Reconstructing Earth

Technology and Environment in the Age of Humans

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Julia Trusdale Allenby, 1925–2002

tarian end point of human existence, many of which are both well-known to environmental audiences and frequently lacking in intellectual rigor. Rather, they are books that delve into the critical areas of knowledge that have yet to be sufficiently integrated into environmentalism—postmodernism, urban systems studies, evolution and function of technological systems, cultural anthropology and sociology, complexity and network theory, and, yes, philosophy and the like. That I have included a book in a chapter's annotated bibliography does not mean I agree with it—but it does mean that I was forced to think in order to disagree with it. In some ways, that is more valuable. By including them, I hope to provide the means for those who seek further dialog, for a discussion with a good book, even one you disagree with, is a powerful path to wisdom.

Certainly you may disagree with my points, or the facility with which I defend them. But I hope that in doing so you will at least be stimulated to reach higher ground where I may have faltered.

CHAPTER 1

The Human Earth

The Earth has become an anthropogenic planet. The dynamics of most natural systems—biological, chemical, and physical—are increasingly affected by the activities of one species, ours. The debate over how to manage global climate change; the efforts to recreate the Everglades and similar regional resource regimes to support both environmental and economic values; the effect of rapidly growing urban areas around the world on their hinterlands; the evolution of a global economy and market-oriented culture networked by information and communication systems that did not exist twenty years ago all testify to a planet whose characteristics, from the biological to the electromagnetic frequencies it radiates to space, are increasingly defined by human action. As the journal *Nature* put it in a 2003 editorial, "Welcome to the Anthropocene"—welcome to the Age of Humans.[1]

This trend is not new, of course. Although this process has been accelerated by the Industrial Revolution, "natural" and human systems at all scales have in fact been affecting each other, and coevolving, for millennia, and they are now more tightly coupled than ever. Copper production during the Sung dynasty, as well as in Athens and the Roman Republic and Empire, are reflected in deposition levels in Greenland ice; and lead production in ancient Athens, Rome, and medieval Europe is reflected in increases in lead concentration in the sediments of Swedish lakes. The buildup of carbon dioxide in the atmosphere began not with the post–World War II growth in consumption of fossil fuel, but with the growth of agriculture in, and thus deforestation of, Europe, Africa, and Asia over the past millennia. Humanity's impacts on biota, both

[1] *Nature* 424:709.

directly through predation and indirectly through the introduction of new species to indigenous habitats, has been going on for centuries as well.

What is different is that the impacts of the past were relatively minor and localized. Since the Industrial Revolution, they have become progressively more global and systematic (see "History, Responsibility, Design"). Indeed, in some areas, such as biotechnology, new fundamental technological and scientific advances have generated the potential for subsuming large chunks of previously (relatively) natural systems into human systems—in this case, genetic engineering combined with existing legal treatments of intellectual property creates the means by which the vast information store of biological genomes can be "commoditized" and made part of human economic systems (see "The Commoditization of Nature"). From a systems perspective, population and economic growth, and the evolution of ever more dense information and communication technology (ICT) infrastructures, has facilitated the linking of previously disparate local and regional patterns of human activity into globally synchronized systems, as well as ever closer coupling of human with fundamental natural systems. For the most part, we neither perceive nor recognize this state, in part perhaps because it has evolved without our conscious guidance; in part because recognition would require that we try to respond responsibly, rationally, and ethically and we do not know how to do that; and in part because the reality conflicts so basically with the popular mythology of "nature" as sacred. After all, to the extent we regard nature as something "outside the human," it becomes that much harder to recognize how much the human has actually affected the natural world.

