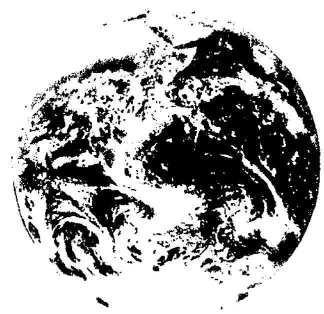
# GLOBAL CLIMATE CHANGE AND LIFE ON EARTH



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# Energy Policy and Global Warming

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### Introduction

Because of the scale at which humans use energy, particularly fossil fuels, we are now a major player in setting the composition of the Earth's atmosphere. As a result, we affect the global temperature balance. Climate disruption is the *biggest environmental problem we have ever faced. A good way to remember* the rate of projected climate change is in terms of temperature migration. Think of temperature regimes moving northward at a rate of 16 km per year. That means 160 km per decade, 1600 km per century (See Andresko and Wells 1988). Although we cannot be sure that these projections are correct, we must act as if they are correct. We cannot take the risk that the global climate models (GCMs) are wrong. Thus, I will assume for the rest of the discussion that they are correct.

In 50 years, a northern state like New York will have the temperature climate of the deep South. Actually, New York will be relatively well off compared to other states, but not for long. As climate change proceeds 10 times more rapidly than experienced in the past, conflicts between humans and wildlife will heighten. Many of our hard-won environmental victories will be overwhelmed (Peters, this volume).

Climate change is likely to take place in an overpopulated and deforested world, with air pollution threatening the survivability of the forests that are not being cut down and that are not being driven to extinction by climate change. A new technology, biotechnology, will be invading the remaining natural lands (Beyea and Keeler 1990). Initially the invasion will be for economic purposes: better crops, better livestock, better suburban lawns, better trees. These new genetically engineered products will turn uneconomic lands into biological factories, ruining them for the wildlife that now depend on them. Unintended migrations will introduce genetically engineered exotics into our National Parks, Forests, and protected Wilderness lands.

After this initial biotechnologic revolution, a second wave of life designers will replace dying trees and wildlife with genetically engineered creatures that can tolerate a deteriorating planet. The prospects are very bleak for the natural world and wildlife as we know it today. These four factors (population increase, climate change, deforestation, and biotechnology) are the four horsemen of the modern apocalypse.

Climate change is discussed in terms of a 50-year horizon, but the effects do not stop after 50 years. Consider this. We have a 400-year supply of coal in the United States. The other countries with major resources are China and the Soviet Union (International Institute for Applied Systems Analysis 1981). If we burn all of ours and tap into our shale and tar oils, if the Soviets and Chinese burn theirs, and, if at the same time, we fail to clamp down on greenhouse gases and deforestation, then the tropics will end up at the poles according to my projections, possibly with an interlude of an ice age up north. In light of possible climate interludes and fluctuations, it is more accurate to refer to "climate disruption" when speaking of the future, rather than global warming. Ultimately, however, any regional cooling trend will be overtaken by increased warmth as more and more carbon dioxide enters the atmosphere.

We cannot expect that tropical wildlife will migrate and that trees will survive. Not even tropical wildlife will be able to stand the summers, which will soar to killing extremes. Trees as we know them will be largely gone. None of the wildlife that many of us love will be able to survive. Wilderness will be a memory. Wildlife remnants will be relegated to air-conditioned zoos, possibly underground, with the remnants of humanity, breathing artificially maintained air. According to these extrapolations, we literally face the end of the natural world as we know it.

But then who cares about what happens in 400 years? Actually, we probably care more than we realize. Four hundred years is not that long in historical terms. Most of us, when we studied history, identified with those who lived 1,000 and 2,000 years ago. Can we accept no future for the natural world in 400 years? Suppose people in the Middle Ages had knowingly used up the land so that nothing natural remained for us? Would we not curse them as monsters?

Climate protection requires a fundamental change in how we, as a society, cope with problems. It requires us to act now to stop destruction long into the future. We must act before the evidence of the destruction is actually visible. We must act on the wisdom of scientific predictions. Those of us alive today have a special responsibility the future. If we do not reverse our course over the next decades, there will be little hope of later generations doing anything but surrendering to the effects of climate disruptions.

There is a key point that must be repeated about global warming, over and over again, until it is widely appreciated. The gases we spew out today will take a long time before they are absorbed into vegetation and oceans. Approximately 50–70% of our $CO_2$ emissions are recycled into the ocean surface waters rather rapidly (Oeschger et al. 1975). However, the residence time in the atmosphere for the remainder is hundreds of years (Maier-Reimer and Hasselman 1987, Solomon et al. 1985). The fraction that stays up for the long haul will determine the climate of our descendants. Every time we drive our car, heat our homes with fossil fuels, or use electricity generated by fossil fuels, we ever so slightly narrow the options of future societies. The analogy with nuclear wastes is very strong. Environmentalists have held it immoral to benefit from nuclear power while passing on the risks to future generations. Our descendants will be the ones who will have to deal with nuclear wastes escaping from repositories, not us. Similarly, they are the ones who will have to cope with fossil wastes, the wastes in the atmosphere after we have reaped the energy benefits for ourselves. Focusing on the moral issue is going to be important for developing an adequate political response to the threat of climate disruption.

