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"Materials, Energy, and Climate Change" by Frank Ackerman

In an industrial economy based on fossil fuels, is sustainable development imaginable? And if so, is it achievable? The hopes of environmental advocates and policymakers face one of their sharpest challenges here: is there, even in theory, such a thing as sustainable industry? It is comparatively easy to describe the possibility of organic agriculture integrated with nature; it is much harder to picture "organic" steel mills or chemical plants.

Yet the invention of more ecologically friendly industry is essential if sustainability is to become meaningful in modern economic life. Economic development inevitably involves widespread industrial activity; a vision of utopia without manufacturing would be unlikely to win many adherents in the lower-income countries of the world. And industry, in its present form, constantly causes critical environmental impacts. Many of the most serious contemporary environmental problems, such as the threat of global climate change, are direct results of the industrial use of energy and materials. There may indeed be viable alternatives, but they require substantial changes in the shape and scale of existing industry.

A sustainable society will still use materials and energy for mass production - but it will have to do so more moderately than rich countries do at present, and in a qualitatively different manner. It is clear that the current patterns of production and consumption are unsustainable. On the production side, extractive and manufacturing industries are overexploiting both renewable and nonrenewable resources, while causing substantial air and water pollution. On the consumption side, ever-escalating standards for new cars, homes, and assorted luxuries, conveyed worldwide by American-influenced or -dominated media, create a consumer demand for unsustainable levels of production. A very different approach will be needed in order to avert the threat of climate change, and to create a society based on sustainable resource flows.

There is an extensive body of research related to these topics, including many detailed, applied analyses. This essay reviews the literature in three related areas: material use; energy; and climate change. Looking beyond the technical details, the discussions reviewed here display a striking divergence in tone. There are some differences about the urgency and magnitude of the environmental problems to be solved. There are also important differences, even among those who see substantial problems facing us, about the feasibility and cost of the needed changes. Some see signs of change in the right direction, and can describe technologically feasible, affordable alternatives. Others point out how far we are from solving basic environmental problems, how much we will have to spend, and how rapidly we need to change in order to prevent ecological crisis. Sorting out the evidence for these contradictory perspectives is one of the challenges in this area.

MATERIALS

There are inescapable natural limits to the use of materials in a sustainable society. For renewable resources, there is a sustainable annual yield – for example, the annual growth in a forest – which harvesting cannot exceed in the long run without causing depletion. For nonrenewable resources, there is no such thing as a sustainable long-run "yield" of virgin material; it is important to seek alternatives and move away from dependence on finite, exhaustible supplies. Are we close to bumping up against those limits, or are they so far away that other problems are more urgent to address? Ominous predictions of material shortages, often heard in environmental circles in the 1970s, have fortunately not been borne out by events to date. Yet the logic of the underlying argument remains unassailable over a longer time frame. Sustainable material use is still ultimately essential, and still far from reality.

A number of overviews of material use are available, such as the comprehensive study by Gary Gardner and Payal Sampat (1998). The use of all materials other than food and fuel reached 101 kilograms per capita per day in the U.S. in 1995; in that year, total U.S. material use was 18 times higher than in 1900. Some progress has been made toward efficiency of materials use (or equivalently, toward declining material intensity of consumption), but much more needs to be done. Gardner and Sampat cite studies suggesting that equitable, sustainable worldwide material use might require a 90 percent reduction in per capita material consumption in industrialized countries, far beyond the level that can be easily achieved through gradual efficiency gains. Thus they conclude with a call for new programmatic initiatives, such as elimination of subsidies to virgin material production, imposition of environmental taxes and fees, and support for both established and new forms of recycling. Other recent overviews and studies along similar lines include Cutler Cleveland and Matthias Ruth (1999), Ruth (1998), and Friedrich Hinterberger and Eberhard Seifert (1997).

The theoretical perspective embodied in many recent studies is called "industrial ecology," stressing the parallels between the interindustry flows of materials, energy, and wastes and the similar flows that occur between species and environments in nature. Just as there are nutrient cycles in nature, with wastes of one organism providing food for another, so, too, there can be material cycles in industry, with wastes and byproducts from one firm providing valuable inputs to another firm. A linear economy, in which everything is used once and then discarded, requires huge resource inputs and generates huge wastes in the process of satisfying consumer demand. In contrast, a cyclical economy, in which one industry's waste is another industry's resource, can achieve the same levels of production and consumption with far lower levels of material "throughput." For an introduction to industrial ecology see Robert Socolow et al. (1994).

