Unit 13 : Looking Forward: Our Global Experiment

View of Earth from the Moon. Source: NASA

Overview

Emerging technologies offer potential solutions to environmental problems. Over the long-term, human ingenuity may ensure the survival not only of our own species but of the complex ecosystems that enhance the quality of human life. In this unit, examine the wide range of efforts now underway to mitigate the worst effects of man-made environmental change, looking toward those that will have a positive impact on the future of our habitable planet.

Sections:

1. Introduction

The preceding units have described how humans have both affected and been affected by the Earth system. Over the next century, human society will have to confront these changes as the scale of environmental degradation reaches a planetary scale. As described throughout this course, human appropriation of natural resources—land, water, fish, minerals, and fossil fuels—has profoundly altered the natural environment. Many scientists fear that human activities may soon push the natural world past any number of tipping points—critical points of instability in the natural Earth system that lead to an irreversible (and undesirable) outcome. This chapter discusses how environmental science can provide solutions to some of our environmental challenges. Solving these challenges does not mean avoiding environmental degradation altogether, but rather containing the damage to allow human societies and natural ecosystems to coexist, avoiding some of the worst consequences of environmental destruction.

It would be impossible to address the question of how human society will deal with environmental challenges in the future without realizing that people make decisions not just based on science, but more often based on economic and political considerations. This is not the focus of this course, and so it will not be discussed here. Instead, this chapter will examine some of the scientific constraints on our environmental challenges over the next century that will guide decision making into the future. In addition, some of the strategies discussed here depend on technological developments that cannot be anticipated. Environmental science cannot predict the future, as the future depends on technological and economic choices that will be made over the next century. However, environmental science can help us make better choices, using everything we know about the Earth system to anticipate how different choices will lead to different outcomes. A discussion of some of those outcomes is presented here.

2. Measuring (and Reducing) the Human Footprint

Population growth and economic development over this century present many different environmental challenges. As described in previous units, some are local in scale, such as certain types of water pollution. Some are regional in scale, such as acid rain. And some are global, such as climate change. In all cases, one simple strategy to minimize harmful impacts on the natural environment is to reduce the human "footprint" on the environment—although this simple concept is sometimes quite complicated to apply to a specific environmental problem.

At some basic level, most of our environmental challenges are related to the rapid increase in human population. As discussed in Unit 5, "Human Population Dynamics," demographers estimate that global population will increase through the middle of this century to approximately 9 billion and may stabilize or even decrease after that. A simple way of thinking about how to solve environmental problems—from atmospheric pollution to climate change—is in the context of how an individual appropriates some of the natural environment for his or her own needs. Addressing climate change can be discussed in terms of how much carbon dioxide and other greenhouse gases are emitted by each person; habitat loss can be discussed in terms of how much land each person requires to extract food and other services; air pollution can be discussed in terms of the amount of pollutants each person emits, etc. In this framework, population growth can be seen as a primary driver of environmental degradation, as the footprint of human society will increase in direct proportion to the number of people. In the purest sense, one's ecological footprint refers to how much land is required to support one's various activities (Fig. 1). However, the concept of a footprint is often used in a more general sense, applied not only to the amount of land, but also to water use, pollution emitted, etc.

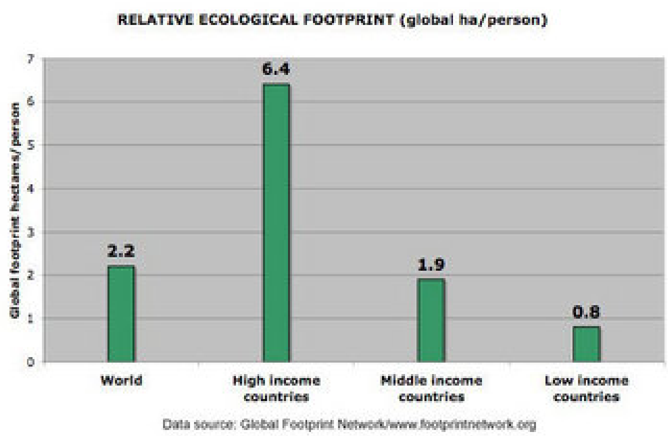

Figure 1. Global footprint (hectares/person)

For some issues, like water resources, calculating one's footprint is relatively straightforward. Per capita water use depends on dietary choices as discussed in Unit 8, "Water Resources," as well as on water use for sanitation, drinking, and other purposes, so calculating the average water needs for a particular society is quite feasible.

