CLIMATE CHANGE

SCIENCE AND SOLUTIONS

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CLIMATE CHANGE

AN INTRODUCTION

As you read this, a massive geologic experiment is underway. It is being conducted not by scientists in a lab, but by the seven billion people who call the earth home. As we go about our daily lives, we are all contributing, often unwittingly, to changes in the earth's atmosphere that could affect the way we live for generations to come.

Every year, humans burn billions of tons of coal and oil. Fossil fuels are the foundation upon which our modern economies are built. The energy that we get from burning fossil fuels powers homes, businesses, cars, and planes. But when we burn something, be it paper, wood, coal, or oil, it releases carbon dioxide into the atmosphere. Carbon dioxide (CO_2) doesn't interact with light from the sun the same way it interacts with heat given off by the earth. It "traps" the heat instead of letting it escape out into space, and the more CO_2 there is in the atmosphere, the more heat it traps. Since we burn a lot of fossil fuels, we also release a lot of CO_2. As a result, the amount of CO_2 in the atmosphere is steadily increasing, and with it the earth's average temperature. Scientists predict that by the end of the century, earth could be somewhere between 3.2°F and 7°F warmer than it is today.[1]

When the media talk about climate change, they tend to focus on melting ice caps and rising sea levels—vivid images to be sure, and easy to turn into a news graphic, but not representative of how climate change will affect many of the world's people. Climate change is about more than just the world getting warmer. A region's temperature plays a significant role in determining how much rain it gets, and when; the timing of winter's first freeze, spring's first thaw; whether it is prone to drought, or flood; and what kinds of plants and animals can live there. A warming world will change all of that—more dramatically in some areas than others, but everyone will be affected in some way. Everyone will have to adjust.

Climate change is not the end of the world. Geologists will tell you that earth has seen its share of global catastrophes, and none of them have managed to "kill" the planet. Human beings will certainly not be the first to succeed where asteroids and continent-scale volcanism have failed. That does not mean, however, that climate change doesn't have the potential to make life on earth much more difficult for us than it needs to be. Unless we take steps to reduce our CO_2 emissions, adapting to the "new normals" of a warmer world will be both unpleasant and expensive.

ABOUT THIS GUIDE

The science of climate change doesn't have to be overly technical. The purpose of this guide is to explain, in plain English, the underlying physical science of global climate change. It will also address how we know that climate change is happening, what its effects might be, and what actions we can take to mitigate them.

CLIMATE VS WEATHER

WHAT'S GOING TO CHANGE, EXACTLY?

When we talk about climate change, it's important to distinguish between climate and weather. When temperatures can swing by ten or twenty degrees from one day to the next, 3.5°F of warming doesn't sound like something to get too excited about. But those day-to-day temperature changes are examples of weather, not climate. Climate can be thought of as the parameters within which a place's weather operates—in other words, a place's climate tells you what kind of weather is normal for that area. For example, Seattle, WA, has a much different climate than Phoenix, AZ. Seattle is relatively wet, with mild temperatures that rarely hit either an extreme high or an extreme low. Phoenix, on the other hand, is very dry, averaging just over eight inches of rain a year, and has temperatures that frequently climb above 110°F in the summer. Temperature is not the only factor that determines an area's climate—elevation, topography, and proximity to water also have an effect—but it is one of the most important.

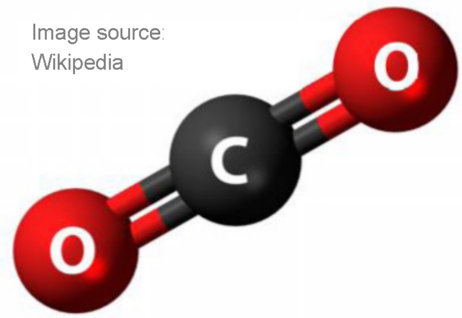
SUMMER THUNDERSTORMS ARE PART OF COLORADO'S CLIMATE.

