CHAPTER 9

REPLACING FOSSIL FUEL WITH CLEAN ENERGY

9.1 The general strategy

Chapter 7 documented a close connection between recent economic activity and widespread ecological degradation. It also laid out reasons for thinking that ecological damage resulting from current economic activity is due largely to use of fossil fuel. There is increasing awareness among scientists and other cognizant people that these damaging side-effects of fossil fuel must be curtailed.

Three strategies were identified in Chapter 8 by which these harmful side-effects might conceivably be reduced. One is to confront the many undesirable consequences of fossil-fuel use on a piecemeal basis. This strategy was examined in the course of that chapter and found unreliable as a general cure of our environmental problems.

Another strategy calls for replacing fossil fuel with so-called “clean energy,” hoping thereby to break the link between economic production and ecological destruction. Like the piecemeal strategy of Chapter 8, this approach is compatible with continued economic growth. Also like the previous strategy, accordingly, it is viewed with general favor both by mainstream economists and by many members of the business community. Because of this, significant steps have already been taken in the development of clean-energy sources.

This is the main reason for dealing with the replacement strategy in the present chapter, following the piecemeal strategy already treated in Chapter 8. Both are strategies already underway. When the shortcomings of these two current approaches have been assessed, we will be in a better position to consider the strengths and weaknesses of the remaining strategy calling for curtailment of economic growth. Treatment of this distinctly less popular strategy is set aside for the next two chapters.

9.2 Clean energy

To understand the significance of the replacement strategy, we need a working definition of the term 'clean energy'. Commonly recognized examples of clean energy include energy got directly from solar radiation (by means other than photosynthesis), from wind, from moving water, and perhaps a few other sources (such as geothermal). What these types of energy have in common to merit the description "clean" is that they can be harnessed and used without direct damage to the biosphere.

One reason clean energy is environmentally benign is that it is available without major disruption of ongoing natural processes. Solar radiation is naturally present without human involvement, along with wind and moving water. Although technology often comes into play in harnessing such energy for human use, the technology involved need not be invasive. Windmills and waterwheels can often be put to use without interrupting the balance of local ecosystems.

For the most part, sources of clean energy are also renewable. An energy source is renewable if it can be replenished without technological assistance. Although technology is sometimes (not always) required to make solar energy available for human use, the radiation providing this energy is continuously renewed on a natural basis. Energy from wind and water is also renewable in this respect. While not always available in quantities or forms desired, energy from such sources is never completely used up.

Other forms of energy frequently touted as clean and renewable are nuclear and biofuel.[1] Thinking of biofuel simply as fuel derived from biomass, we can acknowledge a sense in which its source is renewable. Plant life is constantly being replaced on a natural basis, regardless of its use for human purposes. But biofuels themselves are not renewable. Once consumed, they would never be replenished without extensive involvement of human technology.

Biofuels, moreover, are far from clean. This is the case particularly with ethanol produced from corn. One reason is that ethanol itself is the product of a technological process that releases various noxious chemicals.[2] Another is that most corn used to produce ethanol today is grown with commercial fertilizers and pesticides, which are environmentally harmful in many ways (section 5.8).[3] Yet another reason is that burning ethanol as a fuel generates carbon emissions in amounts only marginally less than those produced by fossil fuels.[4]

As far as nuclear power is concerned, the best to be said in its behalf from an environmental perspective is that nuclear reactors do not emit greenhouse gases. Nonetheless, significant greenhouse gas emissions are involved in the mining and enrichment of nuclear fuel, and ozone-depleting gases are discharged during enrichment as well.[5] For the record, it should be noted that nuclear sources are not renewable either. The only way such sources can be replenished is through complicated, expensive, and dangerous technology.

The overarching environmental objection to nuclear power, of course, is that radioactive waste from the reactors must remain within the biosphere for indefinite periods of time before it loses its capacity for severe ecological damage. Today, more than 60 years after Hiroshima, the nuclear industry has yet to devise more than temporary storage facilities for its radioactive wastes. The time may come when the waste generated in developing the world's nuclear arsenals becomes no less dangerous to the biosphere than the weaponry itself. Be this as it may, nuclear energy is neither clean nor renewable. Most certainly it is not a solution to our clean energy needs.

9.3 Putting the strategy in perspective

The question posed for this chapter is whether substituting clean energy for fossil fuel is an adequate strategy for resolving our environmental crisis. A scenario that comes to mind in this regard is dismantling all power plants that run on fossil fuel and replacing them with banks of solar collectors, fields of wind turbines, and other clean energy installations. Instead of smokestacks belching soot and greenhouse gases, we envisage power stations that operate with zero emissions.

