the phone; an advertising industry to inculcate desire for it; a retail store to sell it; a communications network that allows it to function; an assembly plant to build it; factories to manufacture plastic cases and computer chips and other components; mines where copper, silver, and rare earth elements are dug from the ground; the transportation infrastructure to move raw materials; and of course the energy system (oil wells, coal mines, power plants, hydroelectric dams, etc.) that support the entire operation. It is a very long train, and every car being pulled along must be in place for even one mobile phone to make its first call.

Energy Sprawl

The foremost criterion by which to judge any existing or potential energy source is its systemic ecological impact. A key subset of this analysis is its physical footprint. The useful term "energy sprawl" refers to the ever-increasing area—on land and offshore—that is devoted to energy production. Quantifying the area affected by different energy sources raises challenging methodological questions. It's obvious, for instance, to take into account the drilling pad when considering the energy sprawl impact of oil and gas development. But one should also include the land affected by pipelines, access roads, refining facilities, and other related infrastructure in the calculation. Nuclear power plants occupy a small area relative to their electrical generation output, the smallest physical footprint of any major energy source. That energy sprawl impact grows considerably, however, when one factors in uranium prospecting, mining, processing, nuclear waste disposal, and any new power lines needed for an expanded nuclear industry. Moreover, as past accidents have demonstrated, when nuclear power plants fail, a large area can be contaminated.

Because of their high energy densities, coal, oil, and natural gas have a medium-size footprint if judged on an energy-output-per-acre ratio; but in practice these extractive industries affect a huge and growing area because they dominate energy production, and because of the enormous quantities of energy being consumed. Oil shale development in the American West is a potential area of fossil fuel exploitation that would create massive energy sprawl. Renewables, which harness the diffuse energy sources of wind and solar power, can have a large physical footprint relative to energy produced; they constitute such a small part of the current energy mix in North America that their aggregate energy sprawl impact at present is modest but growing. Because wind turbines require minimum spacing distances to maximize wind energy capture, the physical footprint of wind power is extensive but can be mitigated, whereas decapitated mountains in Appalachia sacrificed for surface coal mining will never grow back. Siting wind turbines in existing agricultural landscapes need not fragment any additional wildlife habitat. Putting solar arrays on rooftops, parking lots, and urban brownfields need not contribute to energy sprawl at all while generating significant energy close to where it is needed, eliminating the sprawl precipitated by new transmission lines.

Devoting land to growing feedstock for liquid biofuels, or growing biomass for generating electricity, augurs the greatest potential energy sprawl of the major energy alternatives under discussion. The energy density of these fuels is low and the amount of land that must be effectively industrialized, even for relatively small quantities of biofuels or biomass-derived electricity, is massive. In the end, the most effective strategy for fighting energy sprawl is to reduce energy consumption.

Energy Slaves

During the vast majority of our species' history, work was done by human muscles (sometimes the muscles of human beings enslaved by others). After people learned to domesticate wild creatures, beasts of burden such as oxen and horses added to our ability to harness the Sun's energy—captured by plants and channeled into the muscles of work animals. (This relationship between domestic animals and the machines we use today is enshrined in the "horsepower" rating of modern engines.) More recently, people began using wind and waterpower to amplify human labor. But with the dawn of the fossil fuel age, the average person was able to command amounts of energy previously available only to kings and commanders of armies.

Where people or work animals formerly toiled in the fields, the petroleum-powered machines of industrial agriculture now do the work of growing food. Need to be on the other side of the planet tomorrow? Jet travel can get you there. Want to sit in the sunshine, gamble, and overeat with a few thousand strangers in a gigantic floating hotel? The cruise "industry" can make your dreams come true. Energy-dense fossil fuels make the seemingly impossible or ridiculously extravagant whims of people a reality.

In effect, the modern energy economy provides power equivalent to that of vast numbers of human or animal servants. That is the idea behind the concept of "energy slaves." Although top athletes can do far better, a typical adult male at sustained labor is estimated to produce 75 to 100 watts of power. Calculate the total energy use of an average American and it seems that there are the energetic equivalent of more than 100 energy slaves working around the clock to prop up the easy lifestyle offered by modern civilization.