In that context, 3.5°F is actually a fairly large amount of warming. It's the difference between living in Milwaukee, WI, and Akron, OH, 150 miles to the south[2]. It's not that it never gets colder in Akron than in Milwaukee—it's pretty much guaranteed to happen at least a few times a year—but in general Akron tends to be the warmer of the two cities. They have different climates. The difference between Athens, GA, and New York, NY, is even more obvious. Athens is about 7°F warmer than New York[2]. If you flew from one to the other, you would probably notice the difference as soon as you stepped off the plane. New Yorkers would be understandably concerned if their city suddenly had Athens' climate, and vice versa.

Saying that the earth will be 3.5°F to 7°F warmer by 2100 can seem a bit abstract. Another way to visualize it would be to imagine that the town where you live is moving two to four miles south every year. You'd hardly notice the change at first, but by the end of the century, when your town is 200- 400 miles further south than it is today, you would definitely be able to tell that, overall, its climate had gotten warmer.

Climate change doesn't mean that it will never be cold again. There will still be winter, no matter how warm the planet gets. What climate change does mean is that warm days will be a little warmer, and cold days a little less cold. The day-to-day effects won't be dramatic, but as with everything else related to climate change, a lot of small changes can add up to something big.

THE SCIENCE



A CARBON DIOXIDE MOLECULE

CARBON DIOXIDE

Carbon dioxide makes up about 0.04% of our atmosphere. While that might not seem like a lot, it still comes out to more than three trillion tons of CO_2 floating around in the air. Structurally, a CO_2 molecule is pretty simple: one carbon atom with an oxygen atom on either side. It has two major environmental functions. First, plants and other photosynthesizing organisms pull it out of the air and combine it with water to create carbohydrates, which are the foundation of the food chain. Second, CO_2 acts as a greenhouse gas, absorbing heat from the earth and preventing it from escaping out into space.

WITHOUT THE GREENHOUSE EFFECT, EARTH WOULD BE COMPLETELY FROZEN.

THE GREENHOUSE EFFECT

Without its atmosphere, earth would be one giant snowball. Earth only gets enough energy from the sun to warm its surface to about 0°F—pretty warm compared to outer space, but still far too cold for life to exist. In reality, earth's average surface temperature is a much more comfortable 58°F. Certain gasses in our atmosphere, such as CO_2, methane, and water vapor, absorb and "recycle" some of the sun's energy, keeping earth much warmer than the sun can by itself. This is the greenhouse effect. Without it, life on earth would not be possible. It occurs because the earth and the sun give off different kinds of electromagnetic energy, and because CO_2 and other greenhouse gasses absorb one kind (from the earth) while allowing the other (from the sun) to pass through them.

ELECTROMAGNETIC ENERGY

Electromagnetic (EM) energy may sound exotic, but it's actually very common. Light from the sun, microwave energy, radio waves, and even heat—all things we encounter on a daily basis—are types of electromagnetic energy. EM energy travels in the form of a wave—that is, it fluctuates between "peaks" where its electromagnetic field is strongest, and "troughs" where it is weakest. Different kinds of EM energy have different wavelengths, which can be visualized as ripples on the surface of a pond. The wavelength of the ripples is the distance from the top of one ripple to the top of the next ripple. Ripples that are very close together have a short wavelength, while more widely spaced ripples have a long wavelength. Wavelength is important because it determines how various kinds of EM energy interact with matter. As far as the greenhouse effect goes, the two kinds of EM energy that we are most interested in are visible light (sunlight), and infrared energy (a kind of heat). The key difference between the two is that visible light has a shorter wavelength than infrared energy.

ENERGY: EMISSION AND EQUILIBRIUM

All objects give off electromagnetic energy of some kind. The kind of energy they emit depends on how hot they are. Warmer objects give off energy with short wavelengths, while cooler objects give off energy with long wavelengths. For example, humans and other animals are only warm enough to give off infrared energy, which has a relatively long wavelength and is invisible to the naked eye. The filament in an incandescent light bulb, on the other hand, gets so hot when you turn it on that it glows with visible light, which has a shorter wavelength.

EMBERS GLOWING HOT ENOUGH TO GIVE OFF VISIBLE LIGHT.