So we should not be surprised that the language and mental models we often rely on in thinking about environmental issues have a powerful ideological and religious content, yet they are regarded by most of us as representing objectively real phenomenon. Thus, for example, terms such as "nature," "wilderness," "sustainable development," and even "environment" tend to be used as if they represented unquestionable, concrete facts and components of objective reality, but they are in fact products of a particular place, time, and culture, and have changed significantly over time. The concepts and meanings of "nature" alone make it one of the most complex of these cultural constructs. It can mean desirable; morally right; an independent source of value; the sacred; and, especially these days, the nonhuman, as "natural" ingredients are taken to mean "not made by humans" despite the fact that the products identified by such adjectives clearly are packaged, processed, and distributed in highly complex human structures. This implies that humans and their products, and especially their technologies, are somehow beyond the pale, profoundly "nonnatural."[2]

The irony, of course, is that this implication arises at the very point in human history characterized by increasing globalization of economic, technological, and cultural patterns. This does not mean that we are entering an era of global monoculture, but, rather, increasing complexity: there are more communities, units, systems, interests, political and social entities, and technology clusters, at many different levels, and more relationships among them and natural systems at many scales than ever before. Production, consumption, economics, culture—and environmental issues—are all part of the same, increasingly complex package, and viable solutions must deal with all the varied dimensions of that package.

Dealing ethically and rationally in such a world requires a sense of realism. Environmental issues are occasionally framed in apocalyptic terms, with people speaking glibly of "saving the planet." It is highly unlikely, however, that "the world," "life," or even the existence of the human species is threatened by current levels of human activity (indeed, as regards the latter, it is well-known that generalist species, of which humans are the outstanding example, do better than others in periods of rapid change). What is threatened is the stability of global economic and social systems; especially endangered, as always, are the poor and powerless, and those who do not belong to the dominant culture. Regional and global current system states—climate and oceanic circulation systems, biological systems at all scales, elemental and hydrological cycles, and the like—are also evolving rapidly. What the dramatic language indicates is not that the planet itself is threatened, for it will certainly continue to evolve, although elements of it will follow a different path than they would in the absence of humans. Rather, it is people's judgments about the world they want, and their underlying mental models and ideologies, that are at risk: it is not the planet, but individual, culturally contingent, and particular visions of a desirable state, that are under threat. And, of course, visions, and values, differ significantly depending on culture, economic status, and the like. Again, this is not to suggest that human activities might not result in sudden and unanticipated shifts in various critical systems—the climate or oceanic circulation systems, for example. But the widespread use of such apocalyptic language does suggest that the environmental discourse—the dialog, ideas, and institutions that taken together form the environmental movement—tends to conflate values, their vision of ideal ultimate ends, and reality with dangerous naïveté. What a "desirable" world is depends greatly on who, or what, is doing the desiring.

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[2] W. Cronon, *Uncommon Ground: Rethinking the Human Place in Nature* (New York: W. W. Norton and Co., 1995) is an excellent source for those wishing to further explore these interesting intellectual byways.

This cultural contingency only adds to the high degree of complexity surrounding environmental issues. Consider scale, an important component of that complexity. The most common dimensions are geographic and temporal; even in these familiar waters, however, confusion arising from a lack of sensitivity to scale issues is all too common. Geographically, many scale issues arise because of a mismatch between the physical extent of human systems—jurisdictional boundaries associated with political systems such as nations, for example, or, more subtly, the geographic dimensions of markets and trading systems—and natural systems.

The temporal scale is a little more subtle. In the short term, social, cultural, and legal systems can reasonably be regarded as fixed, and policy development is relatively easy. Moreover, human individual and institutional perception is oriented to the short term: most people do not think beyond a few years. With the evolution of environmental focus from impacts localized in time and space, such as clean air, clean water, and defined waste sites, to perturbations that express themselves only over many decades, if not centuries, and over continental, if not global, geographical scales, the situation changes dramatically. Cultural constructs, fundamental institutions such as the family unit, the state, private firms and NGOs, and economic systems change profoundly, and none can be regarded as fixed. It is one thing to prescribe a scrubber technology that controls emissions of chlorinated solvent fumes from a manufacturing facility; quite another to mandate reduced fossil fuel use in response to global climate change. The former decision can be easily reversed if wrong; the latter significantly bounds the paths available for continued human evolution. It is not that a particular solution is "right" or "wrong"—rather, it is that scale issues make the latter a much, much more complex question.