Because of the long residence time of $CO_2$, we cannot treat $CO_2$ like other pollutants, such as $SO_2$ and NO, with which we are familiar because of the debate over clean air and acid rain. To prevent climate disaster for future generations, we must reduce emissions essentially to zero within the next 100 years, not simply cut emissions in half. Lightheartedly I advise my daughters and their friends that it is important that they be left at least one challenging problem to solve. No problem of this magnitude can be solved by forgetting one's sense of humor. We cannot afford to let the sheer magnitude of the greenhouse problem constipate us into inaction.

The United States contributes approximately 20% of world $CO_2$ (Krause et al. 1989). Thus, the United States cannot solve the greenhouse problem on its own. Yet, because we are the worst $CO_2$ polluters on a per capita basis, we must put our own house in order first. Only then can we expect other nations to put much effort into controlling emissions. Furthermore, it is up to us and other highly industrialized countries to develop the technology to ease the pain that may be involved in stabilizing the world's climate. In assessing energy policy, it should be understood that no energy solution can make sense without a simultaneous commitment to the stabilization of the human population, a reversal of deforestation, and control of trace gases, like CFCs and methane.

As a result of potential climate disruption, United States and world energy policy must change radically. We need to make every rational effort to conserve energy, to become more efficient, and to steadily shift our economies away from burning hydrocarbon-based fuels. Every time that we advocate one form of energy policy or another, we should make sure that climate protection is part of the equation. We have not always done so. For instance, the environmental community for the last 15 years, out of concern for the dangers of nuclear power, has either explicitly or implicitly supported conventional use of coal.

Before expanding on an overall energy policy, it is appropriate to look at the various options we have. There are many. The world is not going to run out of energy. The real question is how much will we pay for energy and what will happen to economic growth and the environment as a result.

## Energy Options

### Fossil Fuels

Natural gas emits the least $CO_2$ per unit of energy (approximately half that of coal) (JASON 1979). Oil is next in this regard, followed by coal. The worst $CO_2$ emitters are synthetic fuels from coal. A movement toward natural gas will reduce total $CO_2$ emissions, so it has promise as a short term strategy, provided emissions of unburned natural gas, a greenhouse gas itself, are reduced during production and transmission. Oil and gas will be the most difficult to forego, because of their usefulness in transportation. The nontraditional fossil fuels, shale and tar oils, represent another enormous potential supply of energy, comparable to the world coal resources (Jason 1979). If we should ever tap significant amounts of these dirty fuels, any hope of controlling climate disruption will be lost (Sundquist and Miller 1980).

### Novel Ways of Using Fossil Fuels

Fossil fuels, however, should not be written off completely (Fig. 14.1). There may well be ways to improve the consumption of fossil fuels from the climate perspective. $CO_2$ removal is one example. It is possible to remove $CO_2$ from the exhaust gases of fossil fuels at power plants, such as those at utilities and large industries. One estimate is that a 90% removal of $CO_2$ will approximately double the cost of electricity (Cheng and Steinberg 1985). However, in the absence of hard engineering data on costs, it would be wise to expect higher figures.

A possible way to reduce those costs is to burn the coal from the start with pure oxygen. Ordinary air contains lots of elements other than oxygen that are carried along during the burning process and end up as part of the effluent stream. Disposal of the $CO_2$, then, requires either separating out the $CO_2$ prior to disposal or disposing of the whole volume. Either alternative is expensive. In contrast, this new way of burning coal with pure oxygen produces an output that is practically pure $CO_2$. Of course, the oxygen must be separated from air in the first place, but one research group claims the new process is cheaper overall (Golomb et al. 1989).

In any case, disposal of the removed $CO_2$ accounts for a significant fraction of the cost. The most likely way to dispose of large quantities of $CO_2$, beyond that which can be used in industrial processes, is to pipe it down into deep ocean waters, the place it would end up anyway in thousands of years if we allowed it to escape today into the atmosphere. If we put it deep enough, $CO_2$ will sink to the bottom (Cheng and Steinberg 1987). But critics of this approach argue that transporting the scrubbed $CO_2$ across the country to the oceans is too clumsy and impractical. However, this objection seems to be relevant to inland use. Because

| TECHNOLOGY | SOME ASSOCIATED ENVIRONMENTAL PROBLEMS | MITIGATABLE? |
|---|---|---|
| Ocean Disposal of CO-2 Removed From Fossil Fuel Efflu-ents. | Unknown Impacts on Ocean Cycles. | ? |
| Hydrogen Strip-ping From Coal. | Possible Oxidation of Residual Carbon Lead-ing to Delayed CO-2 Emissions. | ? |

**Fig. 14.1.** Some novel ways of using fossil fuels, associated environmental problems, and comments on whether the environmental problems can be mitigated.

most of the population lives close to the coasts, restricting coal to coastal locations would still allow significant quantities of coal to be consumed. Thus, it is likely that economics will be the key to scrubbing $CO_2$, not infrastructure requirements.

