

4

The Shape of the Eco-Economy

In March 2000, at a briefing on *State of the World 2000* for World Bank staff, I noted that proposed projects should help build an economy that is environmentally sustainable, not one that self-destructs. In response, someone said that the Bank always does an environmental assessment of its projects. But that's the problem, I replied. Environmental scientists are assessing the effects of projects *after* economists have decided which investments to make. At best, the scientists can suggest steps to ameliorate the environmental damage from the projects selected by economists.

What are the odds that an economist not trained in ecology will independently design projects that collectively will build an economy that is environmentally sustainable? Not very high. The same could be said of all leading economic decisionmakers—corporate planners, government policymakers, and investment bankers.

As noted in Chapter 1, an economy is sustainable only if it respects the principles of ecology. These principles are as real as those of aerodynamics. If an aircraft is to fly, it has to satisfy certain principles of thrust and lift. So, too, if an economy is to sustain progress, it must satisfy the basic principles of ecology. If it does not, it will decline and eventually collapse. There is no middle

ground. An economy is either sustainable or it is not.

Today's global economy has been shaped by market forces, not by the principles of ecology. Unfortunately, by failing to reflect the full costs of goods and services, the market provides misleading information to economic decisionmakers at all levels. This has created a distorted economy that is out of sync with the earth's ecosystem—an economy that is destroying its natural support systems.

The market does not recognize basic ecological concepts of sustainable yield nor does it respect the balances of nature. For example, it pays no attention to the growing imbalance between carbon emissions and nature's capacity to fix carbon, much less to the role of burning fossil fuels in creating the imbalance. For most economists, a rise in carbon dioxide (CO₂) levels is of little concern. For an ecologist, such a rise—driven by the use of fossil fuels—is a signal to shift to other energy sources in order to avoid rising temperatures, melting ice, and rising sea level.

An eco-economy is one that satisfies our needs without jeopardizing the prospects of future generations to meet their needs, as the Brundtland Commission pointed out nearly 15 years ago. The purpose of this chapter is to provide a sense of what an eco-economy will look like. It also offers some sense of the scope of this change. It is not a trivial undertaking.¹

Ecology Over Economics

Ecologists understand the ecological processes that support life on earth. They understand the fundamental role of photosynthesis, the concept of sustainable yield, the role of nutrient cycles, the hydrological cycle, the sensitive role of climate, and the intricate relationship between the plant and animal kingdom. They know that the earth's ecosystems supply services as well as goods and that the former are often more valuable than the latter.

A sustainable economy respects the sustainable yield of the ecosystems on which it depends: fisheries, forests, rangelands, and croplands. A particular fishery can sustain a catch of a certain size, but if the demands on the fishery exceed the sustainable yield by even the smallest amount—say, 2 percent a year—the fish stocks will begin to shrink and will eventually disappear. As long as the harvest does not exceed the sustainable yield, it can be sustained in perpetuity. The same is true for forests and rangelands.

Nature also relies on balances. These include balances between

soil erosion and new soil formation, between carbon emissions and carbon fixation, and between trees dying and trees regenerating.

Nature depends on cycles to maintain life. In nature, there are no linear flow-throughs, no situations where raw materials go in one end and garbage comes out the other. In nature, one organism's waste is another's sustenance. Nutrients are continuously cycled. This system works. Our challenge is to emulate it in the design of the economy.

Ecologists appreciate the role of photosynthesis, the process by which plants convert solar energy into the biochemical energy that supports life on the earth. Anything that reduces the photosynthetic product, such as desertification, the paving of productive land, or the acidification of lakes by acid rain, reduces the productivity of the earth in the most fundamental sense.