Moreover, it is not clear that meaningful dialog on fundamental environmental perturbations, such as loss of biodiversity, global climate change, anthropogenic shifts in elemental and hydrological cycles, and the like involves only two dimensions. Indeed, one can argue that the appropriate "phase space"—set of dimensions required to functionally define the perturbations at issue—include a cultural dimension, a technological dimension, an economic dimension, and perhaps an information dimension as well.[3] And the choice of phase space may itself reflect the level of the system that one is interested in.

[3] Ideally, these dimensions should be independent of each other, but that is obviously not feasible with human systems such as culture and technology—nor, indeed, given the impact that human systems are now having on physical, chemical, and biological systems at all scales, may it be possible even in the temporal and spatial dimensions. Learning how to define, and perhaps quantify, such dimensions is an interesting challenge.

Choosing information technology as an example, there is a significant increase in complexity as one moves from a component, to a subassembly, to a router, to the Internet as a physical network, to the Internet as it functions in society, to the patterns of cultural change induced by the Internet as they in turn affect environmental systems. However, how to define each level in terms of complexity, and the way each level interacts with other networks reflecting other dimensions of the phase space at the appropriate scale is, to say the least, still opaque.

The challenge of complexity is significantly complicated in the real world by fundamental and accelerating changes in governance systems in a globalizing culture. "Governance"—the multitude of ways in which society is managed and administered—includes but is not limited to governments, which are formal institutions creating and administrating laws and regulations, and maintaining civil order. In the past, "government" and "governance" were quite similar. Indeed, since the Peace of Westphalia in 1648, the traditional global governance structure has been based on the institution of the nation-state. Thus, for example, the negotiations about mitigating global climate change are conducted entirely by nation-states, although firms and environmental NGOs participate and lobby behind the scenes. But this international governance system has become much more complex over the past decade. Where the nation-state used to be dominant, it now is just one of many institutions involved in international governance. Private firms, NGOs, and communities of different kinds now increasingly share responsibility for international policy development and implementation, notably in the environmental, human rights, and financial arenas. We have yet to catch up with this new reality, and most of the relevant players remain somewhat unclear about their roles in the still evolving governance structures.

And it becomes more complicated yet, for modern institutions involved in governance —from major religions and cultural systems, to the family unit, to geographic and virtual (online) communities, to firms, NGOs and activist movements—all continue to rapidly evolve. The power and information relationships they embody, and participate in, are shifting rapidly as well. Under such circumstances, there are no firm points from which one can begin developing intellectual frameworks and policy systems; rather, all is in fundamental flux. Cultural systems, institutions, and individuals tend to find such an environment uncomfortable, and will accordingly try to deny the reality of change and cling to previously valid patterns. Taken another way, rapid change creates the ironic but powerful incentive to neither perceive, nor acknowledge, the change that is actually occurring, and to retreat to the ideologies and mental models of the past. Indeed, the rapid rate of change that characterizes the modern world is probably a significant reason for the upsurge in fundamentalism, from the Middle East to the American South. Such a retreat is also appealing with a discourse as emotionally potent and ideologically charged as environmentalism: would you rather have the task of trying to understand and manage a world that is at the verge of the Anthropocene or be the romantic, muscular, dressed-in-black ecodefense warrior pictured in Foreman and Haywood's 1993 deep green classic, *Ecodefense: A Field Guide to Monkeywrenching*?