Energy Future: A Positive Vision

Everyone engaged in combating human-caused climate change or specific elements of the current energy economy knows that the work is primarily oppositional. It could hardly be otherwise; for citizens who care about ecological integrity, a sustainable economy, and the health of nature and people, there is plenty to oppose—burgeoning biomass logging, mountaintop-removal coal mining, inadequately regulated natural gas and oil drilling, poorly sited solar and wind developments, river-killing megadams, and new nuclear and coal plants around the globe. These and many other fights against destructive energy projects are crucial, but they can be draining and tend to focus the conversation in negative terms. Sometimes it's useful to reframe the discourse about ecological limits and economic restructuring in positive terms, that is, in terms of what we're for. The following list is not comprehensive, but beauty and biodiversity are fundamentals that the energy economy must not diminish. And energy literacy, conservation, relocalization of economic systems, and family planning are necessary tools to achieve our vision of a day when resilient human communities are embedded in healthy ecosystems and all members of the land community have space enough to flourish. In short, what we're for is leaving behind the current energy economy, which is wasteful, polluting, and centralized; assumes perpetual growth; and is anchored by nonrenewable fuels. We envision a bold leap toward a future energy economy that fosters beauty and health; that is resilient because it emphasizes renewable, community-scale energy generation; that supports durable economies, not growth; and that is informed by nature's wisdom. Recognizing that all human economic activity is a subset of nature's economy and must not degrade its vitality is the starting point for systemic transformation of the energy system. While such a transition may seem daunting, reforms may be implemented incrementally, and the destination offers exciting possibilities for building vibrant human communities embedded in healthy ecosystems.

Energy Literacy

Energy is arguably the most decisive factor in both ecosystems and human economies. It is the fulcrum of history, the enabler of all that we do. Yet few people have more than the sketchiest understanding of how energy makes the world go around. Basic energy literacy consists of a familiarity with the laws of thermodynamics, and with the concepts of energy density and net energy (also known as energy return on energy invested, or EROEI). It requires a familiarity with the costs and benefits of our various energy sources—including oil, coal, gas, nuclear, wind, and solar. It also implies numeracy—the ability to meaningfully compare numbers referring to quantities of energy and rates of use, so as to be able to evaluate matters of scale. Without energy literacy, citizens and policy makers are at the mercy of interest groups wanting to sell us their vision and products for the future energy economy. We hear from the fossil fuel industry, for example, that Canada's oil reserves (in the form of "tar sands") are second only to Saudi Arabia's, or that the United States has over one hundred years of natural gas thanks to newly tapped "shale gas" resources. And it's tempting to conclude (as many people do) that there are no real constraints to national fossil fuel supplies other than environmental regulations preventing the exploitation of our immense natural treasures. On the other end of the spectrum, we hear from technooptimists that, with the right mix of innovative energy generation and efficiency technologies, we can run the growth economy on wind, solar, hydropower, and biofuels. And it's tempting to conclude that we only need better government incentives and targeted regulatory reform to open the floodgates to a "green" high-tech sustainable future. Energy literacy arms us with the intellectual tools to ask the right questions: What is the energy density of these new fossil fuel resources? How much energy will have to be invested to produce each energy unit of synthetic crude oil from oil shale, or electricity from thin-film solar panels? How quickly can these energy sources be brought online, and at what rate can they realistically deliver energy to consumers? When we do ask such questions, the situation suddenly looks very different. We realize that the "new" fossil fuels are actually third-rate energy sources that require immense and risky investments and may never be produced at a significant scale. We find that renewable energy technologies face their own serious constraints in energy and material needs, and that transitioning to a majority-renewable energy economy would require a phenomenal retooling of our energy and transportation infrastructure. With energy literacy, citizens and policy makers have a basis for sound decisions. Householders can measure how much energy they use and strategize to obtain the most useful services from the smallest energy input. Cities, states, and nations can invest wisely in infrastructure to both produce and use energy with greatest efficiency and with minimal damage to the natural world. With energy literacy, we can undertake a serious, clear-eyed societal conversation about the policies and actions needed to reshape our energy system.