The best-known, and perhaps the gloomiest, writer in the field of industrial ecology is Robert Ayres (see Robert and Leslie Ayres 1998, Ayres and Paul Weaver 1998, Ayres and Ayres

1996, among many others). Ayres paints a bleak picture of the environmental damage and unsustainable resource consumption caused by current practices, filled in with encyclopedic knowledge of specific industrial processes. He advocates an "industrial metabolism" perspective, in which the circulation of materials and waste products throughout society is viewed holistically, as analogous to the metabolism of a biological organism. For Ayres, this perspective implies that environmental impacts should be viewed on an integrated or life-cycle basis, rather than in isolation. Thus he calls for the creation of closed materials cycles, in which the wastes of one process are always useful inputs into another, as the only long-run strategy that can lead to sustainable industrial production. Sweeping changes in industrial technology would be required to substitute closed materials cycles for the open, waste-generating processes now in use (see Lange and Duchin, 1994).

Counterposed to Ayres are more upbeat writers who find evidence of what they call "dematerialization" - that is, declining material use per constant dollar of GDP, or in some cases per capita, in the developed world. The computer industry provides a familiar, and extreme, example: the material required to produce the same amount of computing power is steadily and rapidly declining. The summarized article by **Iddo Wernick et al.** provides a clear explanation of the argument for dematerialization. There have been long-term declines in the intensity of use (kilograms of material per constant dollar of GDP) of many common materials, including timber, copper, and steel.

If, in fact, social and technological change are steadily reducing the intensity of material use, there is more room for sustainable economic growth before we run into resource constraints. However, the implications of global equity should be considered in this context: raising several billion people up to developed-country levels of material use would create a surge in demand and production, outweighing the reductions achieved by many years of dematerialization. If an industry is growing rapidly enough, declining material use per unit of output may coexist with rising total material use; the computer industry is again a good example.

Dematerialization stems in part from the shift from goods to services, and within manufacturing from the increasing role of technology (as industry relies on more skillful or knowledge-based fabrication, rather than increases in the bulk of materials). In part it also reflects the rise of recycling of waste materials, which lowers the required input of virgin materials per unit of output. The discussion of sustainability therefore intersects the discussion of recycling.

The second summary (**Frank Ackerman** - the concluding chapter of my book on recycling) addresses the connection between recycling and sustainability. A sustainable future economy will have to move increasingly toward reliance on renewable resources for both materials and energy; the rate of recycling is one of several key factors determining how hard it will be to reach and remain at that goal. Emphasis on material conservation and recycling seems to fly in the face of the current abundance of cheap materials; free marketeers unfortunately have a point in suggesting that the freedom to use and discard materials is intrinsic to the feeling of affluence. Yet only in the short run is it imaginable that we can afford to waste materials at current American levels. The act of recycling is a response to environmental concern at least as much as to market signals; it promotes an ethic of conservation, and increases the chances for learning-curve effects that will lead to environmentally desirable future technologies.

The techniques of life-cycle analysis, and the field of industrial ecology in general, have promoted a helpful focus on the comprehensive impacts of material use from cradle to grave. However, most studies show that the principal environmental impacts of nonhazardous material lifecycles occur in raw material extraction and the first stages of purification and processing of the resulting materials (see the discussion in Ackerman 1997, chapter 5). These are by far the dirtiest and most energy-intensive branches of industry. Impacts are much smaller in the later stages of refining, fabrication, transportation, use, and (in most but not all cases) disposal of the resulting materials. Thus the focus on industrial ecology, while considering the entire material lifecycle, can also be read as a study of how to minimize the use of (or the impacts of producing) virgin raw materials.

The industrial ecology of paper production has been particularly controversial. The widespread belief that recycling is environmentally beneficial has been challenged by claims that paper recovery and recycling may be no better than garbage collection and disposal. This is of enormous importance for recycling efforts, since paper and cardboard account for the great majority of recycled materials collected in municipal programs, whether measured by weight, volume, or dollar value.