Governance structures also matter because shifts in power do not necessarily result in public benefit. One advantage of a government-based governance structure is that governments, to a more or less effective degree, are entities that implicitly try to balance mutually exclusive goals and conflicting ontologies, distributing costs and benefits of various policies among disparate groups—they are the integrators of civil society. Firms and NGOs, on the contrary, are far more limited in scope: firms generally exist to make money, and NGOs reflect their own idiosyncratic ideologies and belief systems, often exclusively. Both, given the opportunity, can dominate policy formulation to the exclusion of other voices and interests. It is probable that, as the current fragmented governance structure continues to evolve, mechanisms will emerge that integrate the social, environmental, and economic as the nation-state used to. For now, that desirable result does not always prevail.

This is especially true as the approaches of industry, governments, and NGOs to environmental issues tend to lag economic and technological evolution, and thus run the risk of focusing, like the Maginot Line, on past challenges rather than on present realities. The environmentalism that developed in the 1970s tended to focus on managing the effects of manufacturing and industrial activity, and to a lesser extent on products, particularly chemicals. If one assumes that environmental perturbations arise primarily from such activity, it is reasonably fair to declare victory and turn to other issues. If, however, environmental perturbations arise from the accumulated economic, technological, and cultural evolution of a rapidly growing population, and the increasing dominance of planetary systems by one species, then our ignorance is, in fact, far more pervasive than we might at first think.

Two trends suggest that this may be the case. The first is the shift in developed economies from a primarily manufacturing to a primarily service economy: depending on how "services" are defined, they now constitute 70 to 80 percent of developed economies. Moreover, this is not a simple shift in production technologies, for it is aligned with a substantial increase in the importance of information as economic input and output—the rise of the so-

called knowledge economy. An environmentalism still focused on manufacturing deals but weakly with the environmental costs, and opportunities, of the modern service economy. Second, and equally important, is the growing realization that it is impossible to understand the modern world, and the interactions of human and natural systems, unless one understands technology systems and their evolution. Here, also, we know surprisingly little: in fact, we lack a robust theoretical framework. But it is certainly likely that human society will be profoundly changed by the confluence of information and communication technology, biotechnology, cognitive sciences, and nanotechnology. Consider some potential examples. How will future generations increasingly integrated into information networks rather than outdoor wilderness activities regard "nature"? What happens when biodiversity becomes increasingly a function of genetic engineering rather than existing species preservation? What is the effect of creating systems that enable humans to control machines and mechanical contrivances at a distance, wirelessly (the U.S. military is allegedly working on planes that are directly and wirelessly integrated into the brains of pilots, so that the plane becomes just another appendage of the human pilot)? What happens when medical science and nanotechnology combine to create human lives averaging well over a hundred years? Yet how often are these subjects considered seriously as part of the environmental movement (as opposed to simple Luddite dismissal)? Indeed, when are they considered seriously in public discourse generally? It is not merely rhetorical to wonder what a high-technology, high-information-content, environmentally desirable society might look like, for it is where we are heading—only, there is the distinct risk that the environmental piece might simply be an accidental, unintended, unplanned, and unpleasant result of other systems evolving, rather than a thought out, desired, and important component of our future.

Taken together, these observations suggest a fundamental caution that it is well to emphasize from the beginning: our ignorance about the environment is profound. Moreover, it is not trivial, in the sense that a little more research in the right direction will suffice to overcome it. Rather, it is foundational: it is not just the knowledge and data that are lacking, but even the perception of (and perhaps the ability to perceive) the complexity that we have unleashed over the past centuries. As D. Michael notes in *Barriers and Bridges*, referring to the experiences gained by those scientists trying to manage complex human-natural systems such as the Baltic Sea, the Everglades, the Great Lakes, and the like:

> Persons and organizations view information from their personal and peer-shared myths and boundaries. More informa-

> tion provides an ever-larger pool out of which interested parties can fish differing positions on the history of what has led to current circumstances, on what is now happening, on what needs to be done, and on what the consequences will be. And more information often stimulates the creation of more options, resulting in the creation of still more information. . . . Indeed, in our current world situation, opening oneself or one's group to a larger "data base" reveals the terrifying prospect that the world is now so complex that no one really understands its dynamics and that even rational efforts tend to be washed out or misdirected by processes not understood and consequences not anticipated. Of course . . . those intent on pursuing their interests seldom can risk sociocultural ostracism by acknowledging this to others, and usually not even to themselves.[4]