Conservation

The current energy economy is toxic not simply because of its dependence on climate-altering fossil fuels, but also because of its massive scale and wastefulness. A first step toward reducing its global impacts is simply using less energy, a goal readily accomplished through conservation practices that are widely available and cost-effective. Energy conservation consists of two distinct strategies: efficiency and curtailment. Energy efficiency means using less energy to produce a similar or better service. For example, we can exchange old incandescent lightbulbs for compact fluorescents or LEDs that use a fraction of the electricity and still enjoy satisfactory levels of indoor illumination. Curtailment means exactly what you'd think: cutting out a use of energy altogether. In our previous example of indoor lighting, this strategy might take the form of turning off the lights when we leave a room. Efficiency is typically more attractive to people because it doesn't require them to change their behavior. We want services that energy provides us, not energy per se, and if we can still have all the services we want, then who cares if we're using less energy to get them? Much has been achieved with energy efficiency efforts over recent decades, but much more remains to be done: Nearly all existing buildings need to be better insulated, and most electric power plants are operating at comparatively dismal efficiencies, to mention just two examples. Unfortunately, increasing investments in energy efficiency typically yield diminishing returns. Initial improvements tend to be easy and cheap; later ones are more costly. Sometimes the energy costs of retooling or replacing equipment and infrastructure wipe out gains from efficiency. Nevertheless, the early steps toward efficiency are almost always rewarding. While curtailment of energy use is a less inviting idea, it offers clearer savings. By simply driving fewer miles we unequivocally save energy, whether our car is a more or less efficient model. We've gotten used to using electricity and fuels to do many things that can be done well enough with muscle power, or that don't need doing at all. Conservation helps us appreciate the energy we use. It fosters respect for resources, and for the energy and labor that are embodied in manufactured products. It reduces damage to already stressed ecosystems and helps us focus our attention on dimensions of life other than sheer consumption. During the latter decades of the twentieth century, most Americans achieved a standard of living that was lavish from both historical and cross-cultural perspectives. They were coaxed and cajoled from cradle to grave by advertising to consume as much as possible. Simply by reversing the message of this incessant propaganda, people might be persuaded to make do with less—as occurred during World War II—and be happier as well. Many social scientists claim that our consumptive lifestyle damages communities, families, and individual self-esteem. A national or global ethic of conservation could even be socially therapeutic.

Resilience

Resilience is "the capacity of a system to withstand disturbance while still retaining its fundamental structure, function, and internal feedbacks." Resilience contrasts with brittleness—the tendency to shatter and lose functionality when impacted or perturbed. Ecologists who study resilience in natural systems have noted that ecosystems tend to progress through a series of phases: growth, consolidation and conservation, release (or "collapse"), and reorganization. Each turning of this adaptive cycle provides opportunities for individual species and whole systems to innovate in response to external and internal change (i.e., disturbance). Resilient ecosystems (in the early growth phase) are characterized by species diversity; many of the organisms within such systems are flexible generalists, and the system as a whole contains multiple redundancies. In contrast, less resilient ecosystems tend to be more brittle, showing less diversity and greater specialization particularly in the consolidation phase. Resilience can be applied to human systems as well. Our economic systems, in particular, often face a trade-off between resilience and efficiency. Economic efficiency implies specialization and the elimination of both inventories and redundancy (which typically guarantee greater resilience). If a product can be made most cheaply in one region or nation, manufacturing is concentrated there, reducing costs to both producers and consumers. However, if that nation were to suddenly find it impossible to make or ship the product, that product would become unavailable everywhere. Maintaining dispersed production and local inventories promotes availability under crisis conditions, though at the sacrifice of economic efficiency (and profits) in "normal" times. From a resilience perspective one of the most vulnerable human systems today is the American transportation system. For over seventy years we've spent trillions of dollars building transportation infrastructure that is completely dependent (i.e., "specialized") on affordable petroleum fuels, and we've removed or neglected most alternative methods of transport. As petroleum fuels become less affordable, the effects reverberate throughout the system. Resilience becomes more of a priority during periods of crisis and volatility, such as the world is experiencing today. Households, towns, and regions are better prepared to endure a natural disaster such as a flood or earthquake if they have stores of food and water on hand and if their members have a range of practical self-sufficiency skills. While the loss of economic efficiency implies trade-offs, resilience brings incidental benefits. With increased local self-sufficiency comes a shared sense of confidence in the community's ability to adapt and endure. For the foreseeable future, as global energy, finance, and transport systems become less reliable, the rebalancing of community priorities should generally weigh in favor of resilience.