Controversy is possible because two major life cycle analyses of the paper industry have reached somewhat contradictory conclusions. However, neither is entirely critical of recycling. A study by the Environmental Defense Fund, sponsored by several major paper-using companies and institutions, finds that recycling is almost always environmentally preferable to any form of waste disposal (for an article-length summary see Lauren Blum et al. 1997; see also several related commentaries in the same journal). In contrast, a study performed by the International Institute for Environment and Development, and partially funded by the paper industry, finds that incineration is on balance environmentally preferable to recycling for many but not all grades of paper (Maryanne Grieg-Gran et al. 1997). Despite this disagreement, both studies agree that recycling is almost always preferable to landfilling of paper, which is the only available alternatives for most of North America.

ENERGY

Energy is one of the biggest and dirtiest industries of all, centrally implicated in problems such as acid rain and climate change. The threat of exhaustion of nonrenewable resources has been widely discussed since the oil crises of the 1970s. Early analyses by Amory Lovins, Barry Commoner, and others identified plausible alternatives based on conservation and renewables – the “soft energy path.” Low-cost opportunities for increasing energy efficiency were routinely ignored before the first oil crisis in 1973; for years, total U.S. energy consumption had grown at essentially the same rate as economic output. Yet after 1973, in the atmosphere of crisis, energy conservation suddenly appeared to be a bargain; from 1973 to 1986 there was essentially no change in U.S. energy use, while real GNP grew by 40 percent (Michael Brower 1992). Still more can undoubtedly be done, since energy use per capita in the U.S. remains about twice as high as in Germany or Japan.

Meanwhile, renewable energy sources are becoming steadily cheaper. Wind power and solar water heating are already competitive with conventional energy sources in many areas, and other technologies such as photovoltaics (rooftop solar electricity generation panels) and fuel cells are promising for the long run. Thus advocates of the "soft path" call for using the remaining supplies of fossil fuels to ease the transition to a renewable energy future. For overviews of energy production and consumption see John Holdren (1990), Brower (1992), and Christopher Flavin and Nicholas Lenssen (1994). The challenge at this point is not primarily to develop new alternatives, but rather to overcome the massive political and economic obstacles to moving toward the soft energy path.

The problems of economic development and energy use appear quite different in developing countries, ex-Soviet nations, and the industrialized world. However, the summarized article by **John Byrne et al.** argues that China's energy problems and solutions have many parallels to those in the U.S. A gradual decline in China's energy/GDP ratio has been swamped by rapid economic growth, so that energy use has climbed sharply. In light of the country's abundant coal reserves, the path of least resistance seems to be to burn more of it, with dreadful environmental effects. As in the U.S., increased efficiency of energy use is often a cost-effective short-run alternative. In the long run, China, like the U.S., has ample potential to develop wind, solar, and geothermal energy.

The problem in Russia is almost the opposite. There the energy/GDP ratio remains high, reflecting the legacy of Soviet technology, which evolved in isolation from world markets and in a context of abundant fossil fuel supplies. Yet despite persistently high energy intensity, Russia's long economic slump has held down total energy use. If economic growth were to revive in Russia or other ex-Soviet nations, the prevailing patterns of inefficient energy use would cause severe economic and environmental problems (Eric Martinot 1996).

The hope of achieving efficiency by removing market distortions is a major theme of the World Bank's many studies of energy in developing countries. Robin Bates (1993) argues that developing countries frequently subsidize and control energy prices, tolerate or unintentionally create barriers to investment in energy efficiency, and fail to provide adequate financing or management for energy-producing firms. However, Bates remains optimistic about the ability of market mechanisms to solve these and related energy sector problems. Mohan Munasinghe (1995) offers a broader view from the World Bank, emphasizing issues of sustainability and the need to incorporate externalities and nonquantifiable objectives into developing country energy policy. His analysis points to a few high-priority technical fixes, but otherwise relies on the assumed ability of market-based policies to solve a wide range of problems.