Because there is more than one cause for biodiversity loss, quantifying one's footprint is more complicated. As discussed in Unit 9, "Biodiversity Decline," many fish species are declining in number because of human fishing (or overfishing). For other species, such as those that live in the tropical rainforest, a major threat is the destruction of habitat. Still other species are threatened by toxic pollution. Quantifying exactly how one person affects the decline in biodiversity is therefore a much more complicated affair.

Calculating the impact of the human footprint on climate change brings other complications. At a basic level, one can calculate how much fossil fuel an individual uses and therefore how much carbon dioxide is emitted. However, greenhouse gases are produced not only when we use energy directly but also when we buy products that require energy to make them, from a new house or car to fresh produce that require energy for transportation. This is also an issue at a national scale. For example, the carbon dioxide emission footprint of a country like the United States only includes the fossil fuel that is actually used in the United States, but excludes the energy that is used to make products in other countries that are then shipped to American consumers.

Considering one's environmental footprint—however it is calculated—leads to a fundamental tension between economic development and environmental impacts. As discussed above, population growth is at the root of many environmental problems. But population growth is not the only driver of environmental degradation, and perhaps not even the primary one. It is true that many environmental problems would be much easier to solve if the population were much smaller, but over the next 50 years, demographers predict that the world population will increase another only 50 percent or so and then will start to decline. In comparison, human consumption of goods and services—sometimes measured by economists as gross domestic product (GDP) per capita—is predicted to grow by a factor of ten or even more through this century (Fig. 2). What this means is that the footprint of human society is getting larger, partially because the human population is growing (i.e., more individual footprints), but mostly because humans are getting richer, appropriating more and more of the natural environment for their needs, impacting almost every environmental challenge discussed in this course.

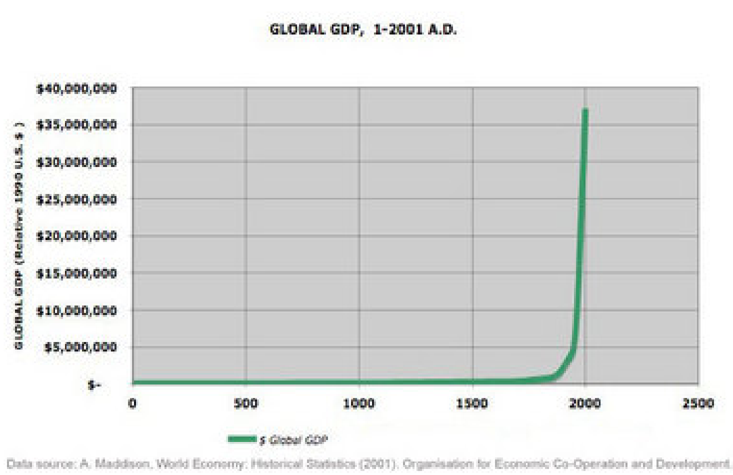

Figure 2. Global GDP

Some people believe a strategy for fixing environmental problems involves restraining economic growth, reducing the human footprint on the environment by using less of the natural world. In many cases, this can be accomplished without reducing the quality of human life. For example, there are many ways to conserve water or electricity that do not sacrifice quality of life. However, preserving the environment is unlikely to happen simply at the expense of economic development. Economic development leads to better quality of life for people all over the world; it raises people up from desperate poverty and gives our societies the capacity to fix many of the environmental challenges. So how can we increase the quality of human life, encourage economic development, and still protect the environment as human appropriation of the natural world becomes greater and greater? The answer may involve new technology. In some cases, new technologies allow us to reduce our environmental footprint while still providing the goods and services we need, allowing our economic well-being to flourish. A good example is the catalytic converter on automobiles that reduced air pollution, improving human health but still allowing us to drive our cars. New technology may not be a panacea for all environmental problems, but it can help societies balance their needs for economic development with their goals for protecting the environment.

