Learn About …

LIMITING CLIMATE DISRUPTION

Human activities are warming the world and disrupting the climate. It's up to each of us to take responsibility to live in ways that limit further warming and disruption that can threaten life on Earth as we know it. The required responses do not mean forsaking all our goods, services, and comforts, but they will mean changes in lifestyle for almost everyone. Let's look first at the cause and consequences of a warming world, so we can understand how our individual actions can have an effect.

How we got where we are

For about 6000 years, since the end of the last ice age, the Earth's climate has been favorable for development of the human species. Beginning as hunter-gatherers, we developed agriculture and permanent settlements (towns) where not everyone had to farm, so specializations in goods production (crafts) were supported. Collecting towns and territory into "countries" or "city-states" enhanced their economic viability, produced new classes of labor—merchants, administrators, military, and so on—and led to substantial populations gathering in cities.

Throughout the millennia during which these changes occurred, there were only a few sources of energy to drive them. Human brawn was supplemented by animal brawn when horses, oxen, and other animals were domesticated and harnessed. Falling water, either in natural waterfalls or man-made millraces, and windmills powered machines that could do the work of many men or animals. Wind also powered ships that expanded exploration, trade, and knowledge of the world.

And then, in the mid-eighteenth century, along came James Watt and his invention of a steam engine powered, usually, by burning coal. Steam engines could be sited almost anywhere that was convenient to drive machines. They were mounted on wheels to produce locomotives and trains that could move goods anywhere humans laid rails. They were also mounted on ships and ultimately displaced wind power for sea transport.

The steam engine revolutionized life for a large fraction of humanity—the Industrial Revolution is well named. With the invention of electric generators and motors in the nineteenth century, steam engines were coupled with generators and the electricity sent on wires to power machines (and illuminate the world) far from the actual steam engine. The introduction of oil and natural gas, in addition to coal, as fuels and the invention of the internal combustion engine burning gasoline from oil further enhanced the revolution.

The revolutionary result is that, in less than three centuries, essentially all human and animal labor in the "developed" world has been replaced by energy derived from burning fossil fuels—coal, oil, and gas. The fantastic array of goods and services you are probably used to and depend on are the result of the Industrial Revolution and its aftermath. Unfortunately, another result has been the release of about two trillion (2,000,000,000,000) metric tonnes of carbon dioxide into the atmosphere. (One metric tonne = 1,000 kilograms (about 2200 pounds) = 1,000,000 grams) About 40% of this gas is still in the atmosphere with the rest about equally divided between being dissolved in the oceans or taken up on land by photosynthesis into plants.

The right amount of carbon dioxide in our atmosphere is essential for life as we know it. Without this greenhouse gas, the temperature of the planet would be too cold to sustain life. During the ice ages of the past million years or so, the amount of carbon dioxide in the atmosphere was about 180 parts per million (ppm). (For every million molecules in the atmosphere, 180 were carbon dioxide; for comparison, about 780,000 are nitrogen and 210,000 oxygen.) The average ice age temperature of the Earth was four or five degrees Celsius colder than now. The northern hemisphere was covered with a two-mile thick sheet of ice about as far south as present-day New York City. Ice age humans and their ancestors were limited to the lower latitudes.

During periodic warm periods, atmospheric carbon dioxide levels rose to 280-300 ppm, the average temperature rose, and the ice retreated. For most of the past 6000 years, the most recent warm period, the carbon dioxide level has been about 280 ppm and the climate pretty much like what we know today. This constancy in carbon dioxide levels and temperatures during the first 800 years of the past millennium is shown in Figure 1. However, since the Industrial Revolution and the burning of huge amounts of fossil fuels, the atmospheric carbon dioxide level and average temperature have risen. Today (2017) atmospheric carbon dioxide is above 400 ppm and the planet's temperature is about one degree Celsius warmer than before Watt invented the steam engine.