How hot an object is, and thus how much energy it emits, depends on how much energy it absorbs from its surroundings. The more energy it absorbs, the hotter it gets and the more energy it emits. If you sit in front of an empty fireplace, you'll only be as warm as the room around you. But if you build a fire in that fireplace, the heat that it gives off will warm you and the rest of the room. By using the fire to add extra energy to the room, you are increasing its overall temperature. This is as true on a planetary scale as it is in your living room. If the earth suddenly started receiving more energy from the sun—or if less of the energy it did receive was able to escape back into space—its overall temperature would go up.

ENERGY-MATTER INTERACTIONS

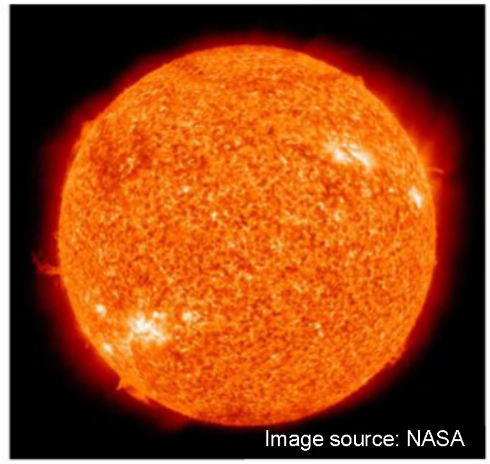
Matter can interact with electromagnetic energy in several ways. Objects can absorb EM energy. Microwave ovens use this interaction to cook food: substances such as water and fat absorb microwave energy (which has a long wavelength) and heat up as a result. An object can also reflect EM energy, as when visible light bounces off a mirror. Transmission occurs when EM energy passes through an object without interacting with it at all. We can see through glass because it transmits visible light instead of absorbing or reflecting it.


SUNGLASSES TRANSMIT SOME WAVELENGTHS OF LIGHT WHILE ABSORBING OTHERS.

Which of these interactions occurs depends on three factors: the object's elemental composition, its molecular structure, and the energy's wavelength. Some objects will absorb one kind of energy while allowing other kinds to pass right through them. For example, the wavelength of visible light ranges from 390 to 700 nanometers. Within that range are bands that correspond to different colors of light (in order of decreasing wavelength: red, orange, yellow, green, blue, and violet). When we wear sunglasses, we see everything with a tint. This is because sunglass lenses do not transmit every wavelength of visible light. Amber-tinted sunglasses are transparent to red, orange, yellow, and green light, but absorb blue and violet light. We can only see the colors that reach our eyes. As it happens, when you can't see blue and violet, the world appears amber-colored.

SOLAR VS TERRESTRIAL ENERGY EMISSIONS

The sun is blindingly hot. Its surface is nearly 10,000°F, more than hot enough to give off visible light, and massive amounts of it. When the earth's surface absorbs light from the sun, it heats up. As the earth's surface gets hotter, it re-emits the energy that it absorbed back into space. However, since the earth absorbs a tiny fraction of the sun's total energy, it only gets warm enough to emit infrared energy, not visible light (as you can probably imagine, a planet hot enough to emit visible light would not be a comfortable place to live). If you've ever stood on a blacktop on a hot, sunny day and felt the heat rising off the asphalt, you have some idea how this works: light goes in, infrared energy (heat) comes out.

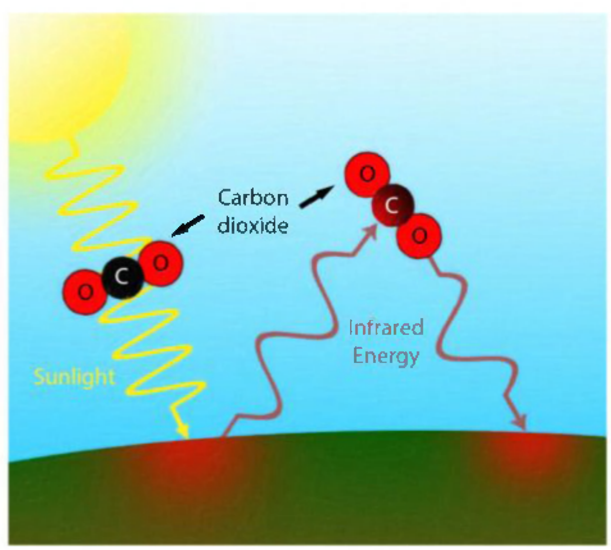


THE SUN HAS A SURFACE TEMPERATURE OF 9,940°F AND EMITS 384 TRILLION TRILLION WATTS OF ENERGY.