Eco-Localism

A central strategy needed to increase societal resilience is localization—or, perhaps more accurately, relocalization. Most pre-industrial human societies produced basic necessities locally. Trade typically centered on easily transportable luxury goods. Crop failures and other disasters therefore tended to be limited in scope: If one town was devastated, others were spared because they had their own regional sources— and stores—of necessities. Economic globalization may have begun centuries ago with the European colonization of the rest of the world, but it really took hold during the past half century with the advent of satellite communications and container ships. The goal was to maximize economic growth by exploiting efficiency gains from local specialization and global transport. In addition to driving down labor costs and yielding profits for international corporations, globalization maximized resource depletion and pollution, simplified ecosystems, and eroded local systems resilience. As transport fuel becomes less affordable, a return to a more localized economic order is likely, if not inevitable. The market's methods of rebalancing economic organization, however, could well be brutal as global transport networks become less reliable, transport costs increase, and regions adapt to less access to goods now produced thousands of miles away. Government planning and leadership could result in a more organized and less chaotic path of adaptation. Nations can begin now to prioritize and create incentives for the local production of food, energy, and manufactured products, and the local development of currency, governance, and culture. Natural ecological boundaries—such as watersheds— bordered traditional societies. Bioregions defined by waterways and mountain ridges could thus become the basis for future relocalized economic and political organization. Deliberate efforts to relocalize economies will succeed best if the benefits of localism are touted and maximized. With decentralized political organization comes greater opportunity for participation in decision making. Regional economic organization offers a wide variety of productive local jobs. Society assumes a human scale in which individuals have a sense of being able to understand and influence the systems that govern their lives. People in locally organized societies see the immediate consequences of their production and waste disposal practices, and are therefore less likely to adopt an "out of sight, out of mind" attitude toward resource depletion and pollution. Local economic organization tends to yield art, music, stories, and literature that reflect the ecological uniqueness of place—and local culture in turn binds together individuals, families, and communities, fostering a sense of responsibility to care for one another and for the land.

Beauty

Discussions about energy rarely focus on beauty. But the presence or absence of this ineffable quality offers us continual clues as to whether or not society is on a regenerative and sustainable path, or on the road to further degrading nature. From the time of the earliest cave paintings, human ideals of beauty have been drawn from the wild world. Animals, plants, rivers, oceans, and mountains all tend to trigger a psychological response describable as pleasure, awe, and wonder. The sight of a great tree or the song of a goldfinch can send poets and mystics into ecstasy, while the deep order inherent in nature inspires mathematicians and physicists. Nature achieves its aesthetic impact largely through anarchic means. Each part appears free to follow its own inner drives, exhibiting economy, balance, color, proportion, and symmetry in the process. And all of these self-actualizing parts appear to cooperate, with multiple balancing feedback loops maintaining homeostasis within constantly shifting population levels and environmental parameters. The result is beauty. Ugliness, by contrast, is our unpleasant aesthetic response to the perception that an underlying natural order has been corrupted and unbalanced—that something is dreadfully out of place. Beauty is a psychological and spiritual need. We seek it everywhere and wither without it. We need beauty not as an add-on feature to manufactured products, but as an integral aspect of our lives. With the gradual expansion of trade—a process that began millennia ago but that quickened dramatically during the past century—beauty has increasingly become a valuable commodity. Wealthy patrons pay fortunes for rare artworks, while music, fashion, architecture, and industrial design have become multibillion-dollar industries. Nature produces the most profound, magnificent, and nurturing examples of beauty in endless abundance, for free. Industrialism, resulting from high rates of energy use, tends to breed ugliness. Our ears are bombarded by the noise of automobiles and trucks to the point that we can scarcely hear birdsong. The visual blight of highways, strip malls, and box stores obscures natural vistas. With industrial-scale production of buildings, we have adopted standardized materials produced globally to substitute for local, natural materials that fit with their surroundings. But industrialism does not just replace and obscure natural beauty—it actively destroys it, gobbling up rivers and forests to provide resources for production and consumption. Large-scale energy production—whether from coal mines and power plants, oil derricks and refineries, or massive wind and solar installations—comes at a cost of beauty. While some energy sources are inherently uglier than others, even the most benign intrude, dominate, and deplete if scaled up to provide energy in the quantities currently used in highly industrialized nations. The aesthetic impact of industrial processes can be mitigated somewhat with better design practices. But the surest path to restoring the beauty of nature is to reduce the scale of human population and per capita production and consumption. Returning to a sustainable way of life need not be thought of as sacrifice; instead it can be seen as an opportunity to increase aesthetic pleasure and the spiritual nourishment that comes from living in the midst of incalculable beauty.