At first blush, it may appear that this strategy deserves support without further debate. As previously defined, clean energy is energy that can be harnessed and used without harm to the biosphere. Given that our current crisis consists largely of ecological damage caused by fossil fuels, replacing those fuels with harmless forms of energy might seem a natural expedient for eliminating the damage.

Upon reflection, however, it becomes evident that things are not nearly that simple. One complication is that fossil resources currently serve in many capacities other than sources of energy. This is true of oil in particular, which is converted into products ranging from lubricants, solvents, and automobile waxes, to fertilizers, paints, and road materials. And oil and natural gas both are used to produce synthetic fabrics, plastics, and pesticides. Although estimates vary, the percentages of oil and natural gas put to non-fuel uses are far from negligible.[6]

The complication in this regard is that clean energy cannot replace fossil sources in their non-fuel uses. Energy from solar collectors cannot be used as feedstock in the production of pesticides, energy from wind turbines cannot provide raw material for the manufacture of plastics, and so forth. As we know all too well, however, several of the more severe forms of ecological damage under consideration are tied in with these non-fuel applications (Chapter 5). This means that there are several major forms of ecological damage that would not be alleviated by the substitution of clean energy for fossil fuel.

Among uses of fossil sources for fuel, moreover, there are many that do not involve electricity. Electricity is obviously involved when coal or natural gas is used to generate electric power conveyed to customers over high voltage power lines. Electricity is also involved in diesel-powered railway engines, for example, which convert diesel fuel into electricity for driving their wheels. By far the major portion of fossil fuel consumption, however, comes with uses in which electricity is not directly involved.[7] Salient examples of non-electricity uses are oil and natural gas for heating, gasoline and diesel for ground transportation, and a close cousin of diesel for aviation.

These non-electricity uses pose a further difficulty because power from clean energy sources is delivered mostly in the form of electricity. There are exceptions of course. Windmills can be used to pump water, water wheels to drive mill stones, and passive solar collectors to heat buildings. In such uses, electricity typically is not involved. For the most part, however, clean energy installations are designed to produce electricity. Power from these sources can be directly substituted for electricity generated from coal and oil.

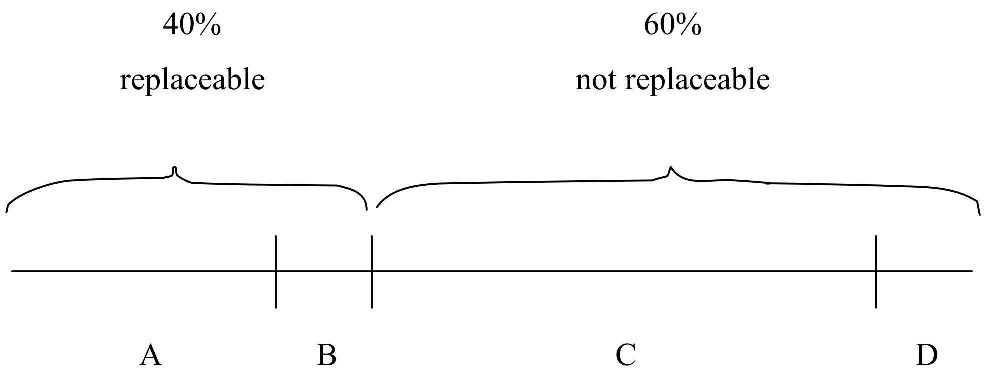
The difficulty here is that clean energy cannot be directly substituted for fossil fuel in applications where electricity is not involved. In some cases it is possible to put electricity to work in tasks previously fueled by other forms of energy. A straightforward example would be shifting from natural gas to electricity in heating one's home. If this electricity were produced from a clean energy source, this would count as a replacement of fossil fuel by clean energy.

Another (and less realistic) example would be to replace most of our petroleum-fueled transportation fleet with electric vehicles. If this were to happen, then the electricity used to power these vehicles in theory could be produced from renewable sources. One reason this scenario is fanciful is the sheer improbability that enough clean energy could be produced to operate such a prodigious number of vehicles. Another is that a wholesale conversion of our petroleum-fueled transportation fleet to electricity would be exceedingly expensive. Yet another is that a conversion of this sort would involve changes in infrastructure more extensive than society could tolerate.[8] From a practical perspective, it is hard to imagine more than a small portion of the world's transportation needs being served by clean energy.