Despite this long-standing body of ecological knowledge, national governments have expanded economic activity with little regard for sustainable yields or the fragile balances in nature. Over the last half-century, the sevenfold expansion of the global economy has pushed the demand on local ecosystems beyond the sustainable yield in country after country. The fivefold growth in the world fish catch since 1950 has pushed the demand of most oceanic fisheries past their ability to produce fish sustainably. The sixfold growth in the worldwide demand for paper is shrinking the world's forests. The doubling of the world's herds of cattle and flocks of sheep and goats since 1950 is damaging rangelands, converting them to desert.²

An ecologist not only recognizes that the services provided by ecosystems may sometimes be worth more than the goods, but that the value of services needs to be calculated and incorporated into market signals if they are to be protected. Although calculating services is not a simple matter, any reasonable estimate is far better than assuming that the costs are zero, as is now the case. For example, a forest in the upper reaches of a watershed may provide services such as flood control and the recycling of rainfall inland that are several times more valuable than its timber yield. Unfortunately, market signals do not reflect this, because the loggers who are cutting the trees do not bear the costs of the reduction in services. National economic policies and corporate strategies are based largely on market signals. The clearcutting of a forest may be profitable for a logging firm, but it is economically costly to society.

Another major failure of the market to provide reliable information comes when governments subsidize the depletion of resources or environmentally destructive activities. (See also Chapter 11.) For example, over several decades the U.S. Forest Service used taxpayer money to build roads into national forests so that logging companies could clearcut forests. This not only artificially lowered the costs of lumber and paper, it led to flooding, soil erosion, and the silting of streams and rivers. In the Pacific Northwest, it destroyed highly productive salmon fisheries. And all this destruction was underwritten by taxpayers.³

In a world where the demands of the economy are pressing against the limits of natural systems, relying on distorted market signals to guide investment decisions is a recipe for disaster. Historically, for example, when the supply of fish was inadequate, the price would rise, encouraging investment in additional fishing trawlers. When there were more fish in the sea than we could ever hope to catch, the market worked well. Today, with the fish catch often exceeding the sustainable yield, investing in more trawlers in response to higher prices will simply accelerate the collapse of these fisheries.

A similar situation exists with other natural systems, such as aquifers, forests, and rangelands. Once the climbing demand for water surpasses the sustainable yield of aquifers, the water tables begin to fall and wells go dry. The market says drill deeper wells. Farmers engage in a competitive orgy of well drilling, chasing the water table downward. On the North China Plain, where 25 percent of the country's grain is produced, this process is under way. In Hebei Province, data for 1999 show 36,000 wells, mostly shallower ones, being abandoned during the year as 55,000 new, much deeper wells were drilled. In Shandong Province, 31,000 were abandoned and 68,000 new wells were drilled.⁴

In an eco-economy, by definition one that respects the principles of ecology, drilling additional wells would be banned once a water table showed signs of falling. Instead of spending money to dig deeper wells, investments would be channeled into measures to boost water efficiency and to stabilize population in order to bring water use into balance with the sustainable supply.

Evidence is accumulating that our global economy is slowly undermining itself on several fronts. If we want economic progress to continue, we have little choice but to systematically

restructure the global economy in order to make it environmentally sustainable.

A Monumental Undertaking

Converting our economy into an eco-economy is a monumental undertaking. There is no precedent for transforming an economy shaped largely by market forces into one shaped by the principles of ecology.

The scale of projected economic growth outlines the dimensions of the challenge. The growth in world output of goods and services from \$6 trillion in 1950 to \$43 trillion in 2000 has caused environmental devastation on a scale that we could not easily have imagined a half-century ago. If the world economy continued to expand at 3 percent annually, the output of goods and services would increase fourfold over the next half-century, reaching \$172 trillion.⁵

Building an eco-economy in the time available requires rapid systemic change. We will not succeed with a project here and a project there. We are winning occasional battles now, but we are losing the war because we do not have a strategy for the systemic economic change that will put the world on a development path that is environmentally sustainable.

Although the concept of environmentally sustainable development evolved a quarter-century ago, not one country has a strategy to build an eco-economy—to restore carbon balances, to stabilize population and water tables, and to conserve its forests, soils, and diversity of plant and animal life. We can find individual countries that are succeeding with one or more elements of the restructuring, but not one that is progressing satisfactorily on all fronts.