3. Multiple Stresses on Interconnected Systems

As we discuss solutions to environmental challenges, we must acknowledge that many environmental problems are interconnected, so we cannot protect one part of the natural environment without considering all the different stresses on the system as a whole. A good example of this is the multiple threats to coral reefs.

Coral reefs occur in a variety of forms throughout tropical and subtropical seas and account for half of the Earth's present production of calcium carbonate (Wood, 1999). The scleractinian coral, the most important Order of reef building corals (also called "stony corals"), contains symbiotic algae within its tissues known as zooxanthellae. While the coral animal is capable of ingesting nutritious particulate material from seawater, an important component of its nutrition is derived from the photosynthetic products of the algae. The algal requirement for light limits the depth to which reef-building corals can live and form new reef complexes.

Coral reef communities are among the most diverse assemblages in the marine environment. Coral reefs occupy less than 0.25 percent of the marine environment but contain more than 25 percent of marine fishes, and in terms of total species diversity, coral reefs are the marine analogue of tropical rainforests. Because coraline skeletal material provides the physical substrate for the reef, the loss of the coral makes the balance of the reef community vulnerable.

Many studies have documented the decline in coral reefs around the world. However, identifying the primary cause of coral reef decline is very difficult because there are so many different environmental stresses on coral reef ecosystems. First, there is the direct destruction of coral reefs by anchoring. Most species of corals grow very slowly—usually around 1 cm of extension per year. This means that when fragments of coral are destroyed by ship anchors, even when the destruction is relatively minor, the cumulative effect of many different ships over several years can ultimately destroy a reef because the reef requires so much time to repair the damage.

A more extreme way of destroying the reef is through dynamite fishing. Dynamite fishing involves setting off charges in the water that stun or kill fish, making them easy to gather with basic skin-diving equipment. Although it is banned in most tropical countries, it is still quite common, especially in poor regions with limited access to deep-water fisheries. A by-product of the blast that kills the fish is the total demolition of coral within many meters of the blast. Left behind is a pile of coral rubble, unsuitable for supporting the diverse communities of organisms that live in a healthy coral reef ecosystem.

Another threat to coral reefs is overfishing. Some of this fishing is not even for food, but for live tropical fish for aquaria in homes. In addition, even pelagic fishing can cause problems for coral reefs because marine food webs are very complicated. Depletion of one species—large, predatory fish, for example—can lead to unforeseen consequences resulting in other species collapsing, ultimately affecting the coral reef ecosystem.

Coral reefs are also threatened by human land use. In many tropical regions, development near the coast has led to an increase in erosion of soil, which can kill coral reefs either by the direct effect of terrestrial soil material on the coral or by adding excess nutrients, which stimulate algal populations that can outcompete the stationary corals for light. Other forms of pollution associated with development are also a problem for coral reefs.

The final threat to coral reefs comes from climate change, although there are two separate impacts. Changes in ocean chemistry resulting from higher CO_2 levels are likely to be more serious threats to the health of coral reef communities. Aragonite—the mineral used by corals for their skeleton—is supersaturated in seawater today by about 400 percent. This will decline as CO_2 concentration in the atmosphere rises, with corresponding reduction in pH. Calculations suggest that aragonite saturation will decline by approximately 30 percent at atmospheric CO_2 concentrations twice the pre-industrial level, and this will lead to lower calcification rates for corals. It is possible that reduced rates of calcification will make reef corals more susceptible to storm damage.

An additional threat to coral reefs from climate change is a condition known as “coral bleaching,” which occurs when the corals lose their symbiotic algae in response to environmental stress (Fig. 3). Some corals do recover following brief periods of bleaching, although the means by which the algae become reestablished is highly speculative. If this fails to happen, the coral tissue dies, leaving the calcareous reef substratum exposed to physical damage and dissolution. Experiments have shown that this condition can be caused by elevated temperatures, reduced salinity, and excessive suspended fine particulate matter, and one or more of these factors has been associated with numerous observed bleaching events. There is also evidence that at elevated temperatures virulence of bacterial pathogens of corals may increase and that these may be involved in the bleaching process.