Debate about energy policy in the U.S. increasingly centers on the role of the market. One goal that receives widespread support, at least in theory, is the elimination of subsidies to nonrenewable energy production. Several studies have identified numerous subsidies to fossil fuel and nuclear power, worth $15 to $35 billion annually depending on the study (see the citations and discussion in Ackerman 1997, Chapter 2, and David Roodman 1996). The "Green Scissors" report from Friends of the Earth targets 20 egregiously wasteful federal energy expenditures that are ripe for repeal, worth several billion dollars annually in total (Friends of the Earth 2000). Unfortunately, many of these expenditures are protected by powerful special interests, and have survived public criticism unscathed. While repeal of wasteful energy subsidies is obviously desirable, the amounts involved are too small, relative to the huge size of the industry, to have a significant effect on prices, consumer demand for energy, or the competitive position of alternative fuels.

In energy modeling, there is a longstanding debate between those who examine detailed energy supply and end-use technologies - so-called “bottom-up” studies - and those who rely on “top-down” or aggregate econometric techniques. Bottom-up studies routinely find ample opportunities for no-cost or low-cost conservation. Top-down models based on economic theory often rule this out a priori, sometimes casting the issue metaphorically as a debate about whether there are any $20 bills (free conservation opportunities) to be found lying on the sidewalk.

Examining U.S. energy use from the perspective of sustainability is a frustrating exercise. Many sensible opportunities to reorganize transportation, for example, are easy to describe in theory -- such as smaller, fuel-efficient autos and more mass transit -- but apparently politically impossible to implement in practice. One area where rapid institutional change is occurring is in the electric utility industry, where deregulation of generation has begun and will be adopted in most states over the next several years. Will this help or hurt the environment? For an overview that favors deregulation, see Keith Kozloff (1997). By breaking down utility monopolies, Kozloff argues that deregulation could allow market access for new, greener producers.

In contrast, the summarized chapters by **Peter Fox-Penner**, an experienced utility analyst, present a more skeptical view. Deregulation pursued without any attention to the environment could undercut the opportunities for conservation and renewable energy sources that were built into older regulatory systems, and could allow existing coal plants to capture a greater share of the national market for electricity. (These coal plants gain an important economic advantage by being “grandfathered” under regulations such as the Clean Air Act; see Ackerman et al. 1999). Fox-Penner argues that deregulation has potentially positive implications for the environment only in those cases, as in Massachusetts, where strong environmental provisions are incorporated into the law. Such provisions demonstrate that it is not the operation of the market per se, but rather the political and regulatory context within which the market operates, that creates the potential to move toward sustainability.

CLIMATE CHANGE

Among the most ominous effects of energy use (along with selected other activities) is the risk of long-term climate change. The basic science is by now familiar, and a formal international consensus of the experts has been reached (see the three volumes of IPCC 1996). Unfortunately, there is no comparable consensus in the political arena about how to proceed. The Kyoto Protocol, an international treaty proposing moderate initial steps toward climate change mitigation, was negotiated in late 1997. Although hailed by many countries and by independent observers, the Kyoto Protocol has thus far been stalled by U.S. Congressional opposition, with conservatives arguing that it asks too little of developing countries and too much of the U.S.

The debate over modeling strategies and assumptions, mentioned in connection with energy analyses, seems even deeper and harder to reconcile in the economics of climate change. Huge, intricate models run by differing researchers yield strikingly inconsistent results. Are there ample opportunities, as some studies find, to reduce carbon emissions at little or no cost? Or is any such "free lunch" implausible, as other studies report, since any substantial carbon reduction would be exorbitantly expensive? In some cases, zero-cost reduction is said to be impossible as a matter of economic theory, not empirical research. This view, quite common among conventional economists, implies that there must be "hidden costs" blocking the implementation of apparently costless opportunities. However, those hidden costs are rarely identified.

Many climate change analyses inappropriately apply very abstract economic models, as argued by Irene Peters et al. (1999). The general equilibrium framework of traditional economic theory is mathematically convenient, but typically rests on unrealistic assumptions associated with models of perfect competition. (For a more extensive theoretical critique, see Ackerman 2000a.) These assumptions rule out a priori some of the most important features of energy and environmental technologies, such as increasing returns to scale and learning curve (or learning-by-doing) effects. The unrealistic assumptions of general equilibrium models lead to the unrealistic conclusion that there is a unique, optimal path for energy development, rather than a choice between multiple options – e.g., soft vs. hard energy paths.