In sum, it is not just the environmentalist discourse that sits uncomfortably on the cusp of unprecedented change. We cannot for much longer continue to evade the realization that we have created an extraordinarily complex anthropogenic world, one in which human systems and natural systems have become so intertwined that they are in many cases, if not yet in our minds and culture, one and the same. The carbon cycle, hydrologic cycle, climate and oceanic systems, biological communities—they all reflect the actions and intentions of one species. We are not yet prepared to manage this complexity—indeed, it is doubtful we understand either the systems, or what our response should be. But if we are to assume a position that is responsible, ethical, and rational, one that moves us beyond today's increasingly irrelevant ideologies and romantic fantasies, we must begin somewhere. We must develop the capability to design, through dialog and continual feedback, systems that achieve the multitudinous goals and desires of humanity, from personal fulfillment and economic security to environmental quality—an earth systems engineering and management (ESEM) capability.

Developing the capability to engineer and manage at the level of global systems—from energy, transportation, and information systems to the carbon and nitrogen cycles—is the next great challenge for our species (see "Earth Systems Engineering"). This ESEM capability is not a new burst of hubris, but an attempt to behave rationally and ethically in light of a basic, if disconcerting, truth: the Earth, as it now exists, is a product of human design. So the question is not, as some might wish, whether we should begin ESEM, because we have been doing it for a long time, albeit unintentionally. The issue is whether we will assume the ethical responsibility to do ESEM rationally and responsibly.

[4] D. N. Michael, "Barriers and Bridges to Learning in a Turbulent Human Ecology," in L.H. Gunderson, C.S. Holling, and S.S. Light, eds., *Barriers and Bridges to the Renewal of Ecosystems and Institutions* (New York: Columbia Univsersity Press, 1995.) pp. 461–488, at 473.

So what is ESEM? It can be defined as the study and practice of designing and managing integrated human-natural systems in such a way as to provide the required functionality while supporting their resiliency and desirable characteristics over time. "Integrated human-natural systems" might range from the climate and carbon cycle, to the Everglades or Baltic, to large industrial systems producing commodity materials and energy, to urban systems. In each case, the relative importance of the human and the natural components of the system will vary, but rare is the system where both are not involved at this point. "Required functionality" is not limited to traditional human goals such as job creation, economic growth, or national security; for a system such as the Everglades, for example, it will include supporting high levels of biotic diversity and areas of reduced human presence. The latter are perfectly legitimate ESEM design goals; we are just not used to thinking of them in those terms. "Resiliency" is a critical property of a well-designed and well-managed system; especially at this early stage where our understanding of the relevant science and systems dynamics is liable to be limited, it is important that the systems we work with be relatively robust when the unexpected happens—as it frequently will. "Desirable" is a more difficult term than it might at first appear, but it marks an absolutely critical point: human values are determining how these systems are being structured currently, even if we often pretend they are not. They will continue to do so. Under these circumstances, whose values should dominate? How should different, often mutually exclusive, values be weighted and prioritized? Is your job worth my spotted owl—and who decides?

Given the complexity of these systems, it is apparent that minimizing the risk and scale of unplanned or undesirable perturbations is an obvious ESEM objective. But there is also an important caution here: the kind of engineering and management approaches that are almost universal today—which assume a high degree of knowledge and certainty about system behavior and a defined endpoint to the process—are not feasible in most ESEM situations. We will not "solve" or "control" in any traditional way ESEM systems such as the Everglades, the Baltic, the climate cycle, or the hydrologic cycle at a large scale. Rather, we will be in constant dialog with them, as they—and we and our cultures—change and coevolve together into the future. It is not our choice anymore as to whether our activities are integrated with these systems and determine their future evolutionary paths. It is only our choice as to whether we respond rationally and ethically to this challenge, or hide in outmoded and oversimplistic ideological systems (see "Climate Change and Social Engineering").