Figure 3. Coral reef after a bleaching event

Corals in today's tropical and subtropical oceans are very near their upper limits for temperature (some within 2°C) during the warm seasons of the year. The response of different species of coral to warmer temperatures is probably sensitive to both the magnitude of the increment of temperature and the rate at which this increase is experienced. Bleaching that isn't necessarily fatal can occur in response to an increase as small as 1°C above normal seasonal maxima. There is evidence that thermal anomalies greater than 3°C are fatal to several coral species. With the death of coral tissue, the reef substrate is subject to erosion from physical and dissolution processes and colonization by other organisms, especially seaweeds.

With so many different threats to coral reefs, how can they be protected? The challenge is to solve many of the different threats simultaneously. Protecting coastal marine ecosystems by setting aside marine preserves will not solve the issue by itself. This is because under predicted climate change conditions, raised carbon dioxide levels and warmer temperatures will destroy reefs even in protected areas.

This basic problem can be generalized to many types of environmental issues—in particular, the relationship between biodiversity loss and climate change. The primary strategy for protecting endangered species has been to set aside natural habitat, either as national parklands or wilderness areas. However, climate change threatens to undo much of the good work accomplished by conservation efforts, as the same barriers to that keep people and development out of these natural habitats also serve to prevent many species of plants and animals from migrating to preferred climate zones as the climate changes. Isolating natural ecosystems into specific protected areas bounded by agricultural or urban areas means that migration of these ecosystems in response to climate change becomes impossible. Thus, if we cannot avoid the most extreme climate change scenarios, many of the conservation efforts will fail. This does not mean that preservation of habitat is not important. Human appropriation of land continues to be the major threat to biodiversity, particularly in tropical forests. However, conservation is not enough when faced with the grand challenge of global climate change.

4. Confronting the Climate-Energy Challenge

The realization that humans are changing the Earth's climate is profound, and yet it is only one of many ways in which humans are changing the physical and biological environment. As discussed in Unit 1, "Many Planets, One Earth," the arrival of humans to the Americas at the end of the last ice age, approximately 14,000 years ago, was accompanied by the extinction of most large mammals, including mammoths and mastodons, presumably from excessive hunting. As discussed in Unit 9, "Biodiversity Decline," human land-use has caused an enormous reduction in biodiversity, as sensitive ecosystems such as wetlands, tropical rainforests, and coral reefs are encroached or destroyed by human activities. Confronted with these and other impacts of human activities, why is anthropogenic climate change so troubling? The answer is that climate change has the potential to make many of the other environmental challenges much more difficult to solve because of the global scale of the impacts and the huge magnitude of the change relative to what the Earth system has experienced over the last tens of millions of years.

Given the dramatic changes we are observing today in the climate system, coupled with our view from Earth history, what can be done? The first challenge we must confront in working toward a solution to future climate change is that any "solution" will be incomplete. Some amount, perhaps even a substantial amount, of climate change is unavoidable. Reducing CO_2 emissions so that they are below the level of CO_2 uptake by the oceans and biosphere will not happen in a decade or two, but only through prolonged actions over 50 years and perhaps longer. In addition, the oceans would continue to warm for decades even if emissions were halted. Ecological changes due to climate change that has already occurred will continue to unfold for decades. CO_2 resides in the atmosphere and surface ocean for centuries and is only slowly taken up by the deep ocean. If we were to reduce our emissions to zero immediately, it would take more than 200 years for terrestrial and oceanic uptake of carbon to restore the atmosphere to its pre-industrial condition. Thus, there is great momentum in the climate system, in the heat capacity of the oceans, in ice sheets, and in the residence time of carbon dioxide in the atmosphere, and this fact makes a certain amount of climate change inevitable. Future impacts discussed in Unit 12, "Earth's Changing Climate," include sea level rise, changes in rainfall patterns, early melting of mountain snow pack and glaciers (which serve as the primary water supply for billions of people), changes in storms and tropical cyclones, and other ecological changes that affect ecosystems crucial to human society.