Even if conversions to electricity like these were made whenever possible, moreover, there would still be many applications in which fossil fuel would remain irreplaceable. Science fiction aside, neither cargo ships nor airplanes can run exclusively on electricity. Heavy-duty construction equipment generally requires fossil energy, as does most of the machinery involved in food production. Also included among types of equipment dependent on fossil energy are the mobile armaments employed in modern warfare.

Summing up, we find that roughly 10% of our natural gas and oil production goes into non-fuel uses,[9] and that about 30% is converted into electricity.[10] As an optimistic estimate, let us assume that another 10% is used for purposes which electricity could serve as well.[11] These last two, totaling 40%, are the only categories of use in which clean energy could be substituted for fossil fuel.[12] The remaining portion of fuel uses (50%) are such that the fossil resources involved could not be replaced by clean energy.

The significance of these percentages may be more apparent if they are presented in graphic form. Think of the line in the figure below as divided into 10 equal segments, each representing one-tenth of the world's total consumption of fossil resources.



A	fuel uses in the form of electricity	(30%)
B	fuel uses convertible to electricity	(10%)
C	fuel uses not convertible to electricity	(50%)
D	non-fuel uses	(10%)

Figure 9.1: Fossil resources replaceable by clean energy

Needless to say, these percentages are rough estimates at best. But the proportions they represent still give us cause to believe that most of the fossil resources on which industrialized economies now rely could not be replaced by supplies of clean energy.

The reason for this conclusion is not just that clean energy supplies are limited, which indeed they are (see section 9.6 following). The main reason is that most fossil resources consumed by contemporary society are employed in uses to which clean energy cannot be applied.

9.4 Positive results of the replacement strategy

The fact that fossil sources are replaceable by clean energy in less than half of their uses does not mean that replacement is not a good strategy in those particular uses. What it means is that the strategy is feasible in some cases but not in many others. One way of putting the strategy to the test is to return to the several forms of ecological damage distinguished in Chapter 5 and to assess its potential impact on these individual problems. This is the task of the present section and the section following.

For this purpose, let us assume that fossil fuel has been replaced when feasible by clean energy. More specifically, we will assume that clean energy has been substituted for coal and natural gas in the production of all electricity used in category A of Figure 9.1. We will also assume that all uses in category B have been converted to electricity, which likewise is produced from clean energy sources. In effect, we are assuming the best possible case, which is that clean energy has replaced fossil fuel to the fullest extent practicable.

Although it is probably unrealistic to assume that fossil fuel can be totally eliminated as a source of electricity, the assumption nonetheless will help us test the strategy in question. It will enable us to determine the environmentally most beneficial results to be achieved by the replacement strategy. If the replacement of fossil sources is only partial (contrary to the best-case assumption), then the results that follow perforce will be less beneficial.

The first ecologically harmful effect of fossil fuel discussed in Chapter 5 is the thermal pollution of lakes and streams supplying water for cooling in the process of generating electricity. Installations for producing electricity from renewable sources (solar radiation, wind, moving water) typically do not require cooling.[13] Replacement of coal and natural gas by such sources, accordingly, would remove this particular cause of thermal pollution.

A more serious and pervasive form of thermal pollution is global warming. As currently understood, this condition is caused by greenhouse gases, of which CO_2 is a prime example. Carbon dioxide is one by-product of burning fossil fuels, and thus is produced by power plants, factories, and internal combustion engines. If fossil fuels were replaced in these uses by clean energy sources, which produce no carbon emissions, this source of greenhouse gas would be eliminated.

Elimination of carbon emissions from power plants and internal combustion engines obviously would have beneficial results. As we shall see in the following section, however, even a total shift away from fuel in these applications would not do away with the problem of global warming. The unfortunate fact of the matter is that there are many sources of greenhouse gases other than exhaust pipes and smokestacks.

Beyond thermal pollution of our waterways and atmosphere, there are a few more problems that would be at least somewhat alleviated if the replacement strategy were systematically pursued. One worth mentioning is the increasing acidification of ocean waters that is destroying coral reefs and their associated ecosystems (section 5.4). Marginal decreases in atmospheric CO_2 presumably would be followed by marginal decreases in rate of acidification. Another matter to bear in mind is the considerable quantities of sludge produced by scrubbers in the smokestacks of fossil fueled power plants (section 8.3). Solid waste such as this would be eliminated if these power plants were replaced by clean energy installations.

9.5 Use of clean energy would not eliminate global warming

Despite these undoubted benefits, the replacement strategy leaves several of the ecological problems distinguished in Chapter 5 relatively untouched. Let us begin with global warming. Although a complete replacement of fossil energy in its uses where electricity could also be used (categories A and B of Figure 9.1) would be a significant step in the right direction, global warming almost certainly would continue even if this step were successfully taken.