The real problem with ocean disposal of $CO_2$ is environmental. We do not know how the ocean systems will be affected. Environmental research is needed before the method can be considered an acceptable alternative. In any case, like all the other supply alternatives being discussed, costs are likely to be higher than the cost of electricity from coal today (Fig. 14.1).

Other options are also of interest. Recent work at Brookhaven Laboratory (Steinberg 1988) involving the "stripping" of hydrogen from coal is so original that it overturns the conventional wisdom that coal consumption is synonymous with $CO_2$ production. By settling for less than maximally extractable energy, the Brookhaven group avoids $CO_2$ as an end product.

Coal is made up of carbon, hydrogen, and oxygen. When coal is burned in conventional fashion, the energy locked up in both carbon and hydrogen is released when combined with atmospheric oxygen. Steinberg's method separates carbon into pure form and makes only the hydrogen available for combination with oxygen. If the carbon is sequestered and not burned, no $CO_2$ is formed. The hydrogen is actually an intermediate product, which can serve as a mobile energy carrier, providing energy when it is eventually burned.

On the negative side, only 25% or so of the potential energy in the coal is obtained. The rest must stay locked up in the pure carbon to prevent $CO_2$ from being produced. However, to make hydrogen from coal through normal means would require producing electricity first, itself a wasteful process, and then separating hydrogen from water. In fact, electricity from coal requires two-thirds of the initial energy as well, so that the Brookhaven method for making hydrogen is not much more wasteful than electrical methods. Thus, to the extent that hydrogen is a desired product, the Brookhaven process looks very interesting. Should hydrogen become the future fuel of choice for transportation, a real possibility according to many analysts, fossil fuels may gain a new lease on life through this process.

Research into this technology makes sense. Its novelty makes one wonder what other original ideas about use of fossil fuels are out there waiting to be discovered? Research dollars now going into conventional fossil fuel technology need to be redirected into these innovative areas.

### Energy Efficiency

Using energy more efficiently is the cheapest and fastest way to reduce $CO_2$ emissions while maintaining economic growth. Also it can be the most environmentally benign. I refer here particularly to eliminating energy waste by modernizing equipment in the home, office, factory, and transportation sectors (Morrison 1990, Carlsmith et al. 1989).

The technologic potential is awesome; the political will weak. Hopefully, concern over climate change will motivate societies to curb bad energy habits and shift dollars away from investment in energy supply to efficient utilization of energy. A reasonable target for conservation is to keep energy consumption constant while the economy grows. Such a target can be achieved with a net economic saving to the consumer, a saving that can be used to offset the cost of supply options that reduce $CO_2$.

Because in the minds of the general public energy efficiency is still a rather esoteric concept, often is confused with "freezing in the dark," there is a need for a dramatic demonstration of the power of the concept. Why not a national effort, comparable to putting up a space station, to develop a 100 km/l car. Such an effort will require years of work from our best engineers, but it will make efficiency chic as well as make possible huge reductions in $CO_2$ emissions.

In addition to the saving of energy with improved vehicles, there is a great potential associated with changing the transportation infrastructure itself. Optimal integration of mass and personal transportation systems is needed. We need special lanes everywhere for vehicles with multiple passengers. We need the promotion of lanes for bike and motor-bike travel, which has barely started in this country. Admittedly, changing the transportation infrastructure is a slow process, but the time frame is matched to the time frame over which we must reduce our $CO_2$ emissions.

All energy options have drawbacks. The biggest one associated with efficiency is potential increases in indoor air pollution associated with tighter buildings. However, buildings with reduced air-quality need not be a part of our efficiency

| TECHNOLOGY | SOME ASSOCIATED ENVIRONMENTAL PROBLEMS | MITIGATABLE? |
|---|---|---|
| Photovoltaics, Solar Thermal. | Landuse Competition.<br><br>Pollution During Production of Materials. | No, but tolerable amounts involved.<br><br>To some extent. |
| Biomass (Solar energy Collected in the Form of Biological Material). | Destruction of Habitat and Loss of Biological Diversity. | To some extent. |
| Wind | Aesthetic.<br><br>Noise. | No.<br><br>Yes. |
| Hydro (Big and Small) | Loss of Key Wildlife Habitat and Recreation Opportunities. | Only by scaling number of projects way down. |
| Geothermal | Water Pollution. | Yes. |
| Ocean Thermal | Interference with Ocean Cycles. | ? |

**Fig. 14.2.** List of solar-related and geothermal technologies, associated environmental problems, and whether the environmental problems can be mitigated.

strategy. Such conservation measures only contribute a small part to the overall efficiency potential.