One source of confusion in discussions on how to reduce CO_2 emissions is that our energy system is really more than one system. As discussed in Unit 10, "Energy Challenges," we use energy for transportation, for electricity to power our lights and electronics, to heat or cool our homes, for manufacturing, and for agriculture. Our energy choices within each of these sectors come with different technological constraints that require different types of solutions if reductions in CO_2 emissions are to be achieved. For example, the internal combustion engine (along with the gas turbine in airplanes) currently dominates the transportation sector and is fueled almost exclusively by petroleum, making transportation responsible for approximately 40 percent of global CO_2 emissions. The electricity industry has a much broader set of energy sources, including coal, natural gas, nuclear, hydroelectric, wind, solar, biomass, and geothermal—although coal, natural gas, and nuclear are currently dominant. Thus, the discussion of strategies for mitigating climate change must address not just sources of energy, but sources in relationship to different societal needs (Fig. 4).

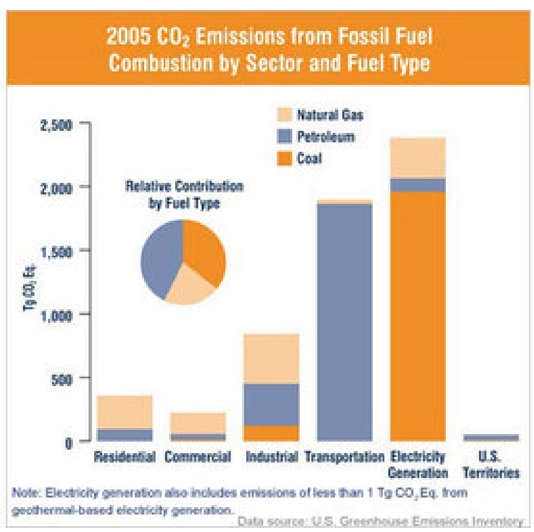

Figure 4. U.S. CO2 emissions from fossil fuel (by sector and fuel type)

Another consideration is differences in energy technologies among countries. Some countries, such as Saudi Arabia and Russia, are rich in hydrocarbon resources, and this guides their energy decisions. Other countries, such as Japan, have almost no domestic energy resources and turn to technological solutions such as solar and nuclear power. The end use of energy also varies among countries. For example, both China and the United States have large coal reserves, but China consumes almost twice as much, in part due to the large manufacturing industry in China versus the service economy of the U.S. (Fig. 5). This means there can be no single strategy for how the world will address climate change but rather we need a portfolio of strategies. Rapidly developing countries will have different solutions from those of developed countries. Even countries with similar levels of economic development will employ different solutions because of geography, political and cultural attitudes, and political systems.

This does not mean that individual solutions must be created for all countries. CO_2 emissions are not distributed evenly; a handful of countries contribute most of the emissions and will be responsible for bringing about most of the reductions. If the United States, China, India, the European Union, Russia, Japan, Australia, Canada, and perhaps Indonesia and Brazil each take significant steps to reduce emissions, it is likely that such efforts will be successful in reducing the impacts of climate change on the rest of the world (Fig. 5).

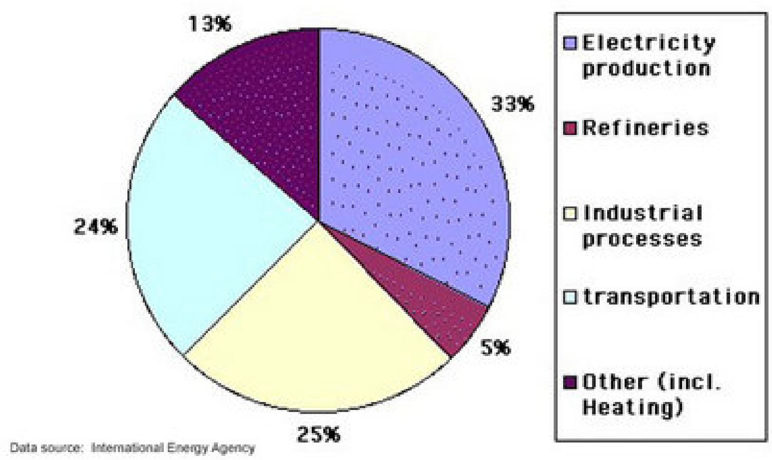

Figure 5. World CO2 emissions from fossil fuel use in 2000 (by sector)