Nevertheless, glimpses of the eco-economy are clearly visible in some countries. For example, 31 countries in Europe, plus Japan, have stabilized their population size, satisfying one of the most basic conditions of an eco-economy. Europe has stabilized its population within its food-producing capacity, leaving it with an exportable surplus of grain to help fill the deficits in developing countries. Furthermore, China—the world's most populous country—now has lower fertility than the United States and is moving toward population stability.⁶

Among countries, Denmark is the eco-economy leader. It has stabilized its population, banned the construction of coal-fired

power plants, banned the use of nonrefillable beverage containers, and is now getting 15 percent of its electricity from wind. In addition, it has restructured its urban transport network; now 32 percent of all trips in Copenhagen are on bicycle. Denmark is still not close to balancing carbon emissions and fixation, but it is moving in that direction.⁷

Other countries have also achieved specific goals. A reforestation program in South Korea, begun more than a generation ago, has blanketed the country's hills and mountains with trees. Costa Rica has a plan to shift entirely to renewable energy by 2025. Iceland, working with a consortium of corporations led by Shell and DaimlerChrysler, plans to be the world's first hydrogen-powered economy.⁸

So we can see pieces of the eco-economy emerging, but systemic change requires a fundamental shift in market signals, signals that respect the principles of ecological sustainability. Unless we are prepared to shift taxes from income to environmentally destructive activities, such as carbon emissions and the wasteful use of water, we will not succeed in building an eco-economy. (See Chapter 11.)

Restoring the balances of nature is a huge undertaking. For energy, it depends on shifting from a carbon-based economy to a hydrogen-based one. Even the most progressive oil companies, such as BP and Royal Dutch Shell, that are talking extensively about building a solar/hydrogen energy economy are still investing overwhelmingly in oil, with funds going into climate-benign sources accounting for a minute share of their investment.⁹

Reducing soil erosion to the level of new soil formation will require changes in farming practices. In some situations, it will mean shifting from intense tillage to minimum tillage or no tillage. Agroforestry will loom large in an eco-economy.

Restoring forests that recycle rainfall inland and control flooding is itself a huge undertaking. It means reversing decades of tree cutting and land clearing with forest restoration, an activity that will require millions of people planting billions of trees.

Building an eco-economy will affect every facet of our lives. It will alter how we light our homes, what we eat, where we live, how we use our leisure time, and how many children we have. It will give us a world where we are a part of nature, instead of estranged from it.

Restructuring the Economy

An economy that is in sync with the earth's ecosystem will contrast profoundly with the polluting, disruptive, and ultimately self-destructing economy of today—the fossil-fuel-based, automobile-centered, throwaway economy. One of the attractions of the western economic model is that it has raised living standards for one fifth of humanity to a level that our ancestors could not have dreamed of, providing a remarkably diverse diet, unprecedented levels of material consumption, and unimagined physical mobility. But unfortunately it will not work over the long term even for the affluent one fifth, much less for the entire world.

Among the key economic sectors—energy, materials, and food—the most profound changes will be in energy and materials. It is difficult to imagine a more fundamental sectoral restructuring than that in the energy sector as it shifts from oil, coal, and natural gas to wind, solar cells, and geothermal energy.

With materials, the change is not so much in the materials used as in the structure of the sector itself as it shifts from the linear economic model, where materials go from the mine or forest to the landfill, to the reuse/recycle model. In this closed loop system, which emulates nature, recycling industries will largely replace extraction industries.

In the food sector, the big changes are not in structure, but in the way the sector is managed. The challenge here is to better manage natural capital, to stabilize aquifers by increasing water productivity, and to conserve topsoil by altering agricultural practices. And above all else, it means sustaining the rise in land productivity in order to avoid clearing more forests for food production.

We can now see what an eco-economy looks like. Instead of being run on fossil fuels, it will be powered by sources of energy that derive from the Sun, such as wind and sunlight, and by geothermal energy from within the earth. (See Chapter 5.) It will be hydrogen-based instead of carbon-based. Cars and buses will run on fuel-cell engines powered by electricity produced with an electrochemical process using hydrogen as the fuel instead of internal combustion engines. With fuel cells powered by hydrogen, there is no climate-disrupting CO₂ or noxious health-damaging pollutants; only water is emitted.