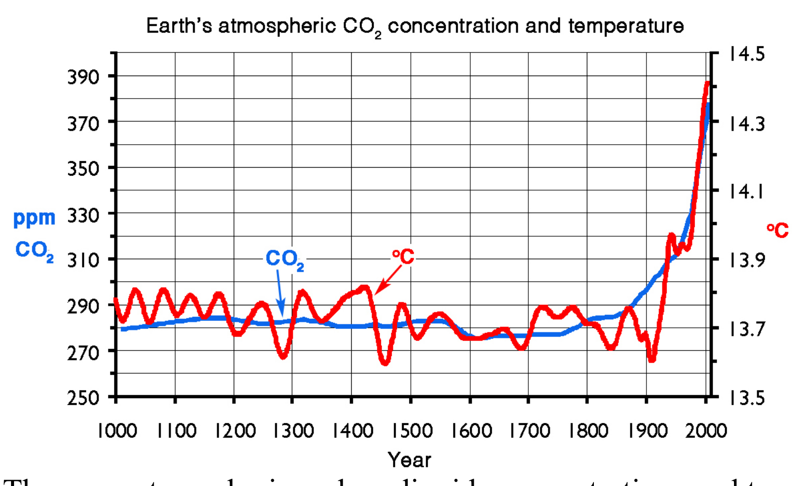

Figure 1. These are atmospheric carbon dioxide concentrations and temperatures from the 11th to the early 21st century.

The climate in a warming world

The great ice sheets of the ice ages mostly melt away during warm periods. As the Earth has warmed further, the remaining ice in ice sheets (mainly on Greenland and Antarctica), in glaciers, and in sea ice at the poles is also disappearing. Glacier loss is one of the most visible changes in a warming world, Figure 2. On a much larger scale, the disappearance of Arctic sea ice can be observed in satellite images, Figure 3.

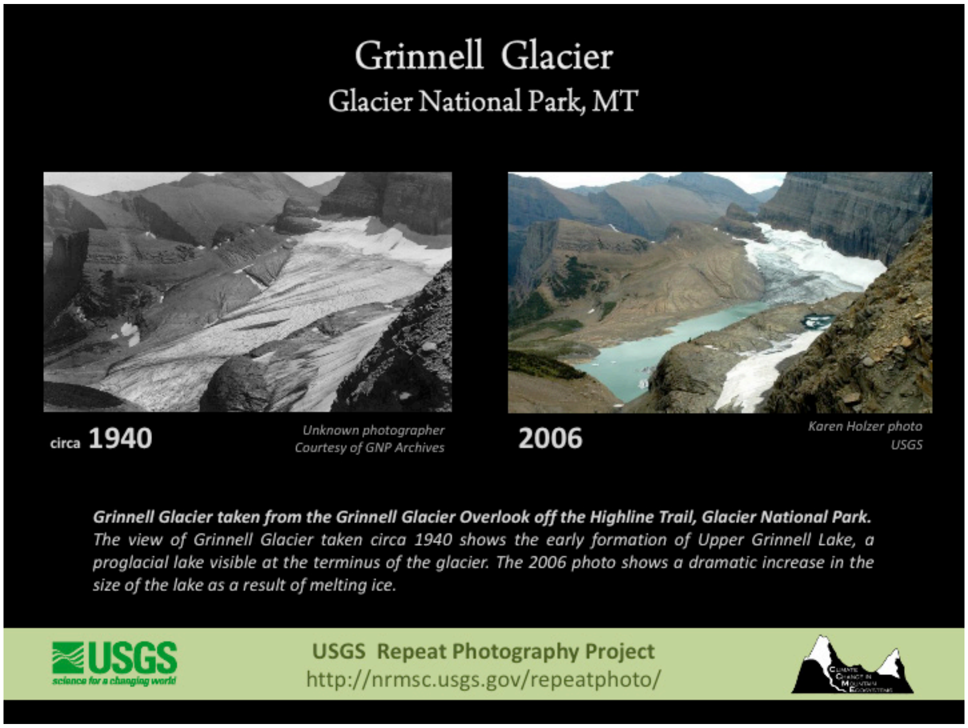

Figure 2. More than half the glaciers in Glacier National Park have disappeared (melted away) and the larger, like this one, are on their way out.