Another constraint is the timescale over which it is possible to build new energy systems. Eliminating carbon emissions from electricity generation by using nuclear power, for example, would require building two large nuclear plants each week for the next 100 years. This rate of change is simply not possible given current constraints on steel production, construction capacity, the education of operators, and many other practical considerations. Taken together with the diverse uses of energy and the different needs of different nations, this means that there is no silver bullet solution for the climate–energy challenge. Myriad approaches are required. One can group these approaches into three broad categories, each of which will play an essential part in any serious climate mitigation effort.

Reduction of Energy Demand

The first category involves reducing CO_2 emissions by reducing energy consumption, as discussed in section 2, "Measuring (and Reducing) the Human Footprint." This does not necessarily require reducing economic activity, i.e. consuming less (although this can be part of the solution); rather, it means restructuring society, either by investing in low-energy adaptations such as efficient public transportation systems or by adopting energy-efficient technologies in buildings, in automobiles, and throughout the economy.

Huge discrepancies in energy efficiency exist today among developed countries. In general, countries with higher historical energy prices, such as most of Western Europe, are more efficient than countries with inexpensive energy including petroleum, although the differences can also be explained by historical investments in cities and suburbs and in highways and public transportation systems, as well as by a variety of other factors. But whatever the cause of the current differences among countries, there is great potential across the developed and the developing world to dramatically lower energy use through smarter and better energy systems.

Much of the efficiency gains can be accomplished with existing technologies, such as compact-fluorescent lighting or more efficient building designs; these are often referred to as the "low hanging fruit," as they are often economically advantageous because they are simple and inexpensive. In addition, there are technological improvements in end use that would contribute greatly to any emissions reductions effort by making large jumps in energy efficiency. For example, if we can develop batteries for electric automobiles that are economical and reliable, and if their use is broadly adopted, we will be able to replace the low-efficiency internal combustion engine with the high-efficiency electric motor. Moreover, electric cars would break the monopoly that petroleum currently has as the source of energy for transportation, thus addressing security concerns involving the geopolitics of oil and allowing transportation fuel to come from carbon-free sources. Whether better batteries are technically possible remains a question.

Non-Fossil Energy Systems

The second category of solutions to the climate–energy challenge involves expansion of non-fossil energy systems, including wind, solar, biomass, geothermal, and nuclear power. Again, there is no silver bullet. Wind is currently the most economical of these energy systems for electricity generation. However, wind requires huge excess capacity because of problems with intermittency, and so it cannot become a source for base load power unless storage technologies improve. Solar-generated electricity has similar problems with energy storage and is also expensive compared with wind or nuclear power. Nuclear power can be used for base load power, unlike wind or solar, but issues of safety, storage, and handling of nuclear waste and security concerns about nuclear weapons proliferation will have to be addressed before widespread expansion is likely, at least in the United States and Western Europe (aside from France, which already has made a significant commitment to nuclear energy).

This category is one with great hopes for technological "breakthroughs"—such as fusion, inexpensive solar, and inexpensive fuel cells—that may revolutionize our energy systems. Thus, basic research and development must be a part of any climate mitigation strategy. However, no responsible strategy should rely exclusively on breakthrough technologies; they may not exist for decades, if ever.

Outside of the electric realm, biomass converted to biofuel may play a major role in reducing CO_2 emissions in the transportation sector, at least until powerful, inexpensive, and reliable battery technologies or some alternative transportation technologies are developed. For example, Brazil currently obtains most of its transportation fuel from fermentation of sugar cane into ethanol, and similar programs are being implemented around the world.

A more efficient technology may be the conversion of biomass into synthetic diesel fuel via the Fischer-Tropsch process, which was used by the Germans in World War II to transform coal into liquid fuel. This process has the advantage of creating a more diverse range of fuel products, including jet fuel for air transport, and of being more efficient through use of all types of biomass, not just sugar (or cellulose for a cellulosic conversion process). The Fischer-Tropsch process, which involves gasification of the biomass by heating it in the presence of oxygen, produces carbon monoxide and hydrogen. This "syngas" is then converted to liquid fuel by passing the gas over a cobalt or iron catalyst.