## Recycling

Recycling can reduce emissions of greenhouse gases directly and indirectly. After the United States establishes a recycling infrastructure, material recycling would lead to a major, cost-effective reduction in direct $CO_2$ emissions now associated with the combustion of used materials. Unfortunately the development of appropriate infrastructure is proceeding slowly. Many communities have established mandatory recycling only to find that they must deposit the presorted and cleaned materials into landfills because the markets are saturated. Indirectly recycling reduces emissions because less energy is needed, and hence less fuel is burnt and fewer emissions produced, to process recycled materials than is required to mine, transport, and manufacture products from raw natural resources.

## Solar Technologies

A number of reports discuss the promising status of solar energy (Andrejko 1989, Chiles 1990). Solar-related technologies (Fig. 14.2) derive their potential power at some point from the sun. Wind, for instance, arises from unequal heating of the earth by solar energy. The success of technologies like *wind turbines* has shown that such alternatives can make a real contribution to the United States energy supply under the right regulatory climate (Chiles, 1990). California has led the way and shown that they can be practical. However, there is no free lunch when it comes to energy sources, so care must be exercised even with solar technologies (Medsker 1982).

*Direct solar.* On the supply side, one of the most promising options is solar electricity. It can be derived from steam produced by high-temperature solar heat, assisted by the burning of natural gas. The cost of producing electricity, at least in the daytime, by this method is not too much greater than the cost of electricity from the latest nuclear power plants (Chiles 1990).

The "hottest" form of solar electricity today is that which is produced directly when sunlight hits photovoltaic cells. The costs of these cells have been dropping dramatically, with the potential for producing electricity at costs well below that of nuclear power (Carlson 1989, Hubbard 1989, Ogden and Williams 1989). Expanding research into photovoltaics would seem to be the most important energy research step that can be taken for the long term. In the United States, replacing fossil fuel units would be a massive job, requiring the laying down of collectors on an area of perhaps the size of the interstate highway system or 5% of the farmland, an equivalent area. These engineering projects are so vast that engineers would clamor to be a part of them. Although a complex undertaking, it would certainly be possible to accomplish the task over a 50-year period.

Although land use of this magnitude would raise eyebrows, the other advantages of solar energy would ensure its widespread public acceptance. In fact, development of photovoltaic cells may represent the most politically viable way of forestalling massive climate change in the next century. However, solar energy is *difficult to* store. The cost of nighttime power may prove very expensive. In fact, the cost of electric storage will dominate *the cost* of solar electricity.

Here is a vision of how this system might work in the future: Central station generation during the day time will consist of large fields of photovoltaics. Utility arrays of photovoltaics will consist of 13,000-v panels that can be connected, after conversion to AC, directly into the electric distribution system. Centralized arrays will dominate over decentralized installations because of economies of scale. Land-use regulations will be needed to prevent use of high-quality farm and forest land for photovoltaics and to shift uses to lands that are not biologically productive.

Electricity from photovoltaics installed on top of commercial establishments and, to a lesser extent, on (or near) residential buildings will feed power into the grid during daytime, where it will be stored by utilities for nighttime use. At night, electricity will flow from the utility as it does today. Under this scenario, electric utilities will play the major role in providing electricity storage. Compressed gas, pumped hydro, and hydrogen production will be the major utility storage technologies. Electricity will cost twice as much to produce at night and will be priced accordingly, leading to the development of home technologies for storing heat and the maintenance of cool temperatures. Computer control of homes will allow for painless scheduling of energy-intensive tasks for hours when electricity costs are cheapest, that is during sunlight hours. Cleaning of the arrays may lead to water pollution. Photovoltaics will be used to make some of the hydrogen that will be used as a transportation fuel (Ogden and Williams 1989). Electricity will be transported across the country along the transmission network to follow the sun. In the early hours of the day on the East Coast, electricity will move westward, whereas late in the day on the West coast, electricity will move eastward.

Based on costs today and costs of storage, in constant dollars, electricity will cost less than 30 cents/kWh during the day, less than 45/kWh during the 2-h-period prior to sunrise and after sunset. It will cost less than 60 cents/kWh at night. Environmental problems from photovoltaic technology will be significant, but nothing compared to the problems that would arise from use of fossil fuels. Pollution from the production of the solar cells will be a problem, as will use of herbicides to keep solar arrays free of vegetation. Are these predictions of the development of photovoltaics valid? We will know in 20 years.

*Hydropower*. Hydropower in moderation is fine, but too much would be a disaster. We have all too few crucial sites left for wildlife and river recreation. The natural flow of rivers is essential to ecosystems. For instance, in the spring when ice melts, the resulting rush carries much-needed nutrients for wildlife far and wide. Dams change the natural rhythms by regulating the flow (Beyea and Rosenthal 1989). By the way, even small hydropower can be a problem, because it requires many dams to make the electrical equivalent of a large dam.

There is a hydropower option that needs consideration, the so-called "run of the river" turbines, which operate during peak flows only. It is not the turbines themselves that cause the major environmental problems, but the flooding of land from dams and the smoothing out of the natural flows. Therefore, by generating electricity in phase with the natural flows (which does not require the construction of a large dam), we can eliminate the greatest problems with hydropower. Although run-of-the-river systems are more expensive, they do offer hope that hydropower can help offset global warming, without causing major damage to natural ecosystems and the creatures that depend on them.