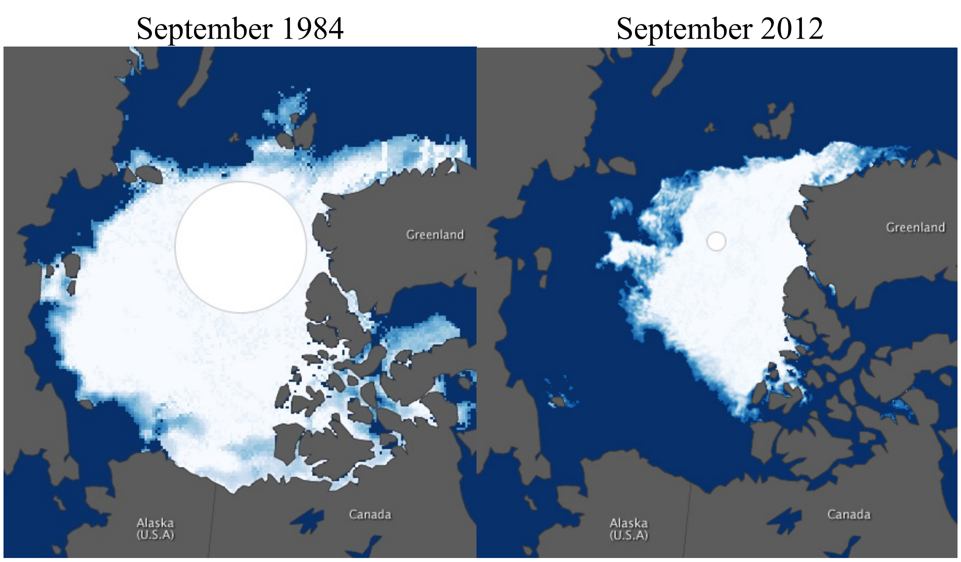

Figure 3. Arctic sea ice cover shown at its annual minimum extent in September. Images are from NASA satellite data; the North Pole is close to the center of each image.

Where do the billions of tonnes of melt water from glaciers, Greenland, and Antarctica go? Into the sea. Sea level is rising across the world. Added to the extra water is extra heat that warms the seas, causes the water to expand, and further increases the sea level rise. Figure 4(a) shows that the average rise over the whole globe has been about ten inches since the late 19th century. Figure 4(b) puts sea level rise in more human terms with a photo of "sunny day flooding" that is becoming more common in low-lying coastal areas like Miami Beach, Florida. Here seawater floods the streets during some high tides, even when there is not a storm in sight.

(a) (b)