One reason is that many other fuel-related uses of fossil resources would remain (the 50% of category C) which continue to produce greenhouse gases. A second reason is that there are many sources of CO_2 other than combustion of fossil fuels. As far as direct human responsibility is concerned, another major source is the intentional burning of tropical rainforests. Add to this the fact that CO_2 is only one of several greenhouse gases. Another is CH_4 (methane), large quantities of which are produced in the guts of animals raised for food. Replacing fossil fuel by clean energy in the generation of electricity would do nothing to remove these (and various other) sources in which people are implicated.

Shifting attention to nonhuman sources, we note that the respiratory and digestive systems of most large animals (not just beef cattle) are effective sources of greenhouse gases as well. Perhaps the most significant nonhuman source under present circumstances, however, is the thawing of permafrost due to global warming already underway. Thawing permafrost under lakes releases CH_4, whereas carbon entrapped by dry thermafrost emerges as CO_2. As more of these newly released gases reach the atmosphere, global warming intensifies, thus hastening the melting of larger expanses of thermafrost, and so on in a continuing spiral.[14] This positive feedback process has the potential to accelerate indefinitely, wiping out any advantage gained by reductions in human consumption of fossil fuel.

Another thing to bear in mind is that once CO_2 enters the atmosphere it can stay there for many decades.[15] Even if humanity gave up fossil fuels overnight, greenhouse gases previously aloft would continue to work mischief for years to come. The process of global warming already has reached the point at which even a complete shift to clean energy would not bring it to a halt.

Apart from these ongoing sources of greenhouse gases, it seems likely that extensive use of clean energy could contribute to global warming in its own right. This is true of solar energy in particular. Given a natural tendency to situate solar collectors in relatively barren areas like deserts, extensive use of solar energy could significantly increase the amount of sunlight converted into low-grade heat before being reradiated back into space.

Of the very large amounts of solar radiation reaching the earth, roughly 35% is reflected back into space directly, leaving about 65% to be absorbed and reradiated back subsequently.[16] Making up the former figure, 24% is reflected by clouds, 7% by the atmosphere, and 4% by the earth's surface (mostly by snow and light soil like desert sand). Making up the latter 65% is 5% reradiated at its original wavelengths (mostly higher than infrared) and 60% reradiated in the infrared range after being absorbed by the atmosphere or by the earth's surface. This 60% is the solar radiation that contributes heat directly (i.e. without human intervention) to global warming.

With regard to heat contributed by human activity, it seems evident that use of electricity produced from solar energy presently contributing to this 60% will not increase the amount of low-grade heat to be discharged through the atmosphere. Heat from this 60% has to exit through the atmosphere anyway, and converting some of this energy to electricity will not add to the total amount of heat in question. In other words, heat from the use of electricity derived from this 60% will not increase global warming.

But this is not the end of the matter. As just mentioned, there is a tendency to situate solar collectors in relatively barren lands like deserts which reflect most of the solar radiation falling on them directly back into space. And since radiation reflected back directly does not convert to low-grade heat, it does not contribute appreciably to global warming. Generating electricity from collectors situated in areas like these, accordingly, decreases the amount of solar energy that does not contribute to global warming and increases the amount that has to pass through the atmosphere as low-grade heat.

In this somewhat indirect manner, extensive use of solar energy could have a potentially substantial effect on global warming. For a hypothetical example, if one-fourth of the 4% currently reflected back into space from the earth's surface were converted into electricity instead, then the amount of total solar radiation ending up as low-grade heat would increase from 60% to 61%. The upshot would be close to a 2% increase in the amount of low-grade heat waiting to exit through the atmosphere. It seems not unreasonable to expect that any increase in the neighborhood of one to two percent would have a significant impact on global warming.

9.6 Other problems the strategy leaves unresolved

Global warming is not the only ecological problem left unresolved by the replacement strategy. Another problem left untouched is the accumulation of plastic junk building up in our oceans and terrestrial landfills (section 5.5). Until recently, plastic artifacts were all made of petrochemical polymers, which are materials manufactured from fossil resources. Traditional plastics (celluloid, rayon, cellophane, Styrofoam) are non-biodegradable,[17] which means that refuse from such products now cluttering up the environment may be expected to stay there indefinitely. Inasmuch as manufacture of plastics falls under the non-fuel use of fossil resources (D of Figure 9.1), however, replacement of fossil fuel with clean energy would do nothing to alleviate this problem.

No matter how zealously the replacement strategy is pursued, plastic junk in the environment will continue to accumulate.