*Wind*. Germany is planning to get 20% of its energy from electricity generated by wind. Wind is a real option from a technical point of view. The tendency is to place wind-turbines on mountain path sites where there are high winds. These sites may be environmentally sensitive. Turbines could be spread out in the Great Plains, where there is less environmental risk but lower average power. Because of inherent aesthetic problems, photovoltaics may be preferred.

*Ocean thermal*. The ocean thermal (OTEC) option takes advantages of vertical temperature differences in the ocean to extract useful energy. However, the environmental impacts of large-scale use of OTEC are largely unknown. For this reason, this technology may not be a viable alternative to fossil fuels.

*Geothermal.* Geothermal energy is obtained from hot waters deep underground. The waters are heated as a result of radioactive decay deep in the earth. The practical potential for long-term replacement of fossil fuels by this technology is not well known. However, the world's geothermal energy base is very large, comparable to the world's coal resource base (Tester et al. 1988). Most current United States geothermal energy facilities are in California (Rhoads 1987). Its use elsewhere in the United States will depend on the price of competing fuels. To avoid environmental contamination, geothermal water should be reinjected, after the heat has been extracted, into the underground layers from which it was originally pumped. Otherwise, the chemicals in such waters will contaminate surface-water systems.

*Biomass.* Biomass refers to biological matter that contains stored energy. Consider trees and plants, which collect sunshine and use it, along with $CO_2$ extracted from the atmosphere, to build up biological molecules, storing energy in the process. The stored energy can be extracted from these molecules for human use. (Note that biomass also includes living matter that eats plants or other living things. With very rare exceptions, all of the energy in biological systems can be traced back along the food chain to solar energy.)

Considerable biomass in the form of wood is already consumed in this country (Energy Information Administration 1989). The real potential for biomass, however, lies in its ability to be converted to a transportation fuel, for example alcohol. It is quite conceivable that the costs of producing alcohol from biomass will be dramatically reduced due to bioengineering, making ethanol the cheapest alternative to gasoline (Bath 1989, Beyea and Keeler 1990).

Although biomass produces $CO_2$ when consumed for energy purposes, the next crop absorbs $CO_2$ back from the air. Equilibrium results when the next crop stores as much biomass as did the original. In contrast, should a forest be cut down and replaced with corn or short crops, the difference in biomass appears in the atmosphere as $CO_2$ (Houghton, this volume). Once equilibrium is reached with biomass, it is an energy source that does not contribute to global climate disruption. The problem is that too great reliance on this energy source could have disastrous environmental impacts on land and habitat, unless agricultural and silvicultural practices are radically changed. Suppose, for example, the current United States transportation fleet were powered by alcohol. It could take 400 million acres of land to grow the necessary crops and wood (Beyea and Keeler 1990). This is an area equivalent to our current crop base and would practically saturate our entire agricultural and silvicultural resource. The pressure to build so-called "biomass farms" would be enormous. If not properly designed, biomass farms could eliminate much of the wildlife habitat in the United States and put

| TECHNOLOGY | SOME ASSOCIATED ENVIRONMENTAL PROBLEMS | MITIGATABLE? |
|---|---|---|
| Hot Fusion (Using Conventional Fuel Cycles). | Radioactive Wastes from Neutron Activation.<br><br>Proliferation of Weapons-grade Material. | Yes, but expensive.<br><br>? |
| Cold Fusion | If works, and if power too cheap, will lead to massive interference in environment by humans. | No. |

**Fig. 14.3.** Fusion technologies, their associated environmental problems, and whether the environmental problems can be mitigated.

equivalent stress on the environment in other countries. Environmentally sound biomass plantations should be designed to provide habitat diversity that will allow wildlife to survive.

**Fusion**

Fusion energy (Fig. 14.3), which powers the sun, would not produce $CO_2$. Hot fusion technology attempts to produce temperatures as hot as the sun and hence tap fusion power. So far, success has been elusive. Current fusion cycles under study in the United States with government support are inherently radioactive, because they produce neutrons. When neutrons stop in the matter surrounding the reactor, they generate long-lived radioactivity, unless very pure (and expensive) materials are used. Another problem with neutronic fusion is that neutrons can easily be made to produce fissionable materials that can be used in conventional nuclear power reactors and for making nuclear weapons. In fact, the most practical uses of neutronic fusion power will be as a fission breeder. As a result, I doubt that conventional fusion can compete with gentler technologies such as photovoltaics.

There do exist nonneutronic fusion cycles, but research into these cycles is not supported by the United States government because they are technologically less promising. True enough, but man does not live by technology alone. The alternate cycles would at least have a chance of proving politically acceptable (Beyea 1990).

During 1989, there was a flurry of media reports about the possibility of cold fusion, or fusion taking place at low temperatures inside a metal matrix. Most exciting was the apparent absence of neutrons and the possibility of cheap power. Cold fusion could solve the coming energy crisis. However, if true, the environmental implications could be disastrous. Why? If man can move mountains cheaply, the natural world will be transformed. As the saying goes, "power corrupts and cheap power corrupts absolutely."