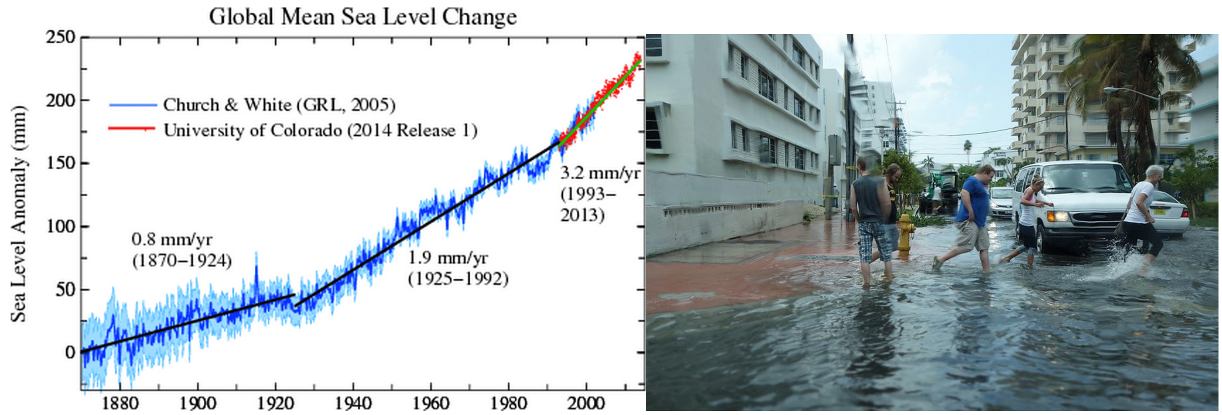

Figure 4. (a) is the change (rise) in sea level since 1870 measured from tide gauges (blue) and satellites (red) more recently. (b) shows water flooding a Miami Beach street during a high tide on a sunny day. During storms, the flooding can be worse and more destructive.

It should be no surprise that the seasons are changing in a warming world. Winters are becoming shorter and warmer. Again, we can look to the effects on the freezing and melting of water as an indicator of seasonal changes. Examples are the number of days that ice covers large freshwater lakes. Data spanning more than 150 years are available for several lakes around the world, including, Figure 5, Lake Mendota in southeastern Wisconsin. There is obviously a good deal of natural variation in these data, but the trend is clear—the winter ice season has become one month shorter since the middle of the 19th century.

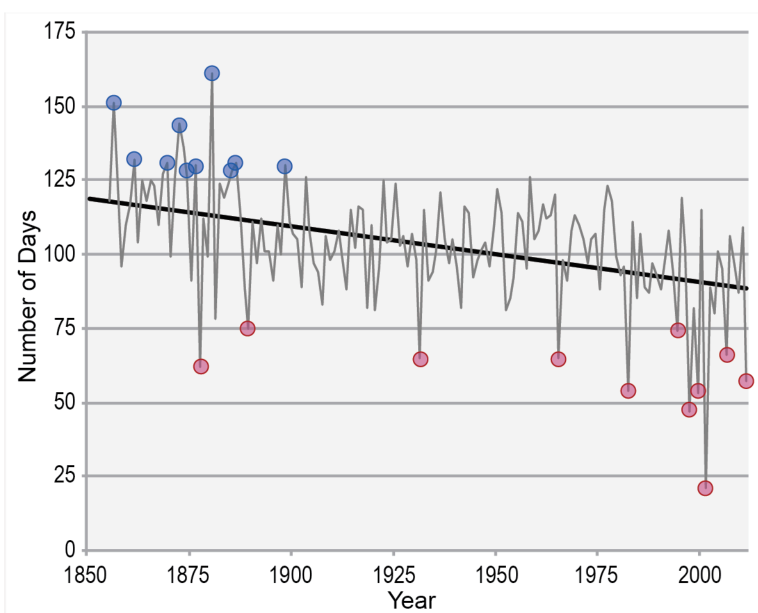

Figure 5. Number of days Wisconsin's Lake Mendota has been ice covered each winter season. Blue circles highlight the 10 longest ice seasons (all more than 100 years ago) and red circles the 10 shortest ice seasons (half in the past 25 years).

Changing seasons disrupt life for many plants and animals. Consider the extensive damage being done by pine bark beetles in a swath of pine forests from Canada through the U.S. Rocky Mountains to Mexico. The beetles burrow into a tree to lay their eggs and leave behind, also, a fungus that converts the wood to food for the beetle larvae and, in the process, kills the tree. Cold winters freeze a lot of the larvae and keep the number of beetles low enough to be a nuisance, but not devastating. As winters warm, more larvae survive to become mature beetles to attack more trees. Dead trees do not produce the pine cones that many birds, squirrels, and bears depend on for a good deal of their diet, so the changing climate and increase in beetles affects a great deal more than the trees.

There are many other examples of food webs going awry as the seasons change. Generally, when the climate changes, it does so slowly and plants and animals have time to adapt and evolve to meet the challenge. Unfortunately the climate change humans are making is many times faster than most of those in the past and it is not clear that all species will be able to adapt before it is too late for them to survive. Since we are causing the problems for ourselves, as well as the rest of life on Earth, it seems reasonable that we take responsibility for making the changes as small as possible and reducing them, if possible.