In the new economy, atmospheric CO₂ levels will be stable. In contrast to today's energy economy, where the world's reserves of

oil and coal are concentrated in a handful of countries, energy sources in the eco-economy will be widely dispersed—as widely distributed as sunlight and wind. The heavy dependence of the entire world on one geographic region—the Middle East—for much of its energy will likely decline as the new climate-benign energy sources and fuel-cell engines take over.

The energy economy will be essentially a solar/hydrogen economy with various energy sources deriving from the Sun used either directly for heating and cooling or indirectly to produce electricity. Wind-generated electricity, which is likely to be the lowest-cost source of energy, will be used to electrolyze water, producing hydrogen. This provides a means of both storing and transporting wind energy. Initially, existing natural gas pipelines will be used to distribute hydrogen. But over the longer term, both natural gas and oil pipeline networks can be adapted to carry hydrogen as the world shifts from a carbon-based to a hydrogen-based economy.

The transport systems of cities will change—indeed, they already are. Instead of the noisy, congested, polluting, auto-centered transport systems of today, cities will have rail-centered transport systems and they will be bicycle- and pedestrian-friendly, offering more mobility, more exercise, cleaner air, and less frustration. (See Chapter 9.) Historians looking back on the current system will likely see it as a dark age in urban evolution.

Urban transport systems will have the same components as they do today: automobile, rail, bus, and bicycle. The difference will be in the mix. As more and more city planners recognize the inherent conflict between the automobile and the city, new, cleaner, more efficient transport systems will develop. Urban personal mobility will increase as automobile use and traffic congestion decline.

The materials sector of the eco-economy will look far different too. (See Chapter 6.) Mature industrial economies with stable populations can operate largely by recycling the materials already in use. The materials loop will be closed, yielding no waste and nothing for the landfills.

One of the keys to reversing the deforestation of the earth is paper recycling; the potential here has been only partly realized. A second key is developing alternative energy sources that will reduce the amount of wood used as fuel. In addition, boosting the efficiency of wood burning can measurably lighten the load on forests.

Another promising option is the use of carefully designed, ecologically managed, and highly productive tree plantations. A small area devoted to plantations may be essential to protecting forests at the global level. Plantations can yield several times as much wood per hectare as can a natural forest.

In the economy of the future, the use of water will be in balance with supply. Water tables will be stable, not falling. The economic restructuring will be designed to raise water productivity in every facet of economic activity.

In this environmentally sustainable economy, harvests from oceanic fisheries, a major source of animal protein in the human diet, will be reduced to the sustainable yield. Additional demand will be satisfied by fish farming. This is, in effect, an aquatic version of the same shift that occurred during the transition from hunting and gathering to farming. The freshwater, herbivorous carp polyculture on which the Chinese rely heavily for their vast production of farmed fish offers an ecological model for the rest of the world.¹⁰

A somewhat similar situation exists for rangelands. One of the keys to alleviating the excessive pressure on rangelands is to feed livestock the crop residues that are otherwise being burned for fuel or for disposal. This trend, already well under way in India and China, may hold the key to stabilizing the world's rangelands. (See Chapter 7.)¹¹

And finally, the new economy will have a stable population. Over the longer term, the only sustainable society is one in which couples have an average of two children.

New Industries, New Jobs

Describing the eco-economy is obviously a somewhat speculative undertaking. In the end, however, it is not as open-ended as it might seem because the eco-economy's broad outlines are defined by the principles of ecology.

The purpose of describing the restructuring of the overall economy before turning to chapters on the key sectors is to give a sense of the dynamics at work. The specific trends and shifts described are not projections of what will happen, though the term "will" is often used here for the sake of efficiency. No one knows if these shifts "will" in fact occur, but we do know that something like this is needed if we are to build an eco-economy.