### Nuclear

*Conventional.* Nuclear power emits very little carbon dioxide and little is emitted indirectly during the mining and transportation of the fuel, but the current technology has lost so much credibility that it is unlikely to be a viable alternative. The majority view is that conventional nuclear power has proved too vulnerable to human error, too expensive, and the waste problem is not close to a solution. Although nuclear advocates vigorously dispute all these criticisms, their arguments have proven unconvincing. A Harris poll taken in January 1989 shows that two-thirds of the public does not want any more new nuclear plants. To replace coal electricity with nuclear power would require the siting of 500 facilities over the next 50 years. It is doubtful that there are even a fraction of 500 communities that would tolerate the siting of a new nuclear reactor. Any attempts to build new ones would generate strong community resistance, comparable to the current fights over Seabrook and Shoreham. It does not make sense to try to plan for our electricity future with a technology that polarizes our society.

*Second generation.* There is the possibility of developing new designs of nuclear power that are meltdown free (Weinberg 1990). Research into them should be started, but we must recognize that they do not address other problems and other public concerns. They do not address the transportation of radioactive materials, their disposal, and the proliferation of weapons-grade material. Furthermore, it is questionable that the new designs can compete economically with other methods for avoiding $CO_2$ emissions, especially if they are really built to reassure the public on safety and quality assurance.

More important than designing a reactor to meet tough goals will be demonstrating safety. It will be necessary to convince independent engineers and scientists, as well as the public, that the designs will work. That is certainly not going to happen based on engineering promises. Full-scale tests aimed at destroying a reactor will be required to build the necessary confidence. It is important to mention that successful demonstration of idiot-proof reactors is decades off, if it should prove possible at all. Even then, acceptance is problematic. The battleground of the nuclear debate will shift. Local communities will be skeptical that an actual plant will be built to the same standards as the demonstration plants. They will be afraid that small releases will still be possible. They will be unhappy that radioactive waste will have to be stored at the reactor, and transported through

| TECHNOLOGY | SOME ASSOCIATED ENVIRONMENTAL PROBLEMS | MITIGATABLE? |
|---|---|---|
| New Nuclear Designs. | Radioactive Wastes. | ? |
| | Proliferation of Weapons-grade Materials. | ? |

**Fig. 14.4.** Summary of potential new nuclear technologies and their associated environmental problems.

the community to waste repositories in which few people will have any confidence (Fig. 14.4).

For these reasons, the siting of even second-generation reactors is likely to meet strong public resistance. Only if all other alternatives to climate disruption have failed, do I see public acceptance of a second nuclear era. These reactors must be viewed as an insurance policy, not a component of our main line of defense.

## An Energy Policy for a Greenhouse World

### Vision

Based on this review of energy options, the most practical program for solving the greenhouse problem in the next century involves equal attention today to both the supply side and the demand side of the energy equation:

*Demand side.* Improved energy efficiency, material recycling, lifestyle changes.

*Supply side.* Direct solar technologies, such as photovoltaics.

The obstacle to this solution is not a shortage of technologies or resources, but concern about its economics. We can gradually eliminate $CO_2$, if we are willing to gradually pay more for energy. Whatever the costs turn out to be initially, research should be able to cut them.

Increasing costs will have an impact on economic growth, because the costs of living in a deteriorated world begin to dominate other costs. A hypothetical energy price scenario that might result from forcing a steady decline in $CO_2$ emissions by 2% per year shows that prices eventually triple over 1989 values. This an upper limit scenario, because it is based on current technology (Fig. 14.5). Although the overall growth rate is projected to slow, economic wealth would remain high and would eventually surpass the wealth in the baseline scenario (Fig. 14.6).