Biodiversity

The family of life on Earth is large: More than a million species have been identified and formally described by taxonomists, and estimates of the total number of species on the planet range from 3 million to 100 million. We humans depend for our very existence on this web of life of which we are a part. Indeed, it is part of us: Each human is inhabited by thousands of species of microbes that enable digestion and other basic functions. Yet through our species' appropriation and destruction of natural habitat we are shredding microbial, forest, prairie, oceanic, riparian, desert, and other ecosystems. Habitat loss, overharvesting, climate change, and other results of human numbers and behavior endanger untold numbers of species with extinction. Extinction is nothing new: It is an essential part of the process of evolution. Throughout the billions of years of life's history, life forms have appeared, persisted for thousands or millions of years, and vanished, usually individually but occasionally in convulsive mass events triggered by geological or astrophysical phenomena. There were five ancient extinction events so catastrophic that 50–95 percent of all species died out. Today humans are bringing about the sixth mass extinction in the history of life on Earth. While the normal rate of extinction is about one in a million species per year, the extinction rate today is roughly a thousand times that. According to recent studies, one in five plant species faces extinction as a result of climate change, deforestation, and urban growth. One of every eight bird species will likely be extinct by the end of this century, while one-third of amphibian and one-quarter of mammal species are threatened. As species disappear, we are only beginning to understand what we are losing. A recent United Nations study determined that businesses and insurance companies now see biodiversity loss as presenting a greater risk of financial loss than terrorism—a problem that governments currently spend hundreds of billions of dollars per year to contain or prevent. Nonhuman species perform ecosystem services that only indirectly benefit our kind, but in ways that often turn out to be crucial. Phytoplankton, for example, are not a direct food source for people, but comprise the base of oceanic food chains, in addition to supplying half of the oxygen produced each year by nature. The abundance of plankton in the world's oceans has declined 40 percent since 1950, according to a recent study, for reasons not entirely clear. This is one of the main explanations for a gradual decline in atmospheric oxygen levels recorded worldwide. Efforts to determine a price for the world's environmental assets have concluded that the annual destruction of rainforests alone entails an ultimate cost to society of $4.5 trillion—roughly $650 for each person on the planet. Many species have existing or potential economically significant uses, but the value of biodiversity transcends economics: The spiritual and psychological benefits to humans of interaction with other species are profound. Most fundamentally, however, nonhuman species have intrinsic value. Shaped by the same forces that produced humanity, our kin in the community of life exist for their own sake, not for the pleasure or profit of people. It is the greatest moral blot, the greatest shame on our species, for our actions to be driving other life forms into the endless night of extinction.

Family Planning

The human demographic explosion, amplified by rapacious consumption in the overdeveloped world, is at the root of the global eco-social crisis. Virtually every environmental and social problem is worsened by overpopulation. With more mouths to feed—and freshwater becoming scarcer and topsoil eroding—global famine becomes an ever-greater likelihood. An expanding population leads to increased consumption of just about every significant resource, and thus to increasing rates of ecological damage, from deforestation to climate change. Family planning helps avert those threats. If we want future generations to enjoy a healthy planet with wild spaces, biodiversity, abundant resources, and a livable climate we should reduce fertility now. But family planning can do more than mitigate future resource depletion; it has direct and in some cases nearly immediate benefits. Some of those benefits are economic. For example, Ireland's declining birth rate in the 1970s is often credited as one of the factors leading to its economic boom in the 1980s and 1990s. China's one-child policy similarly contributed to its economic ascendancy. The mechanism? In poor societies where family size is typically large, all household income must go toward food and shelter, and none is left over for education and business formation. If the birth rate is reduced, household income is freed up to improve quality of life and economic prospects for the next generation. Without access to contraceptives, the average woman would have from 12 to 15 pregnancies in her lifetime. In contrast, women in industrial nations want, on average, only two children. It turns out that when women are economically and— this is critical—culturally empowered to make decisions about their own fertility, the result is improved health for mother and children, fewer unplanned pregnancies and births, and reduced incidence of abortion. Numerous studies have shown that women who have control over their fertility also tend to have more educational and employment opportunities, enhancing their social and economic status and improving the wellbeing of their families.