What is not so clear is how ecological principles will translate

into economic design since, for example, each country has a unique combination of renewable energy sources that will power its economy. Some countries may draw broadly on all their renewable energy sources, while others may concentrate heavily on one that is particularly abundant, say wind or solar energy. A country with a wealth of geothermal energy may choose to structure its energy economy around this subterranean energy source.

Building a new economy involves phasing out old industries, restructuring existing ones, and creating new ones. World coal use is already being phased out, dropping 7 percent since peaking in 1996. It is being replaced by efficiency gains in some countries; by natural gas in others, such as the United Kingdom and China; and by wind power in others such as Denmark.¹²

The automobile industry faces a major restructuring as it changes power sources, shifting from the gasoline-powered internal combustion engine to the hydrogen-powered fuel cell engine. This shift from the explosive energy that derives from igniting gasoline vapor to a chemical reaction that generates electricity will require both a retooling of engine plants and the retraining of automotive engineers and automobile mechanics.

The new economy will also bring major new industries, ones that either do not yet exist or that are just beginning. Wind electricity generation is one such industry. (See Table 4-1.) Now in its embryonic stage, it promises to become the foundation of the new energy economy. Millions of turbines soon will be converting wind into electricity, becoming part of the global landscape. In many countries, wind will supply both electricity and, through the electrolysis of water, hydrogen. Together, electricity and hydrogen can meet all the energy needs of a modern society.

In effect, there will be three new subsidiary industries associated with wind power: turbine manufacturing, installation, and maintenance. Manufacturing facilities will be found in scores of countries, industrial and developing. Installation, which is basically a construction industry, will be more local in nature. Maintenance, since it is a day-to-day activity, will be a source of ongoing local employment.

The robustness of the wind turbine industry was evident in 2000 and 2001 when high tech stocks were in a free fall worldwide. While high tech firms as a group were performing poorly, sales of wind turbines were climbing, pushing the earnings of turbine manu-

Table 4–1. *Examples of Eco-Economy Industries*

Industry	Description
Fish farming	Although growth will slow from the double-digit rate of the last decade, rapid expansion is likely to continue.
Bicycle manufacturing	Because bicycles are nonpolluting, quiet, require little parking space, and provide much-needed exercise in exercise-deprived societies, they will become increasingly common.
Wind farm construction	Wind electric generation, including off-shore wind farms, will grow rapidly over the next few decades, until wind is supplying most of the world's electricity.
Wind turbine manufacturing	Today the number of utility-scale wind turbines is measured in the thousands, but soon it will be measured in the millions, creating an enormous manufacturing opportunity.
Hydrogen generation	As the transition from a carbon-based to a hydrogen-based energy economy progresses, hydrogen generation will become a huge industry as hydrogen replaces coal and oil.
Fuel cell manufacturing	As fuel cells replace internal combustion engines in automobiles and begin generating power in buildings, a huge market will evolve.
Solar cell manufacturing	For many of the 2 billion people living in rural Third World communities who lack electricity, solar cells will be the best bet for electrification.
Light rail construction	As people tire of the traffic congestion and pollution associated with the automobile, cities in industrial and developing countries alike will be turning to light rail to provide mobility.
Tree planting	As efforts to reforest the earth gain momentum and as tree plantations expand, tree planting will emerge as a leading economic activity.

facturers to the top of the charts. Continuing growth of this sector is expected for the next few decades.

As wind power emerges as a low-cost source of electricity and a mainstream energy source, it will spawn another industry—hydrogen production. Once wind turbines are in wide use, there will be a large, unused capacity during the night when electricity use drops. With this essentially free electricity, turbine owners can turn on the hydrogen generators, converting the wind power into hydrogen, ideal for fuel cell engines. Hydrogen generators will start to replace oil refineries. The wind turbine will replace both the coal mine and the oil well. (See Table 4–2.) Both wind turbines and hydrogen generators will be widely dispersed as countries take advantage of local wind resources.