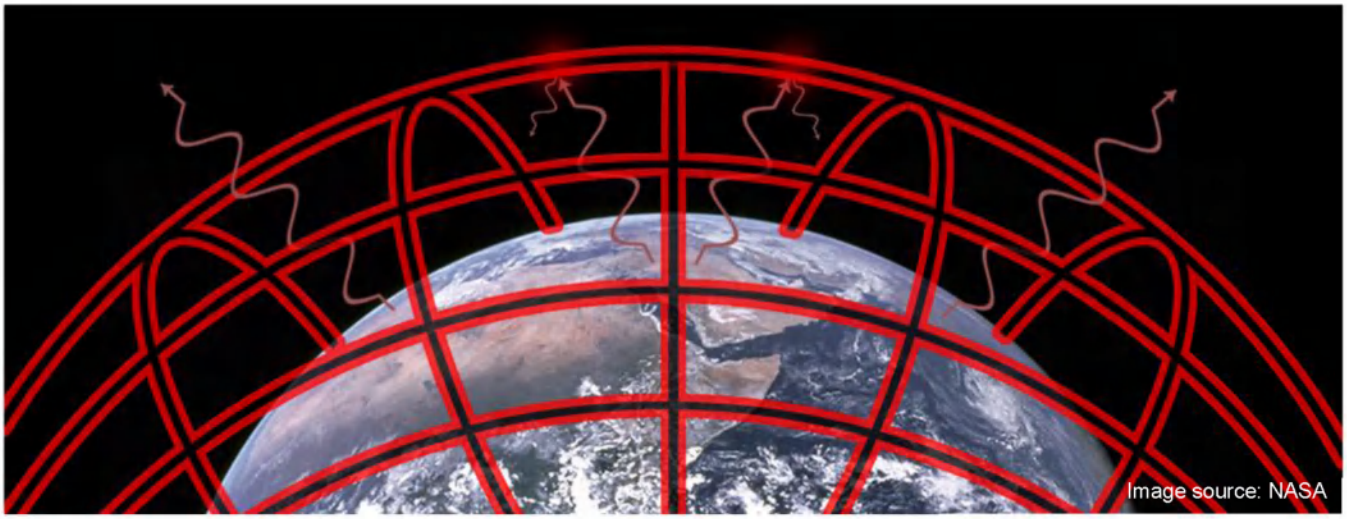
THE GREENHOUSE GASSES

Not all of the gasses that make up our atmosphere interact with energy in the same way. Nitrogen and oxygen, which make up the vast majority of our atmosphere (78% and 20%, respectively) let both visible light from the sun and infrared energy from the earth pass right through them. Other gasses in the atmosphere, including water vapor, carbon dioxide, and methane, are also transparent to visible light, but behave much differently when they come into contact with infrared energy emitted by the earth. Instead of letting infrared energy pass through them, these "greenhouse gasses" absorb it, which causes them to heat up. As they get hotter, they emit infrared energy of their own, some of which is directed back toward the earth's surface, where it gets reabsorbed. As noted earlier, the earth only gets enough energy from the sun to warm it to 0°F. By recycling some of the earth's outgoing energy, greenhouse gasses increase the overall amount of energy that earth receives. More incoming energy means warmer surface temperatures. It's this extra energy that pushes the earth's average surface temperature up to 58°F. Without them, earth would be too cold for life to exist.

It's worth pointing out that the term "greenhouse effect" is actually somewhat misleading. A greenhouse stays warm because its glass windows let visible light in to warm its interior, but physically block warm air from leaving. Carbon dioxide and other greenhouse gasses do not trap warm air. They absorb outgoing electromagnetic energy and then reradiate some of it back toward the earth's surface, supplementing the energy that earth gets from the sun. However, since there isn't a better term to describe this phenomenon, we'll just have to stick with "greenhouse effect."



CARBON DIOXIDE DOES NOT INTERACT WITH VISIBLE LIGHT, BUT ABSORBS AND REEMITS INFRARED ENERGY.