You in a warming world

Burning fossil fuels has added and continues to add large amounts of carbon dioxide to our atmosphere. Its increased greenhouse effect has raised the temperature of the planet about one degree Celsius and continues to raise the temperature even further, so we can look ahead to even more disruption. The only sure way to mitigate (slow) the disruption is to stop adding carbon dioxide to the atmosphere and, if possible, begin to remove what we have added. First and foremost, this means we must stop burning fossil fuels. This is a complicated task, because the great majority of the energy that supports civilization depends on the energy derived from burning fossil fuel. However, even if there were no climate disrupting problems, we need to be preparing for the end of fossil fuels when they are all burned up. Global warming and climate disruption simply make the necessity more immediate.

There is actually an enormous amount of energy available to us for as long as we wish—sunlight. The amount of solar energy reaching the Earth's surface in about two hours is equivalent to the total amount of energy humanity uses in a year. Harnessing this energy in various ways that are already available and being improved can produce a limitless amount of carbon-free energy and make essentially all fossil fuel burning unnecessary. Obviously, this change cannot occur overnight, so what should be our strategy to minimize fossil fuel burning, as we work to eliminate it?

The world will reach this goal more quickly if energy use is reduced, so that less fossil fuel will need to be burned as it is phased out as fast as possible and the sun, in turn, is harnessed as fast as possible. But the world is made up of individuals and each of us plays a role in reducing overall energy use. There are many sources of ideas for ways you can reduce the amount of energy you use and hence reduce the amount of carbon dioxide added to the atmosphere. One of the most comprehensive is a well-researched publication from the Union of Concerned Scientists (UCS), *Cooler Smarter: Practical Steps for Low-Carbon Living* (Island Press, Washington, DC, 2012). Visit their website, ucsusa.org, to learn about the organization, including its publications. *Cooler Smarter* is available in paper (recycled), or (save a tree and its carbon dioxide absorbing ability) as an ebook for your reader, tablet, or phone. To help, if necessary, get you started, the rest of this discussion provides a few suggestions and their rationales.

Buy less stuff. It takes energy to make stuff. If less stuff is purchased, less will be made and less energy will be used. This is one third of the "Reduce-Reuse-Recycle" environmental mantra, which, at its heart, is a low-energy-use lifestyle. A further enormous advantage is that less stuff means using smaller amounts of the finite natural resources available on the planet.

Use energy-efficient devices. The amount of energy saved (not produced) by using more energy-efficient devices can be mind-boggling. Light bulbs are probably the most familiar example. Within the past couple of decades there have been two revolutions in lighting technology. First, compact fluorescent bulbs displaced the incandescent Edison bulb and, now, light emitting diode (LED) bulbs are replacing both. For the same amount of light, an LED bulb uses about half as much energy as a compact fluorescent and almost *nine times less energy* than an incandescent. Nine times less energy can mean nine times less carbon dioxide emitted. Home appliances are being made more energy efficient, so, when the time comes to replace a dryer, refrigerator, dishwasher, and so on (repair costs are higher than replacement), look for energy efficient models. Personal computers and TVs can also be energy hogs and manufacturers are working to reduce the energy use in new models.

Turn devices off when not in use. Amazingly, your devices use the least energy (zero) when they are turned *completely off* (not in standby mode). Again, lights are an easy, visual example to make this point. Turning off lights (including energy-efficient LEDs) when they are not needed is a simple step to reducing energy use around a home, office, or business. Much less visible is the "phantom energy" that pours into computers, printers, TVs, and many other electronic devices that are kept in standby mode. To make it less onerous to turn off devices individually, those used together, say in a home or business office, can be plugged into a power strip, so they can all be turned off together.