Changes in the world food economy will also be substantial. (See Chapter 7.) Some of these, such as the shift to fish farming, are already under way. The fastest growing subsector of the world food economy during the 1990s was aquaculture, expanding at more than 11 percent a year. Fish farming is likely to continue to expand simply because of its efficiency in converting grain into animal protein.¹³

Even allowing for slower future growth in aquaculture, fish farm output will likely overtake beef production during this decade. Perhaps more surprising, fish farming could eventually exceed the oceanic fish catch. Indeed, for China—the world’s leading consumer of seafood—fish farming already supplies two thirds of the seafood while the oceanic catch accounts for the other third.¹⁴

With this development comes the need for a mixed-feed industry, one analogous to that which provides the nutritionally balanced rations used by the poultry industry today. There will also be a need for aquatic ecologists, fish nutritionists, and marine veterinarians.

Another growth industry of the future is bicycle manufacturing and servicing. Because the bicycle is nonpolluting, frugal in its use of land, and provides the exercise much needed in sedentary societies, future reliance on it is expected to grow. As recently as 1965, the production of cars and bikes was essentially the same, but today more than twice as many bikes as cars are manufactured each year. Among industrial countries, the urban transport model being pioneered in the Netherlands and Denmark, where bikes are featured prominently, gives a sense of the bicycle’s future role worldwide.¹⁵

Table 4–2. *Examples of Eco-Economy Sunset Industries*

Industry	Description
Coal mining	The 7 percent decline in world coal burning since it peaked in 1996 will continue in the years ahead.
Oil pumping	Projections based on shrinking oil reserves indicate production will peak and start declining in the next 5–20 years. Concern about global warming could bring the decline closer.
Nuclear power generation	Although public concern focuses on safety issues, it is the high cost that is ensuring the industry's decline.
Clearcut logging	The rapid spread in eco-labeling of forest products will likely force logging firms to change to sustainable harvesting or be driven out of business.
Manufacture of throwaway products	As efforts to close the materials cycle intensify, many throwaway products will be either banned or taxed out of existence.
Automobile manufacturing	As world population urbanizes, the conflict between the automobile and the city will intensify, reducing dependence on automobiles.

As bicycle use expands, interest in electrically assisted bikes is also growing. Similar to existing bicycles, except for a tiny battery-powered electric motor that can either power the bicycle entirely or assist elderly riders or those living in hilly terrain, its soaring sales are expected to continue climbing in the years ahead.

Yet another growth industry is raising water productivity. Just as the last half-century has been devoted to raising land productivity, the next half-century will be focused on raising water productivity. Virtually all societies will be turning to the management of water at the watershed level in order to manage available supply most efficiently. Irrigation technologies will become more efficient. Urban waste water recycling will become common. At present, water tends to flow into and out of cities, carrying waste with it. In the

future, water will be used over and over, never discharged. Since water does not wear out, there is no limit to how long it can be used, as long as it is purified before reuse.

Another industry that will play a prominent role in the new economy, one that will reduce energy use, is teleconferencing. Increasingly for environmental reasons and to save time, individuals will be “attending” conferences electronically with both audio and visual connections. This industry involves developing the electronic global infrastructure, as well as the services, to make this possible. One day there will likely be literally thousands of firms organizing electronic conferences.

Restructuring the global economy will create not only new industries, but also new jobs—indeed, whole new professions and new specialties within professions. (See Table 4–3.) For example, as wind becomes an increasingly prominent energy source, there will be a need for thousands of wind meteorologists to analyze potential wind sites, monitor wind speeds, and select the best sites for wind farms. The better the data on wind resources, the more efficient the industry will become.

Closely related to this new profession will be the wind engineers who design the wind turbines. Again, the appropriate turbine size and design can vary widely according to site. It will be the job of wind engineers to tailor designs to specific wind regimes in order to maximize electricity generation.

Environmental architecture is another fast-growing profession. Among the signposts of an environmentally sustainable economy are buildings that are in harmony with the environment. Environmental architects design buildings that are energy- and materials-efficient and that maximize natural heating, cooling, and lighting.