An obvious subject for the ESEM approach is the human relationship with climate systems, most recently and visibly through the global climate change research and negotiation process. While there are any number of criticisms of the Kyoto process, a few stand out. Some have to do with adequacy of governance: thus, for example, even though firms, trade groups, and NGOs are critical participants in any climate change policy initiative, the underlying structure of the negotiating process presupposes the traditional international governance system where states alone have sovereignty. Another fundamental problem with the Kyoto process is that it imposes a command-and-control, end-of-pipe mentality on a system where such thinking is manifestly inadequate. Even though a number of mechanisms are under discussion, Kyoto's principal focus is to limit emissions of carbon dioxide—in other words, to place a massive end-of-pipe control on the world's economy. This reflects traditional regulatory approaches, but it is grossly inadequate to both the problem and our responsibilities. Moreover, it assumes static technology and institutions just at the time that new technologies, such as active carbon sequestration at fossil fuel plants, offer the potential to achieve new ways of carbon-cycle stabilization.

The failure to appreciate the potential of technological evolution is fairly common, of course, but when one is dealing with policy structures that purport to extend over many decades, such a failure can render the entire exercise moot, for the power of technological evolution to radically redefine worldviews and unquestioned assumptions is evident. In the case of Kyoto, the negotiations began with the strong assumption that fossil fuel use must be reduced. As a second step, it is now being accepted by more moderate environmentalists that industrial carbon sequestration technologies, which capture carbon dioxide resulting from fossil fuel combustion in power plants and sequester it for centuries in deep aquifers, the ocean, geologic formations, or other reasonably long-term sinks, can enable fossil fuel use while reducing or eliminating associated emissions of global climate change gases. This is particularly important given the role coal may need to play in the development of large nations such as China or India.

But recent research indicates that it may be possible to scrub carbon dioxide from the atmosphere directly. This raises a significant cultural challenge, for it completely shifts the focus of climate change debate from "How do we stop affecting the climate" to "What kind of climate do we want?" The former question presupposes a world where human activities can be scaled back to the point where they have minimal impact; the second accepts a world where

human demographics, economic and technological systems, and cultural evolution operate at a scale where simply withdrawing is a wistful utopian fantasy with the unfortunate effect of enabling a willful failure to accept ethical responsibility for the world as it is.

That we live in an anthropogenic world, and so obviously lack the necessary tools to do so rationally and ethically, may seem discouraging, both generally and more specifically for environmentalism. But this would be unduly pessimistic. A strong, responsible, and sophisticated environmental voice is necessary in shaping the world, and subsequent chapters will suggest some ways in which such a voice can be encouraged. And while it is true that ESEM is a new concept, we can already identify a number of principles from fields such as industrial ecology, adaptive management, and systems engineering that can be relied on to enable rapid progress in developing such an approach. A number of these principles are discussed in the last chapter. The Anthropocene is unquestionably a challenge, but—as this book itself shows—one to which we can begin to respond, always remembering not to let the best become the enemy of the good we can begin to do today.

Earth Systems Engineering
(December 1999)

Last month this column discussed the need to apply an industrial ecology approach not just within the firm, but to broader human/natural systems as well. In particular, the need to move away from a traditional end-of-pipe model of global climate change mitigation and toward active carbon cycle management was highlighted. But the implications of earth systems engineering for environmental and business professionals are much broader than that.