Another non-fuel (category D) use of petroleum is the manufacture of such ozone-depleting chemicals as CFCs (section 5.6). Despite the initial success of the Montreal Protocol (section 8.2), the ozone layer has continued to deteriorate under the influence of replacement petrochemicals such as HCFCs (section 8.3). Moreover, since these chemicals disperse only slowly once they reach the upper atmosphere, the ozone layer is not expected to regain its integrity before the end of the century (section 8.3). In the long run, this problem may prove even more severe than global warming. And the replacement strategy will not help resolve it.

Equally regrettable is that this strategy shows little promise of relieving the very extensive ecological damage inflicted by industrial agriculture (section 5.8). For purposes of brief review this damage can be classified under four or five headings. Of these, the most widespread may be the damage caused by commercial fertilizers.

Ecological damage caused by use of nitrogen-based fertilizers includes eutrophication of lakes and other waterways (section 5.2), dead zones at the mouths of rivers caused by fertilizer run-off (section 5.5), release of nitrous oxide (a greenhouse gas) into the atmosphere by denitrification (section 5.7), and their contribution to acid rain (section 8.4) by release of ammonia. Production of commercial fertilizer is a non-fuel (category D) use of fossil resources involved. A consequence is that such damage cannot be relieved by substituting clean energy for fossil fuel.

Another ecologically pernicious practice of industrialized farming is the extensive use of pesticides. Although designed to kill competing plants ("weeds") and unwelcome insects, these poisons endanger ecologically beneficial life forms as well. Pesticides kill honeybees instrumental in pollinating crops, decimate populations of birds that control noxious insects like mosquitoes, and destroy decomposers (earthworms, beetles, etc.)

essential for healthy soil (sections 5.8, 8.2). Manufacture of pesticides, once again, is a non-fuel (category D) use of fossil resources. And once again, the damage they cause would not be affected by a shift to clean energy.

A third class of damage caused by factory farming pertains to loss of species diversity. Although agriculture by nature involves giving special care to individual plant species, industrial farming tends to focus on crops that are particularly profitable (corn, wheat, soybeans, etc). As already noted, whereas humans once used roughly 3,000 species of plants for food, only about 150 of these are grown commercially today and most of the rest have gone extinct (section 5.8). By declining to cultivate unprofitable species, the monoculture practiced by factory farming has radically reduced the variety of plants available for human consumption.

Species loss among sustenance crops has been exacerbated by a growing reliance on genetically modified (GM) seeds. Within the first four years of the present century, for example, the proportion of GM corn grown in the U.S. doubled to 45% (section 5.8). It seems not inconceivable that GM varieties will completely dominate the world's food markets in a matter of decades, while the natural varieties they replace will simply disappear. This would constitute a dramatic loss of species diversity.

Whether or not loss due to genetic modification is to be treated as a separate class of ecological damage, species loss itself is beyond reach of the replacement strategy. To whatever extent petrochemicals are a contributing factor, the effect stems from a non-fuel (category D) use of the fossil resources involved. The substitution of clean energy sources for fossil fuel would do nothing to stem the loss of species diversity.

The last kind of damage to be considered is caused by use of heavy farm equipment that cannot be powered by electricity. Included are tractors, combines, and bulldozers, along with trucks used for harvesting and for delivery of products. Use of fossil fuel to power such machines belongs to category C, the category of fuel use not convertible to renewable energy. The associated problems will not be helped by the replacement strategy.

On balance, the observations of these last two sections are not encouraging. While there are types of ecological damage that would be somewhat alleviated by a shift to clean energy (section 9.4), even in these cases the damage would not be wholly eliminated. And since most forms of damage we have surveyed are due to petrochemicals, meaning fossil resources put to non-fuel uses, most of the damage they cause is beyond reach of the strategy in question. Sobering as it may be, the only reasonable conclusion is that replacing fossil fuel with clean energy would contribute far less than is needed to resolve our environmental crisis.

9.7 Ecological problems initiated by use of clean energy

Not only will the replacement strategy leave most of our current ecological problems unresolved, but there are other problems that arise with use of clean energy itself. Although details are hard to predict, the more serious of these will probably center on the quantities of space required for its production and distribution. Currently available technologies for producing clean energy, as will be recalled, include solar collectors, wind turbines, and generators run by moving water. It is instructive to compare siting requirements of these technologies with those of the chlorophyll-bearing organisms responsible for almost all our renewable energy before the industrial era.