In a future of water scarcity, watershed hydrologists will be in demand. It will be their responsibility to understand the hydrological cycle, including the movement of underground water, and to know the depth of aquifers and determine their sustainable yield. They will be at the center of watershed management regimes.

As the world shifts from a throwaway economy, engineers will be needed to design products that can be recycled—from cars to computers. Once products are designed to be disassembled quickly and easily into component parts and materials, comprehensive recycling is relatively easy.

Technologies used in recycling are sometimes quite different from

Table 4–3. *Expanding Professions in an Eco-Economy*

Profession	Description
Wind meteorologists	Wind meteorologists will play a role in the new energy economy comparable to that of petroleum geologists in the old one.
Family planning midwives	If world population is to stabilize soon, literally millions of family planning midwives will be needed.
Foresters	Reforestation of the earth will require professional guidance on what species to plant where and in what combination.
Hydrologists	As water scarcity spreads, the demand for hydrologists to advise on watershed management, water sources, and water efficiency will increase.
Recycling engineers	Designing consumer appliances so they can be easily disassembled and completely recycled will become an engineering specialty.
Aquacultural veterinarians	Until now, veterinarians have typically specialized in either large animals or small animals, but with fish farming likely to overtake beef production before the end of this decade, marine veterinarians will be in demand.
Ecological economists	As it becomes clear that the basic principles of ecology must be incorporated into economic planning and policymaking, the demand for economists able to think like ecologists will grow.
Geothermal geologists	With the likelihood that large areas of the world will turn to geothermal energy both for electricity and for heating, the demands for geothermal geologists will climb.
Environmental architects	Architects are learning the principles of ecology so they can incorporate them into the buildings in which we live and work.
Bicycle mechanics	As the world turns to the bicycle for transportation and exercise, bicycle mechanics will be needed to keep the fleet running.
Wind turbine engineers	With millions of wind turbines likely to be installed in the decades ahead, there will be strong worldwide demand for wind turbine engineers.

those used in producing from virgin raw materials. Within the U.S. steel industry, for example, where nearly 60 percent of all steel is produced from scrap, the technologies used differ depending on the feedstock. Steel manufactured in electric arc furnaces from scrap uses far less energy than traditional open-hearth furnaces using pig iron. It will be the responsibility of the recycling engineers to close the materials loop, converting the linear flow-through economy into a comprehensive recycling economy.¹⁶

In countries with a wealth of geothermal energy, it will be up to geothermal geologists to locate the best sites either for power plants or for tapping directly to heat buildings. Retraining petroleum geologists to master geothermal technologies is one way of satisfying the likely surge in demand for geothermal geologists.

If the world is to stabilize population sooner rather than later, it will need far more family planning midwives in Third World communities. This growth sector will be concentrated largely in developing countries, where millions of women lack access to family planning. The same family planning counselors who advise on reproductive health and contraceptive use can also play a central role in controlling the spread of HIV.

Another pressing need, particularly in developing countries, is for sanitary engineers who can design sewage systems not dependent on water, a trend that is already under way in some water-scarce countries. As it becomes clear that using water to wash waste away is a reckless use of a scarce resource, a new breed of sanitary engineers will be in wide demand. Washing waste away is even less acceptable today as marine ecosystems are overwhelmed by nutrient flows. Apart from the ecological disruption of a water-based disposal method, there are also much higher priorities in the use of water, such as drinking, bathing, and irrigation.

Yet another new specialty that is likely to expand rapidly in agriculture as productive farmland becomes scarce is agronomists who specialize in multiple cropping and intercropping. This requires an expertise both in the selection of crops that can fit together well in a tight rotation in various locales and in agricultural practices that facilitate multiple cropping.

History's Greatest Investment Opportunity

Restructuring the global economy so that economic progress can be sustained represents the greatest investment opportunity in his-

tory. As noted in Chapter 1, the conceptual shift is comparable to that of the Copernican Revolution in the sixteenth century. In scale, the Environmental Revolution is comparable to the Agricultural and Industrial Revolutions that preceded it.