To start with the big picture, it is important to recognize the systemic meaning of the Industrial Revolution and concomitant changes in our population levels, industrial and agricultural activities, technology systems, and culture. The result is a world in which the dynamics of major natural systems—carbon, nitrogen, hydrologic, sulfur, and heavy metal cycles; ocean and atmospheric patterns; the biosphere at every level from genetic to ecosystem—are dominated by human activity. Frequently, as in the case of invasive species, the impacts may be both unintended and a result of cumulative individual decisions, rather than directly engineered, but the results are the same. Managing these perturbations, and the future evolution of tightly coupled human/natural systems, will require the development of a capability to rationally "engineer" them—not in the usual engineering sense of control and precise definition, but by developing new managerial and engineering approaches which become part of an ongoing process of developing sustainably.

This capability is earth systems engineering, the study and practice of engineering technology systems so as to facilitate the active management of the dynamics of coupled natural systems. The goal is not to try to "engineer" natural systems in the traditional sense (engineering as control); with complex systems, such an approach is doomed to failure. Rather, the intent is to assume responsibility for any perturbations of natural systems that result from technological or industrial initiatives, and try to "design" the perturbations, rather than simply letting them happen (or, worse yet, pretending that they will not).

It sounds daunting, but in some ways we are already experimenting with it. The demand by stakeholders that firms consider the triple bottom line (TBL)—integrated social, economic, and environmental performance—is a move, albeit nascent and primitive, toward an earth systems engineering ethic. How so? Consider the example of biotechnology firms and the powerful reaction against genetically modified organisms, or GMOs, in Europe. Many of the firms involved had already gone beyond the traditional role of considering themselves only as profit-oriented entities. Yet they approached the issue of introducing GMO products as if it were a relatively routine business operation. In fact, it was quite different: the role of the firm shifted from being a developer and producer of products to being the manager, in the full social sense, of the introduction of critical new technologies with significant social and ethical dimensions. The firm shifted from the usual forms of business management and traditional responsibilities to being an important part of what can be seen as earth systems engineering.

Similarly, telecommunications firms, long used to pricing and equity issues being managed in the context of heavily regulated national markets, are suddenly participants in an "information revolution" that is global, unpredictable, and largely unregulated, and which could have significant social dimensions. Among the most important issues that arise are the environmental impacts of innovations growing from the Internet, such as e-commerce, and the distributional impacts of rapid technological evolution and growth of the knowledge economy (will the information revolution increase or decrease social and economic inequality?). Or, take fossil fuel firms: it is apparent that using fossil fuels can have environmental impacts. It is also apparent that nation-states such as China and India are hardly likely to eschew development if it involves the use of fossil fuels (both countries have significant coal reserves). What is the responsibility of fossil fuel firms to implement carbon sequestration and clean combustion technologies? What is their responsibility to facilitate the creation of a hydrogen energy distribution system so that carbon can be captured at a central location, and clean energy in the form of hydrogen deployed for mobile and perhaps stationary uses?

That these questions are even being asked illustrates several things. First, the scale of modern industrial and economic activity has indeed grown to be commensurate with that of natural systems: earth systems engineering is occurring, and will continue to occur, whether we consciously try to do better or not. Second, this dynamic is changing the traditional roles and responsibilities of firms, and their relationships to technology and society itself. Third, firms that understand this will have a greater probability of success in an increasingly complex world; firms that fail to adapt, like all complex systems that fail their evolutionary tests, will fail.

Annotated Bibliography

There are a few books that anyone who seriously wants to understand environmental issues should read at some point in her or his career. Many of them do not deal with environmental themes, or do so in unfamiliar ways, and indeed this is part of their value, for they help illuminate the context surrounding the environmentalist discourse. Indeed, this is a problem with many of the usual "environmental" books, which are so much a part of the current environmental discourse that they cannot help anyone see beyond it; they are in some ways explorations of the past rather than anticipations of the future. So, think about . . .