Before the industrial era, the role of converting solar energy into forms usable by other creatures fell exclusively to plants. Ecosystems supporting consumer organisms developed only where there was adequate plant life to support them. As a consequence, most ecosystems had adequate supplies of energy in their immediate vicinities.

This held true of ecosystems supporting human existence in particular. Early human society had neither need nor opportunity to import energy from distant places. A hallmark of modern industrial society, on the other hand, is that it requires technology for moving energy supplies over long distances. Railways carry coal, ships carry oil, pipelines carry natural gas, and so forth. While local industry can thrive with local sources of energy, the fact that energy sources are found only in localized areas means that society at large must move energy from one place to another.

This is the case with clean energy no less than with fossil fuels. Although solar energy is available almost anywhere on earth, converting it to electricity is feasible only under fairly restrictive conditions. Collection by photovaltic cells, for instance, is inefficient in regions with low insolation as well as in regions with frequent cloud cover. This means that use of solar energy for commercial purposes would be impractical, among other places, in much of Canada and northern Eurasia.

Siting of wind turbines, in turn, is commercially feasible only in areas where average wind velocity exceeds a certain minimum level.[18] For this reason, wind turbines most often are located offshore (where wind flows freely) or on mountain ridges and other high elevations. These restrictions have limited commercial development of wind power to a relatively small portion of the globe. To date, wind farms account for about 1/5 of one percent of worldwide energy production, with concentrations in Spain, the U.S., and India[19]

As far as hydropower is concerned, siting is limited mostly to offshore tidal fields and to areas featuring dams and natural waterfalls. Use of inland streams to produce electricity is generally impractical. Although hydroelectric installations currently supply almost one-fifth of the world's electricity,[20] further expansion is unlikely save in a few especially suitable locations.

A consequence of these several limitations is that if clean energy were to take over from fossil fuel in production of the world's electricity, a lion's share would have to be conveyed considerable distances from origin to point of consumption. This would necessitate vast networks of power lines traversing every inhabited region of the earth. The ecological consequences of these massive delivery systems would be far more intrusive than our current criss-cross of high-tension power lines (think of the region around Niagara falls), which are responsible for widespread ecological damage as matters stand.[21]

Another ecological drawback of clean-energy technologies is the sheer space required for their installation. Take wind-turbine technology as an example. For optimal aerodynamic efficiency, individual turbines must be placed considerable distances from each other. A terrestrial wind farm of 20 turbines, for example, might occupy an area of one square kilometer.[22] Although the spaces between towers could be used for grazing, and sometimes farming, the rotating blades would rule out ecosystems supporting avian wild life.

A point in favor of solar technology is that photovoltaic cells (currently the most practical way of converting sunlight to electricity) can be installed adjacent to each other. Whereas the spacing among turbines allows wind farms to be used for other purposes as well, however, the close juxtaposition of collectors on solar farms typically prevents much sunlight from reaching the ground underneath. A consequence is that areas set aside for solar power generation tend to be ecologically impoverished, and generally unavailable for other human uses. It has been estimated that, given the conversion efficiency of current photovoltaic collectors, about 2% of the total land area of the contiguous U.S.A. would be required to supply its power needs with solar energy.[23] This means that if the country were to go completely solar (ignoring the distinctions in Figure 9.1), a total land area roughly the size of Nevada would be totally given over to the production of electricity.

Yet another shortcoming of the clean energy sources we have been considering is that they rely on humanly designed and fabricated machinery. Unlike solar conversion processes in the plant world, which if left undisturbed can continue to supply energy in useful forms indefinitely, machinery wears out and needs replacing. Manufacturers' estimates suggest that a wind turbine, if properly lubricated and maintained, should last about 20 years.[24] Comparable estimates for photovoltaic collectors range from 20 to 50 years.[25] Apart from conventional generators in existing hydroelectric plants, with life expectancies of 100 years or so,[26] technologies for converting motion of tidal waters into electricity are too new for informed estimates of longevity. But a lifetime of more than a few decades seems unlikely.

Assuming a generous average of 30 to 40 years of operating life for a typical clean energy installation, the upshot is that the machinery providing a country's supply of clean energy will require continuous updating and replacement. Old equipment will have to be dismantled and added to the debris in our crowded landfills. And replacement equipment constantly will be under construction, with the ecological disadvantages attendant upon the various manufacturing processes involved. In one sense of the term, technologies of this sort provide a source of renewable energy. Although the energy itself is renewable, however, the technology for harnessing it is not. As we see, these technologies stand in need of constant renewal themselves.