The Agricultural Revolution involved restructuring the food economy, shifting from a nomadic life-style based on hunting and gathering to a settled life-style based on tilling the soil. Although agriculture started as a supplement to hunting and gathering, it eventually replaced it almost entirely. The Agricultural Revolution entailed clearing one tenth of the earth's land surface of either grass or trees so it could be plowed. Unlike the hunter-gatherer culture that had little effect on the earth, this new farming culture literally transformed the surface of the earth.¹⁷

The Industrial Revolution has been under way for two centuries, although in some countries it is still in its early stages. At its foundation was a shift in sources of energy from wood to fossil fuels, a shift that set the stage for a massive expansion in economic activity. Indeed, its distinguishing feature is the harnessing of vast amounts of fossil energy for economic purposes. While the Agricultural Revolution transformed the earth's surface, the Industrial Revolution is transforming the earth's atmosphere.

The additional productivity that the Industrial Revolution made possible unleashed enormous creative energies. It also gave birth to new life-styles and to the most environmentally destructive era in human history, setting the world firmly on a course of eventual economic decline.

The Environmental Revolution resembles the Industrial Revolution in that each is dependent on the shift to a new energy source. And like both earlier revolutions, the Environmental Revolution will affect the entire world.

There are differences in scale, timing, and origin among the three revolutions. Unlike the other two, the Environmental Revolution must be compressed into a matter of decades. The other revolutions were driven by new discoveries, by advances in technology, whereas this revolution is being driven more by our instinct for survival.

As noted earlier, there has not been an investment situation like this before. The amount that the world spends now each year on oil, the leading source of energy, provides some insight into how much it could spend on energy in the eco-economy. In 2000, the

world used nearly 28 billion barrels of oil, some 76 million barrels per day. At \$27 a barrel, this comes to \$756 billion per year. How many wind turbines will it take to produce this much energy? How many solar rooftops? How many geothermal wells?¹⁸

One big difference between the investments in fossil fuels and those in wind power, solar cells, and geothermal energy is that the latter will supply energy in perpetuity. These “wells” will not run dry. If the money spent on oil in one year were invested in wind turbines, the electricity generated would be enough to meet one fifth of the world’s needs.¹⁹

Investments in the infrastructure for the new energy economy, which would eventually have to be made as fossil fuels are depleted, will obviously be huge. These include the transmission lines that connect wind farms with electricity consumers, and the pipelines that link hydrogen supply sources with end-users. To a substantial degree, the infrastructure for the existing energy economy—the transmission lines for electricity and the pipelines for natural gas—can be used in the new energy economy as well. The local pipeline distribution network in various cities for natural gas can easily be converted to hydrogen.

For developing countries, the new energy sources promise to reduce dependence on imported oil, freeing up capital for investment in domestic energy sources. Although few countries have their own oil fields, all have wind and solar energy. In terms of economic expansion and job generation, these new energy technologies are a godsend.

Investments in energy efficiency are also likely to grow rapidly simply because they are so profitable. In virtually all countries, industrial and developing, saved energy is the cheapest source of new energy. Replacing inefficient incandescent light bulbs with highly efficient compact fluorescent lamps offers a rate of return that stock markets are unlikely to match.

There are also abundant investment opportunities in the food economy. It is likely that the world demand for seafood, for example, will increase at least by half over the next 50 years, and perhaps much more. If so, fish farming output—now 31 million tons a year—will roughly need to triple, as will investments in fish farming. Although aquaculture’s growth is likely to slow from the 11 percent a year of the last decade, it is nonetheless likely to be robust, presenting a promising opportunity for future investment.²⁰

A similar situation exists for tree plantations. At present, tree plantations cover some 113 million hectares. An expansion of these by at least half, along with a continuing rise in productivity, is likely to be needed both to satisfy future demand and to eliminate one of the pressures that are shrinking forests. This, too, presents a huge opportunity for investment.²¹

No sector of the global economy will be untouched by the Environmental Revolution. In this new economy, some companies will be winners and some will be losers. Those who anticipate the emerging eco-economy and plan for it will be the winners. Those who cling to the past risk becoming part of it.