Eat less meat (especially beef and lamb). Figure 6 compares the amount of carbon dioxide equivalent, CO_2e, emitted to produce, process, and serve the same amount of several foods. CO_2e is a combination of carbon dioxide itself, plus other greenhouse gases, mainly methane and nitrous oxide, that are also emitted in agricultural practice. (These other gases have larger greenhouse warming effects than carbon dioxide, so to get CO_2e, the amounts released are converted to the amounts of carbon dioxide that would give the equivalent greenhouse effect.) The large emissions that result from eating beef and lamb (even relative to other meat) leap out of the graph. Substituting poultry, fish, or pork for some or all of the beef or lamb in your diet will reduce your contribution to increasing global warming. It's also evident that moving toward a more vegetarian diet further reduces your contribution, even if you are not already, or do not become, a vegetarian or vegan.

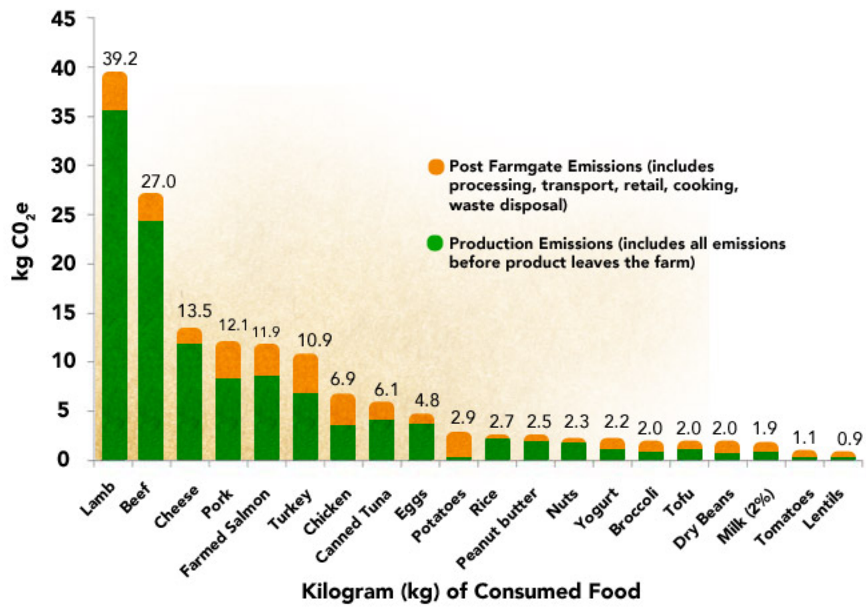

Figure 6. Comparing greenhouse gas emissions resulting from the production, processing, and serving the same amount of several foods.

Several factors are responsible for the high emission profiles for beef and lamb. These are ruminant animals that depend on the microorganisms in their stomachs to break down the cellulose in their diets. In addition to compounds the animal uses as food, this process produces methane gas that is mostly excreted by belching. In addition, the decomposition of their manure creates more methane (as well as nitrous oxide). Raising cattle accounts for about a quarter of the methane produced by human activity in the U.S. The majority of these animals are raised in feed lots where they are fed grain and hay whose growth and harvesting produce greenhouse gas emissions (from fertilizer and energy use) that are included in the figure. In some parts of the world, forests are cut down to open land to raise cattle. Loss of the trees' photosynthesis reduces the amount of carbon dioxide removed from the atmosphere. This tree loss effectively "adds" carbon dioxide by eliminating one of its natural sinks.

Drive low-emission vehicles. Burning fossil fuels in cars and light trucks produces about 15% of human-caused U.S. greenhouse gas emissions. Almost all these vehicles are owned by individuals, so individual choice of what to drive can have a major effect on the amount of carbon emitted to the atmosphere. More options for low emission vehicles come on the market every year. The miles per gallon for conventional internal combustion engine (ICE) cars have increased (largely as a result of governmental regulations in many countries). Even more efficient, hybrid gas-electric vehicles are available from essentially all manufacturers and their prices have become comparable to ICEs, removing the economic argument against them.