Carbon Sequestration

The third category of solutions involves CO_2 capture from emissions sources and storage in geologic repositories, a process often referred to as carbon sequestration. This is an essential component of any climate mitigation portfolio because of the abundance of inexpensive coal in the largest economies of the world. Even with huge improvements in efficiency and increases in nuclear, solar, wind, and biomass power, the world is likely to depend heavily on coal, especially the five countries that hold 75 percent of the world's reserves: the United States, Russia, China, India, and Australia. However, as a technological strategy, carbon capture and storage (CCS) need not apply only to coal; any point source of CO_2 can be sequestered, including biomass gasification, which would result in negative emissions.

The scientific questions about CCS deal with the reliability of storage of vast quantities of CO_2 in underground repositories—and the quantities are indeed vast. Reservoir capacity required over the next century is conservatively estimated at one trillion tons of CO_2, and it may exceed twice this quantity. This amount far exceeds the capacity of old oil and gas fields, which will be among the first targets for sequestration projects because of additional revenues earned from enhanced oil recovery. However, there is more than enough capacity in deep saline aquifers to store centuries of emissions, and also in deep-sea sediments, which may provide leakproof storage in coastal sites. In general, the storage issues do not involve large technological innovations, but rather improved understanding of the behavior of CO_2 at high pressure in natural geologic formations that contain fractures and faults. Geologic storage does not have to last forever—only long enough to allow the natural carbon cycle to reduce the atmospheric CO_2 to near pre-industrial levels. This means that storage for 2000 years is long enough if deep-ocean mixing is not impeded significantly by stratification. It seems likely that many geological settings will provide adequate storage, but the data to demonstrate this over millennia do not yet exist. A more expansive program aimed at monitoring underground CO_2 injections in a wide variety of geologic settings is essential if CCS is to be adopted before the middle of the century.

The technological advances in CCS necessitate improving the efficiency of the capture of CO_2 from a coal-fired power plant. Capture can take place either by postcombustion adsorption, or through design of a power plant (either oxy-combustion or gasification) that produces a pure stream of CO_2 as an effluent. Either way, the capture of CO_2 is expensive, both financially and energetically. It has been suggested that capture and storage combined would use roughly 30 percent of the energy from the coal combustion in the first place and may raise the cost of generating electricity from coal by 50 percent, with two-thirds of this increase coming from capture. Even though these estimates are uncertain, given that carbon sequestration is not yet practiced at any coal plant, it is clear that technological innovation in the capture of CO_2 from a mixed gas stream is important.

Carbon sequestration also occurs through enhanced biological uptake such as reforestation or fertilization of marine phytoplankton. These approaches could be considered a separate category, as, for example, planting trees is quite different from injecting vast quantities of CO_2 underground. If pursued aggressively, such strategies might offset CO_2 emissions by as much as 7 Gigatons (Gt) of CO_2 (2 Gt of carbon) per year by the end of the century, out of total emissions of more than 80 Gt per year of CO_2 (22 Gt of carbon) as forecast in most business-as-usual scenarios. These approaches might be an important piece of a solution, but they will not replace the need for improved energy efficiency, non-fossil energy sources, and carbon sequestration.

The nature of the climate experiment means that no one truly knows what a safe level of CO_2 really is, apart from the impossible goal of the pre-industrial level of 280 parts per million (ppm). It is possible that nations will implement many of the approaches outlined above over the next few decades, which would stabilize atmospheric CO_2 below 600 ppm; it is difficult to imagine that a much lower stabilization level will be realized given the current state of the world energy systems. It is possible that this effort will be enough, that the world will warm another 2 or 3°C, that ice sheets will slowly melt, and that most of the severe consequences will be gradual, allowing adaptation by humans and natural ecosystems. On the other hand, it is also possible that even with concerted effort and cooperation among the large nations of the world, the climate system will respond too quickly for humans to adapt, that the Greenland and West Antarctic ice sheets will decay more quickly than expected, and that the impacts of a warmer world on humans and on natural ecosystems will be worse than we now predict.