9.8 Summary assessment of the replacement strategy

Like the piecemeal approach of Chapter 8, the replacement strategy is already being implemented in many industrial economies. One reason for its ready acceptance, again like the previous strategy, is that it involves new products (e.g., solar installations, wind turbines) on which businesses can make a profit. A more compelling reason for acceptance among mainstream economists is that both strategies appear to be compatible with continuing growth. The general idea seems to be that if specific problems are handled piecemeal when they appear, and if clean energy is substituted for fossil fuel, then economic growth can continue indefinitely.

In the case of the replacement strategy, at least, the appearance of compatibility may prove illusory. Although fossil resources are replaceable in less than half of their uses (categories A and B of figure 9.1), the strategy calls for replacement in such uses rather than cutting back on the amount of energy consumed. A consequence is that demand for clean energy will tend to increase with an expanding economy.

Despite clean energy's generally being renewable, however, there are practical limits on its availability. In respects laid out previously, there are limits in the siting of clean energy instillations, limits on the size of delivery systems that society will tolerate, and limits on the amount of clean-energy technology in which society will find it profitable to invest. As the economy continues to expand, these limits might make use of clean energy increasingly unattractive. In effect, continued expansion might actually derail the replacement strategy.

Let us summarize the generally discouraging results of this chapter. We have seen that clean energy can be substituted for fossil resources in only about 40% of their current uses (section 9.3). Although substitution when possible may be expected to have some moderately beneficial results (section 9.4), we have seen that it would have little impact on many of our environmental problems (sections 9.5, 9.6). We have seen, furthermore, that extensive use of clean energy technology would create environmental problems in its own right (section 9.7). These results are enough to show that the replacement of fossil fuel by clean energy will not do much to alleviate our environmental crisis.

It should be emphasized that these results do *not* show that current efforts to phase out fossil fuel in favor of clean energy are themselves counterproductive. All in all, such efforts are a good thing and should be continued to the fullest extent feasible. As far as our environmental crisis is concerned, nonetheless, we should realize by now that it will not be resolved by strategies pursued in conjunction with continuing growth. Economic growth itself is the source of the crisis. The next two chapters are given over to an examination of the remaining strategy. Unpalatable as it may be in certain sectors of society, this third strategy calls for a curtailment of economic growth.

Notes

1. Fuel cells also are sometimes described as clean sources of energy. Fuel cells produce electricity by recombining hydrogen with oxygen after it has been extracted from water (i.e., separated from oxygen) at a previous stage in the process. Although recombining hydrogen and oxygen produces only "clean" H_2O as a by-product, most technologies for extracting hydrogen from water are run by electricity generated by other technologies that are polluting in their own right. Strictly speaking, moreover, a fuel cell is not an energy source in the first place. It rather functions as part of a larger system that operates in the manner of a storage battery, being "charged" by the electricity used to produce free hydrogen and subsequently "discharged" with the production of electricity by recombining hydrogen and oxygen.

2. According to an EPA study conducted in the early stages of the ethanol boom, factories making ethanol from corn are releasing carbon monoxide, methanol, and various carcinogens at rates far greater than initially expected. Among carcinogens involved are acetic acid and formaldehyde. See http://www.cbsnews.com/stories/2002/05/03/tech/main508006.shtml (accessed Feb. 2009).

3. It should be borne in mind that ethanol can also be produced from other biomass sources such as perennial switchgrass and organic wastes. Switch grass can be grown without commercial fertilizers or pesticides, and the fuel it yields burns with few if any

carbon emissions. See the Rocky Mountain Institute article “Setting the Record Straight on Ethanol” (No. 14, 2005), by Nathan Glasgow and Lena Hansen.

4. According to a report by the Energy Information Administration (1994), vehicles using corn-based ethanol for fuel emitted 7,400 millimoles of CO_2 per vehicle mile traveled (VMT), compared with 9,900 millimoles for gasoline. Another greenhouse gas is N_2O. Ethanol use resulted in 58.3 millimoles of nitrogen oxides per VMT against 26.5 millimoles for gasoline. See http://www.eia.doe.gov/cheaf/alternate/page/environment/exec2.html (accessed January 2008).

5. See http://www.scec.org.au/anti_nuclear.php (accessed September 2006)

6. Non-fuel use of fossil resources was estimated at 7% in 1997 (Energy Information Administration, U.S. Department of Energy, 1998). A more recent estimation came from the National Petrochemical and Refiners Association, pegging U.S. non-fuel use of petroleum in 2006 at 22%. Non-fuel uses of natural gas presumably are lower in percentage, and those of coal lower yet. It seems reasonable to locate current U.S. non-fuel use in the neighborhood of 10% - 15%.