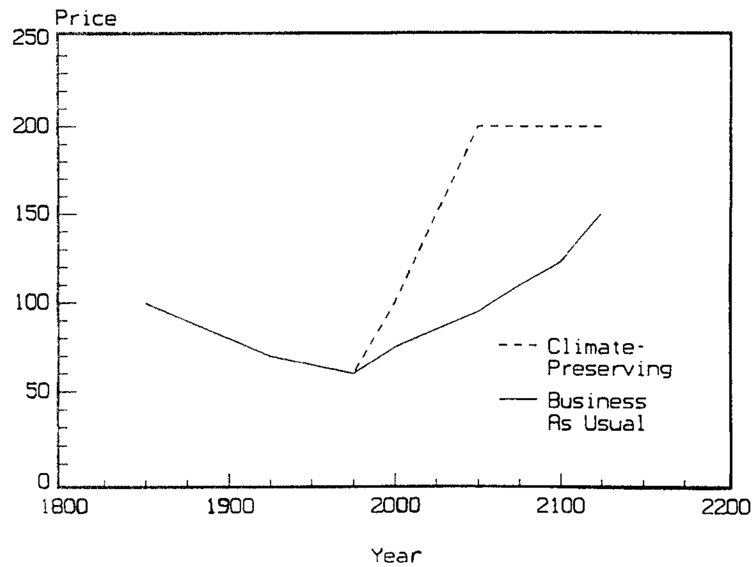


**Fig. 14.5.** Hypothetical future energy prices under a climate-preserving (worst case) scenario.

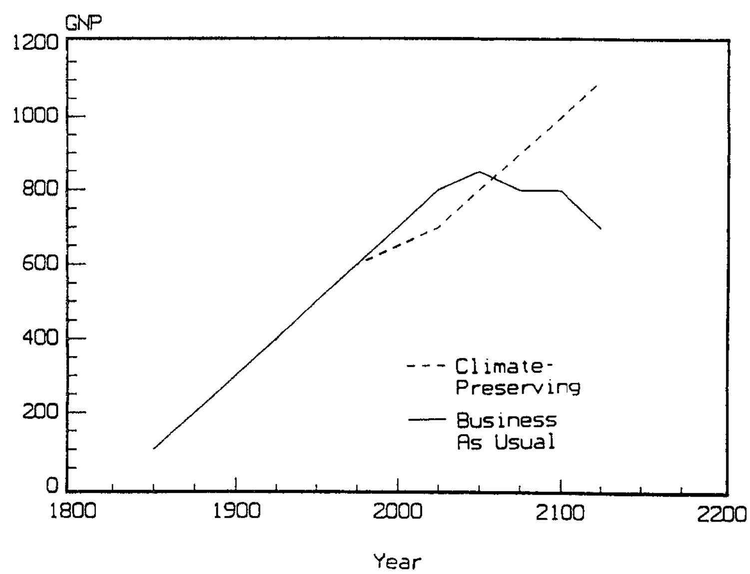


**Fig. 14.6.** Hypothetical future GNP under a climate-preserving (worse case) scenario.

When looking at the reduced economic growth in the early years, it is important to remember that conventional definitions of wealth, such as GNP, are necessarily limited. There are costs we pay other than those represented by dollars. These indirect costs—damage to the environment, to health, and to the quality of life—can be reduced as a by-product of following the $CO_2$ strategy I have outlined.

**Practical Scenario**

How can this future come about? How can we insure in a practical way that emission of $CO_2$ declines steadily, say at 2% per year over the next 50 years? (Note that a 2% per year reduction translates into approximately a 20% reduction by the year 2000.) The only realistic way to achieve this goal is by legislation, for instance, by placing a $CO_2$ limit per unit of energy on both new and existing plants, a limit that would tighten each year. To gain political acceptance, it will be important that any such law not specify a specific technology. We should give all non-$CO_2$ technologies a fair chance to compete.

On the supply side, efficiency (conservation) can reduce $CO_2$ emissions and we can therefore reduce the $CO_2$ limits accordingly. Practically, we can use efficiency to keep energy growth from rising, and possibly cause it to decline slightly, while still increasing GNP. As stated earlier, this strategy can actually save money, helping to offset the costs of solar power. To ensure that we get the full benefit from conservation, we must enact standards on buildings, automobiles, appliances, and so on. These standards should be imposed whenever engineering calculations predict that the standards will both save consumers money and reduce $CO_2$ emissions. Technically, this is interference in the marketplace. It is possible that engineers are wrong. But we have no choice. If we are serious about protecting our world, we will have to take some risks. It seems wiser to take the risk that investments elsewhere may earn more money than to take the risk that the climate will run out of control.

When it comes to setting energy standards, there are times when we need to interfere with the free market. For instance, it is an environmental crime to put up the inefficient buildings we build today. Why? They require more energy to operate than would be most cost-effective for the occupants; they are energy wasters. They will last for 75 years on average. They will be the energy guzzlers of the next century. Yet many still say the market must not be interfered with. Standards will be very important to ease the pain of other steps on the economy, for example, moving faster into solar than pure economics would warrant.

Suppose efficiency keeps energy consumption constant or slightly declining, while the economy is growing. Carbon dioxide emissions still need to be cut. Keeping them constant is not enough. The reduction of 2% per year will have to be met by changes in the supply mix. At the beginning, the easiest way for an industry to meet the fuel limit would be to add natural gas to coal. As time passed and the limit became more stringent, it would be necessary to phase out many fossil units, although flexibility could be introduced by allowing the purchase of emission offsets from facilities (like solar units) that do not surpass the $CO_2$ limit.

The use of emission offsets is a general strategy to improve economic efficiency. In this case, owners of energy sources with a margin to spare below the limit would be allowed to sell the margin to the highest bidder. Purchase of an offset would be made legally equivalent to a comparable $CO_2$ reduction. A facility above the limit would have the choice of either installing its own solar equipment or buying a solar (or other) offset from someone who could reduce $CO_2$ at lower cost. Economic allocation of $CO_2$ controls would thereby be promoted. An interesting offset concept involves reforestation, which one utility in Connecticut has already undertaken voluntarily (Trexler et al. 1989). At a trivial cost per kilowatt hour, they found they could pay for the planting of sufficient number of trees (which remove $CO_2$ from the atmosphere) to completely offset the $CO_2$ that will be emitted over the lifetime of the generating plant.