Coming over the horizon are "emission-free" vehicles with electric motors powered by either plug-in batteries or fuel cells. "Emission-free" has to be taken with a grain of salt. What this means is that during their operation, the vehicles emit no greenhouse gases. (Emission from hydrogen fuel cells is water, which is a greenhouse gas, but one that is condensable and over which we have no control. The temperature of the environment controls the amount of water vapor in the air, the humidity.) However, the electricity to charge the plug-in batteries and the hydrogen for the fuel cells has to come from somewhere. That somewhere may be a greenhouse-gas emitting power plant or oil refinery where the hydrogen is produced by an energy-intensive process breaking down hydrocarbons. Emissions resulting from the power plants or refineries have to be accounted for in assessing the emissions from all-electric vehicles. As we move closer to a sun-powered world, the electric power sources will no longer be burning fossil fuel and hydrogen will likely be produced using the sun's energy to break down water. In the meantime, even with the caveats, electric vehicles are almost always less emitting than those burning fossil fuels, and they are really fun to drive because the electric motors are so responsive compared to ICEs.

Drive less. Just as with your electricity-powered devices, the emissions from your car (whatever kind) go to zero when it is not driven. The idea here is to walk, bike, or use public transportation for more of your local travel. This is the rationale and incentive for many cities around the world to create special bike lanes and more bike-sharing options. (The exercise is also good for the citizens' health.) Combining errands, so that a single trip accomplishes several goals, is a simple way to reduce vehicle use.

Fly less. Each passenger on a round trip U.S. coast-to-coast commercial flight is responsible for the release of about one tonne of carbon dioxide to the atmosphere. Was the trip necessary? Could a vacation have been taken closer to home? Could the meeting have been done by phone or by Skype? In an increasingly interconnected and global world, some travel to interact with colleagues is necessary. But careful consideration of lower emission alternatives that meet the same objectives should be the norm, especially as electronic conferencing becomes ever more common and available.

Support decarbonizing the economy. The individual actions listed above (and many others) are necessary and vital, but not sufficient to stem greenhouse gas emissions before more severe climate disruption occurs. Societal actions are necessary, which means they must be taken by local, state, and national governments. This, in turn, means that you need to support, reinforce, and vote for candidates who are committed to take these actions.

These actions can take many forms, including support and incentives for sun-powered energy sources like solar voltaic arrays, wind farms, solar heating, and so on. The bottom line, as pointed out above, is reducing the emission of greenhouse gases, especially carbon dioxide from fossil fuel burning. From an economic point of view, the problem with the Industrial Revolution (that has brought us so much good) is that we have neglected the costs associated with the release of enormous amounts of carbon dioxide that have shown up as climate disruption. Two approaches to solving this problem are for governments to set limits on allowed emissions or to tax the producers (or users) of fossil fuels to "recover" the costs.

The former approach is usually a "cap-and-trade" system in which the government sets an overall cap on emissions and emitters can trade emission rights among themselves to balance higher and lower emitters to stay within the cap. Over time, the government reduces the cap and the number of emission rights, so the emitters are forced to reduce their emissions. This is a pretty direct approach to lowering emissions, but is objectionable to many who feel that this is governmental interference in the economy, which should be self-regulating, based on supply and demand.

The alternative approach is, in principle, based on supply and demand. In one form, called a revenue-neutral carbon tax (or fee), the government levies a "social cost of climate change" tax on fossil fuel producers (or emitters) on the amount of carbon their product will emit (or has emitted) and the revenue from the tax is distributed equally to all citizens. (This is part of the revenue-neutral part. The government collects the tax, but gives it all to its citizens.) The producers will, of course, pass on the additional expense of the tax to consumers in the form of higher prices for energy and goods produced by energy. Thus, there will be a disincentive for consumers to spend more (they will buy less stuff), the demand for stuff will go down, less will be produced, and the amount of fossil fuel energy used will go down. Consumers who economize and spend less will "win", because their share of the tax revenue will more than compensate for the higher costs of what they do buy. In this indirect approach to reducing carbon emissions, there is no targeted amount of reduction, and some find this objectionable.

Both cap-and-trade and carbon tax approaches are being used in various countries and states around the world. Watch for news of their results, emission reductions, in the next few years.