It is very difficult to know which scenario is correct. The magnitude of the consequences depends in part on how we deal with them. Because of the potential for catastrophe, it seems prudent to ask what societies might do if the rate of climate change were to accelerate over the next few decades and if the consequences were to be much worse than anticipated. One approach that has long been discussed is the engineering of our climate system by adjusting the incoming solar radiation by means of reflectors in space or in the upper atmosphere; indeed, there may be some ways to accomplish a reduction in solar radiation at very low cost relative to other strategies of mitigation. Recently, such ideas have gained more prominence, not as a substitute for serious emissions reductions, but in the sober realization that efforts to reduce emissions may not be sufficient to avoid dangerous consequences. The power to engineer the climate comes with an awesome responsibility. How could we engineer such a system to be failsafe? Which countries would control this effort? Who would decide how much to use, or when? And what would happen if something went wrong, if we discovered some unforeseen consequences that required shutting the effort down once human societies and natural ecosystems depended on it?

Ultimately, our path in dealing with climate change, as with many other environmental challenges, will depend on the choices we make—not just we as individuals, but nations and human society as a whole. The good news is that there are strategies that can solve these problems. Tropical rain forests can be protected from deforestation. Marine ecosystems can be protected from overfishing. And although we are already committed to substantial climate change, we can choose to rebuild our energy infrastructure to avoid the worst impacts. Some of these choices involve new technologies that require spending money; others simply involve a change in behavior, perhaps enforced by laws and regulations. Environmental science helps clarify what the consequences of our choices are likely to be and hopefully guides society to make better choices in caring for our habitable planet.

5. Further Reading

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Glossary

acid rain : Rainfall with a greater acidity than normal.

adsorption : Process that occurs when a gas or liquid solute accumulates on the surface of a solid or, more rarely, a liquid (adsorbent), forming a molecular or atomic film (the adsorbate). It is different from absorption, in which a substance diffuses into a liquid or solid to form a solution.

anthropogenic : Describing effects or processes that are derived from human activities, as opposed to effects or processes that occur in the natural environment without human influences.

aquifers : Underground formations, usually composed of sand, gravel, or permeable rock, capable of storing and yielding significant quantities of water.

aragonite : A carbonate mineral that forms naturally in almost all mollusk shells, as well as the calcareous endoskeleton of warm- and cold-water corals

base load power : The average amount of electricity consumed at any given time. Base load power stations are designed to operate continuously, unlike peaking power stations that generally run only when there is a high demand.

coral bleaching : Refers to the loss of color of corals due to stress-induced expulsion of symbiotic, unicellular algae called zooxanthellae that live within their tissues. Stress can be induced by: increased water temperatures (often attributed to global warming), starvation caused by a decline in zooplankton levels as a result of overfishing, solar irradiance (photosynthetically active radiation and ultraviolet band light), changes in water chemistry, silt runoff, or pathogen infections.

effluent : An outflowing of water from a natural body of water, or from a man-made structure, generally considered to be pollution, such as the outflow from a sewage treatment facility or the wastewater discharge from industrial facilities.

Fischer-Tropsch process : A catalyzed chemical reaction in which carbon monoxide and hydrogen are converted into liquid hydrocarbons of various forms. The principal purpose of this process is to produce a synthetic petroleum substitute, typically from coal or natural gas, for use as synthetic lubrication oil or as synthetic fuel.

greenhouse gases : Atmospheric gases or vapors that absorb outgoing infrared energy emitted from the Earth naturally or as a result of human activities. Greenhouse gases are components of the atmosphere that contribute to the Greenhouse effect.

pathogen : A biological agent that causes disease or illness to its host.

pelagic : Water coming from the part of the open sea or ocean that is not near the coast

scleractinian corals : Stony or hard corals responsible for the very existence of the reef. As living animals, they provide habitats for many other organisms. The breakdown of their skeletons during calcium-carbonate accretion and especially after death provides material for redistribution and consolidation into the reef framework.

zooxanthellae : Unicellular yellow-brown (dinoflagellate) algae which live symbiotically in the gastrodermis of reef-building coral.