To obtain a 2% reduction in $CO_2$ in the transportation sector, fuel economy standards would have to tighten each year. Mixing grain or wood alcohol with gasoline should also count as a credit toward $CO_2$ reduction, because biomass energy offsets its own $CO_2$ in the growing process. Although it is difficult to estimate the cost of a 2% reduction in $CO_2$ transportation emissions, my preliminary calculations suggest average energy costs will increase a few percent a year. Although tolerable domestically, it would not take too many years before the United States would begin to be hurt competitively in international markets, unless other countries joined in. Consequently, international cooperation will be essential to make it politically feasible for the United States to continue $CO_2$ skimping. However, we cannot wait for international cooperation to start the process. We must take the first step.

There is an important geopolitical fact in favor of international cooperation: three countries (the United States, the Soviet Union, and China) control most of world's coal. Agreement need only be reached among them to gain the leverage to restrict coal use to globally responsible technologies.

### Political Considerations

Although the scenario discussed here is technically possible, the likely result is that such efforts will fail, unless old patterns are broken. Environmentalists tend to be purists, taking on the automobile industry, the coal industry, the oil industry, and the nuclear power industry—industries that earn more than $400 billion per year. These industries will dig in their heels, fighting both environmentalists and each other. Deadlock. We have seen it happen with acid rain legislation over the last 10 years, with "only" a few billion dollars per year at stake. The potential for deadlock is much greater with global climate issues.

Because the political situation is so grim, environmentalists must propose a realistic $CO_2$ strategy that can pass Congress and other governing bodies around the world. We must minimize any compromises, but we must be sure that the $CO_2$ reduction goal is met. If no compromises are made, no legislation will be passed. On the other hand, if too much compromise is made, victory will not be worth much. Finding the right path will not be easy. Whatever strategy is followed domestically, it is essential to look outward. We must never forget that the problem is inherently international and that the role of the United States is to set an example. The United States must take the lead in developing technological and social solutions. No one is going to cut $CO_2$ emissions, if the rich United States is not out there ahead of them.

A key part of the solution is citizen activism. Millions of people are going to have to dedicate their lives to saving the planet from climate disruption. Become part of National Audubon's climate activist network. Write for a copy of the "Carbon Dioxide Diet" (Beyea et al. 1990). Moreover, elected representatives need to know that this issue is a priority and that your vote depends upon their support for a responsible public policy on climate protection. Let them know that climate protection is an international issue, a national security issue, and that you want our best scientists, best diplomats, and best planners tackling this one with all their energy. Write your senators and representative to tell them to support efforts to invest in climate protection. It is not necessary to support every item in each bill. Climate bills are at an early stage. However, do demand that we develop a concrete plan for reducing $CO_2$ emissions, no less than 2% per year. Urge that we draw other nations into this debate and commit to a 50% reduction in greenhouse gases by 2015.

I have outlined the necessary steps that must be taken to come to grips with global climate change. Many of them are difficult. Yet, there is hope. The Montreal convention restricting growth of CFCs to protect the ozone layer is an indication that it is possible to cooperate on global climate issues. The very magnitude of the climate issue raises hopes that the world will finally cooperate. Solving the greenhouse problem has benefits that will spill over into other areas of international concern.

We must not forget the need to develop a plan that can pass the Congress and equivalent governing bodies around the world. If we lose this fight it could be a disaster. We are out to save the world!

## Summary

We have a moral responsibility to prevent climate disaster. We can do so without disruption by steadily cutting $CO_2$ emissions 2% a year over the next 50 years. The United States must set an example in developing an environmentally responsible energy policy, one that always takes climate protection into consideration. For their part, environmentalists must realize that conventional use of coal can no longer be considered an acceptable substitute for nuclear power.

We have many options and must consider the environmental pluses and minuses

of each. As the first part of the solution, the public must be educated about energy efficiency, including the need to change transportation and recycling infrastructures. Keeping energy consumption constant or slightly declining while the economy is growing is a worthy goal. To accomplish it efficiency standards must be imposed, even at the risk of interfering with the free market.

The other half of the solution is solar technologies. They can make a big difference, for they cause much fewer environmental problems than fossil fuels. Expanding research into photovoltaics could be the most important energy research step that can be taken for the future. Photovoltaics alone could power the entire economy in an environmentally responsible manner. Other possibilities, such as hydropower, wind, ocean-thermal, geothermal, biomass, and fusion have less potential. Nuclear power does protect the climate but has other problems and is in public disfavor. For it to replace coal electricity would require the siting of 500 facilities over the next 50 years, which would certainly meet resistance. However, second-generation nuclear designs are worth researching as an insurance policy, to guard against failure of the solar option.

Over the long term, we will have to pay more for energy to cut down $CO_2$ emissions sufficiently, but the cost of living in a deteriorated world for our descendants would be much greater.

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