7. Specific numbers in this regard are hard to come by. According to Vaclav Smil (*Energy*, p. 187), one-quarter of the world’s fossil fuel output was converted into electricity in 1990, up from one-tenth in 1945. A rough extrapolation from these figures makes it unlikely that the electricity portion will reach one-third before the next two or three decades.

8. People and goods would have to be moved in smaller vehicles operating at slower speeds, filling stations would have to be replaced by recharging stations, substantially larger power grids would have to be constructed to supply these stations, and so forth. Moreover, given that something like one out of ten jobs in developed countries depend on the manufacture, sale, and maintenance of petroleum-powered vehicles

(http://news.thomasnet.com/IMT/archives/2003/10/automotive_indu.html; accessed February 2009), major disruptions of a social nature could be expected as well.

9. The U.S. estimate of 10% - 15% in note 6 above is collapsed to 10% on the assumption that U.S. non-fuel use is greater than the average worldwide.

10. This is a mid-range estimate based on Smil's 25% for 1990 and the projection in note 7 above of one-third for two or three decades from now.

11. No estimate like this for hypothetical (currently nonexistent) circumstances could be more than a guess. The 10% suggested in the text may be overly optimistic.

12. The reason, to repeat, is that power from clean energy sources comes almost exclusively in the form of electricity.

13. An exception is advanced solar technology that concentrates sunlight with mirrors and require cooling to operate at maximum efficiency (http://www.stanford.edu/group/solarcar/solarenergy.htm; accessed September 2006).

14. Concern among scientists that positive feedback of this sort has already taken over was widely reported in late 2006, leading to the conclusion by one group that "the issue of global warming is no longer a question of just cutting down on the burning of fossil fuels to decrease carbon dioxide levels" (http://www.itwire.com.au/content/view/5553/53/; accessed September 2006). A related effect, intensifying this concern, is that global warming might hasten the release of vast amounts of CH_4 trapped beneath open oceans (http://www.msnbc.msn.com/id/13969811/; accessed September 2006). Natural feedback processes like these leave little hope that global warming at this point can be controlled by minor changes in human energy-use patterns.

15. See http://climate.wri.org/pubs_contest_text.cfm/ ContentID=2162 (accessed September 2006)

16. Data in this paragraph comes from http://www.udel.edu/Geography/DeLiberty/Geog474/geor474_energy_interact.html; (accessed July 2008). Specific surfaces reflect specific percentages of solar radiation falling on them, a property referred to as their albedo. Fresh snow has an albedo of about 90%, thick clouds about 75%, and water (perpendicular to the sun's radiation) about 4%. Accordingly, ocean water absorbs a much greater percentage of radiation than dense clouds and snow.

17. Studies are underway investigating means of converting petrochemically derived plastic waste into biodegradable form (http://www.eurekalert.org/pub_releases/2006-02/acs-mc022306.php; accessed Feb. 2009). Ways also have been discovered of producing plastics from vegetable starches that are biodegradable in their own right (http://encyclopedia.thefreedictionary.com/Decomposable+plastic; accessed Feb. 2009), called "bioplastics" to distinguish them from petrochemical plastics that can be degraded by biological technology. These developments are ecologically beneficial, but have nothing to do directly with clean energy.

18. The cut-off point is in the neighborhood of 10 mph or more (http://wiki.answers.com/Q/FAQ/3752; accessed Feb. 2009). There are also temperature restrictions having to do with lubrication of the turbines.

19. See http://ecoworld.com/blog/2008/11/04/wind_power_surges (accessed February 2009).

20. See http://www.uk-energy-saving.com/hydro_electric_power.html (accessed February 2009)

21. Electricity transmission lines require areas stripped of vegetation for supporting structures and motorized access, and cause the death of hundreds of millions of birds and wild animals a year (http://www.awea.org/faq/sagrillo/swbirds.html; accessed February

2009). To this carnage should be added the not insignificant number of birds killed by the blades of wind turbines themselves or by the vortices the moving blades produce.

22. See http://www.bwea.com/ref/faq.html (accessed February 2009).

23. See source in note 13 above.

24. See http://library.witpress.com/pages/Peperinfo.asp?PaperID=17822 (accessed Feb. 2009).

25. Estimates of 20 or 30 years lifetime expectancy for photovoltaic collectors seem fairly common. For a 50-year estimate, see http://www.backwoodshome.com/articles/heckeroth63.html (accessed February 2009).

26. See http://peter.mapledesign.co.uk/writings/physics/2005_Hydroelectric_Power_Feasible_or_Desirable.pdf (accessed Feb. 2009).