The essay by **Robert Repetto and Duncan Austin** summarized here demonstrates that it is possible to reconcile the estimates of the costs of climate change mitigation from numerous different economic models. A handful of key economic assumptions, described in the summary, turn out to account for virtually all of the differences in cost estimates. Under the most favorable assumptions, substantial reduction in carbon emissions could have a net positive economic impact; under the least favorable case, it has a very large net cost. Repetto and Austin conclude, on balance, that policy proposals such as carbon taxes would do no damage to the economy, and would bring long-term environmental benefits. However, many uncertainties surround several of the key assumptions, and further analysis is needed. A helpful agenda for further research on the economics of climate is proposed by Michael Toman (1998).

Some of the dilemmas in the field are matters of theory, not of empirical research. The summarized article by **Robert Lind and Richard Schuler** attacks one of the controversial theoretical foundations of climate change modeling, namely the use of discounting for events far in the future. The greatest benefits of climate change mitigation will be enjoyed by generations long after those who pay the costs. As discussed in Part I of this volume, there is no logical basis for adopting a numerical discount rate for intergenerational calculations; rather, there is a need for careful examination of costs, and public debate over alternatives. (Agreeing that the conventional approaches to discounting do not make sense, Cédric Philibert 1999 reviews the theoretical debates on these questions and proposes a different solution, a gradually declining discount rate combined with gradually rising prices for non-reproducible environmental assets.)

Lind and Schuler also raise the fundamental question of the equity implications of climate policy. Investment in climate change mitigation involves equity between rich and poor, as well as between present and future generations. Is it logically contradictory, and/or politically self-defeating, to recommend substantial investment on behalf of the future without doing the same on behalf of today's poor?

As important as these larger theoretical debates may be, it is also worth remembering that numerous studies do find practical steps that can be taken today at little or no net cost. Even if these steps do not yet lead all the way to a comprehensive long-term strategy, there is little harm, and potentially a lot to be gained, by starting as soon as possible. For a widely discussed economic analysis advocating immediate action, see William Cline (1992). More recent studies that reach similar conclusions include Stephen Bernow and Max Duckworth (1998), and Union of Concerned Scientists / Tellus Institute (1998).

Detailed engineering analyses of emissions of methane, the second most important greenhouse gas, also identify low-cost/no-cost options for reduction (EPA 1999). Familiar "low-technology" policies such as recycling of municipal waste have substantial climate benefits, due to the combined effects of the reduction in landfill methane emissions, the reduction in industrial energy requirements, and (in the case of paper recycling) the increase in forest carbon sequestration (Ackerman 2000b).

Greenhouse emissions per capita are currently lower, but are growing faster, in developing countries. This is due both to the rate of economic growth and to structural change, e.g. from agriculture to manufacturing (Xiaoli Han and Lata Chatterjee 1997). Thus it is particularly important to develop strategies for emission reduction in developing countries. Options for technology transfer oriented to climate change mitigation are discussed in Martinot et al. (1997). There is no iron law of development requiring a fixed ratio of carbon emissions to GDP; in practice these ratios vary widely, suggesting that even with existing technology there is room for improvement almost everywhere (William Moomaw and Mark Tullis 1994).

CONCLUSION

Are we already moving toward solutions to the long-run problems of energy, materials, and climate change? Or are we far from doing enough to create a sustainable material world? The answer is undoubtedly yes to both questions. There are encouraging signs of change, and researchers have identified numerous technologically feasible solutions to serious environmental problems. The image of relentless and unmitigated ecological disaster, all too common in speeches and fundraising appeals, is both misleading as description and counterproductive (because it is so demoralizing) as advocacy.

At the same time, the magnitude of required changes is enormous, and the existing pace of environmental gains is only a start toward what will ultimately be needed. The Kyoto agreement on climate change, which to date has proved too controversial for U.S. congressional approval, still proposes to do noticeably less than what is called for in most scientific analyses of global warming. To create a world of renewable energy, sustainable material use, and low, limited carbon emissions -- the world that we can and should leave to future generations -- we will have to move much farther and faster.

In short, great things have been done, and greater things still need to be done, to address the problems of sustainable materials and energy use, and to respond to the threat of climate change.