1. Marx. A brilliant critic (and thus architect) of capitalism and a source for much that is implicit in environmentalist critiques of capitalism and industrial society. As Robert Heilbroner has observed, "We turn to Marx, therefore, not because he is infallible, but because he is inescapable. Everyone who wishes to pursue the kind of investigation that Marx opened up, finds Marx there ahead of him, and must therefore agree with or confute, expand or discard, explain or explain away the ideas that are his legacy."[9] *The Communist Manifesto* is accessible and covers a number of relevant themes; other writings are somewhat more opaque and cover a lot of interesting, though possibly not entirely relevant, ground (I would go with a Marx reader, rather than *Capital* or some of his other complete works if you explore further). But if you want to understand utopian sustainability, globalization, commoditization, and a number of other important trends, Marx is still a good place to start.
2. D. Harvey, *Justice, Nature and the Geography of Difference* (Oxford: Blackwell Publishers, 1996). A wonderful book on postmodernity, cultural and economic transformation, "nature" and "environment" as cultural constructs, and how and what justice and environmentalism mean in a socially constructed world. Some of the language and approach is quasi-Marxist ("Fordism" might throw you the first time, and there are dialectics galore), but bear with it: the book is brilliant and commonsensical at the same time.
3. J. Diamond, *Guns, Germs, and Steel* (New York: W. W. Norton and Co., 1997) and D. S. Landes, *The Wealth and Poverty of Nations* (New York: W. W. Norton and Co., 1998). Most people see these books as somehow contradictory (Diamond viewed as a leftist and Landes as a rightist), but I think they are best read as complementary. Neither is an "environmental" book, but both address an absolutely critical environmental question: why does the modern world look the way it does, with a globalized, Eurocentric Enlightenment culture? After all, if you do not understand at least a little about why the world looks the way it does and what the critical dynamics are, how do you think you are going to change it?

[9] R. L. Heilbroner, *Marxism: For and Against* (New York: W. W. Norton and Co., 1980), 15.

4. J. R. McNeill, *Something New Under the Sun* (New York: W. W. Norton and Co., 2000) and B. L. Turner, W. C. Clark, R. W. Kates, J. F. Richards, J. T. Mathews, and W. B. Meyers, eds., *The Earth as Transformed by Human Action* (Cambridge: Cambridge University Press, 1990). Environmentalists, like many moderns, frequently lack a sense of history and, accordingly, are not very good at explaining what exactly has changed over time to elevate environmental issues to the level of concern they now occupy. The short answer is "scale," but that will not get you very far. These books will. McNeill's book, since it is not an edited volume, is more readable and uniform in quality; the Turner et al. volume is a good, if a little dated, source for detail on particular issues.
5. K. S. Robinson, *Red Mars*, 1993; *Green Mars*, 1994; and *Blue Mars*, 1996 (New York: Bantam Books). This series, like many science fiction books, deals with, among other things, the ethical implications of terraforming a planet. What is interesting is that there is a large and relatively sophisticated literature on the ethical and philosophic implications of terraforming other planets (especially Mars), but virtually no discussion of those implications in the case of the only planet which, so far as we know, has been terraformed in fact—the Earth. One is tempted to think that this may be because we are unable to admit even to ourselves the illicit knowledge that we are doing precisely that—perhaps because we have for so long regarded the Earth, and now nature, as sacred?
6. F. Berkes and C. Folke, eds., *Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience* (Cambridge: Cambridge University Press, 1998) and L. H. Gunderson, C. S. Holling, and S. S. Light, eds., *Barriers and Bridges to the Renewal of Ecosystems and Institutions* (New York: Columbia University Press, 1995). Both of these edited volumes discuss, and provide case studies of, a relatively new area of study and practice called "adaptive management." This is defined in Gunderson et al. as "ways for active adaptation and learning in dealing with uncertainty in the management of complex regional ecosystems" (ix). The themes of complexity, the integration of human and natural systems, the necessary coupling of natural and social science research and expertise, and the dysfunctionality of ideology come across clearly in these works, which should be a part of every environmentalist's store of intellectual capital. Can you imagine the difficulty of actually trying to create an Everglades system in Florida that meets the design objectives and constraints of the various, mutually opposed stakeholders? Good. Because that is the current state of the entire planet.