THE MORE CARBON DIOXIDE THERE IS IN THE ATMOSPHERE, THE MORE OPPORTUNITIES THERE ARE FOR INFRARED ENERGY TO GET ABSORBED BY THE ATMOSPHERE INSTEAD OF ESCAPING INTO SPACE.

HUMANS AND THE GREENHOUSE EFFECT

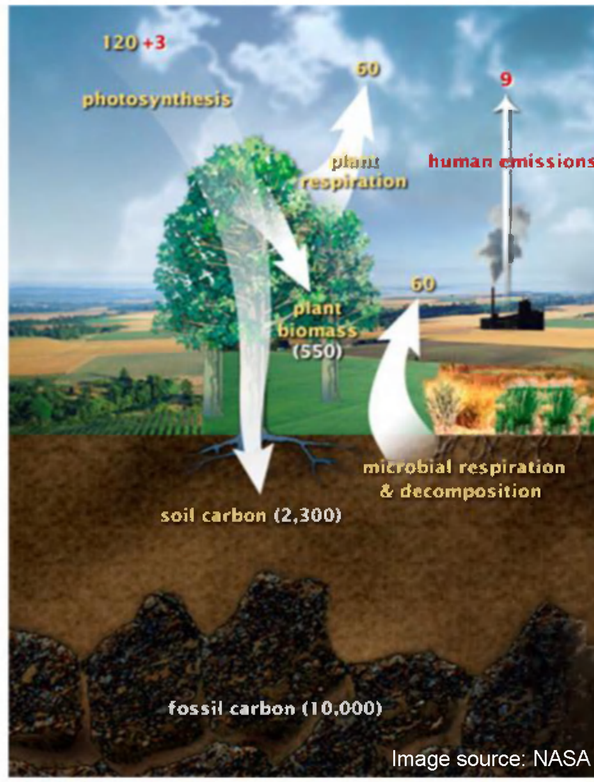
CO_2 CONCENTRATIONS AND TEMPERATURE

The strength of the greenhouse effect—how much extra energy it directs toward the earth's surface—depends on how many greenhouse gas molecules there are in the atmosphere. When greenhouse gas concentrations are high, they absorb a greater percentage of the earth's infrared energy emissions. This means that more energy gets reemitted back toward the earth's surface, raising its average surface temperature. The reverse is also true: taking CO_2 out of the atmosphere would reduce the amount of infrared energy that it absorbs and cause the earth to cool. Vascular plants first appeared on earth around 420 million years ago.[3] Before then, land plants had been restricted to only the wettest environments, but the evolution of vascular systems allowed them to colonize a much wider variety of terrestrial environments. Over the following 90 million years, the resulting increase in photosynthetic activity removed so much CO_2 from the atmosphere that it helped set off a 60 million year ice age.[3, 4]

Think of the atmosphere as a heat-trapping "net" surrounding the earth. Carbon dioxide and other greenhouse gasses are the "ropes," while nitrogen and oxygen are the open spaces between the ropes. When infrared energy hits an open space, it escapes into outer space and dissipates; but when it hits a rope, the rope heats up and reradiates some portion of the energy back toward the planet, raising its overall temperature. The more CO_2 molecules there are in the atmosphere, the more ropes there are in the net, shrinking the open spaces and making it harder for infrared energy to escape into space without hitting a rope. The tighter the net, the more energy it absorbs, and the hotter the earth gets.

THE CARBON CYCLE

The carbon found in atmospheric CO_2 is just a tiny fraction of earth's total carbon reserves. Carbon is also found in rocks, oceans, fossil fuel deposits, and all living things. The movement of carbon atoms between these reservoirs is known as the carbon cycle. Carbon leaves the atmosphere when photosynthesizing organisms such as plants, algae, and some kinds of bacteria pull it out of the air and combine it with water to form carbohydrates. It gets returned to the atmosphere as CO_2 when humans and other animals breathe it out, or when plants die and decompose. Sometimes, instead of rotting and releasing their carbon back into the atmosphere, photosynthesizers get buried deep underground, locking their carbon away in the earth for millions of years. With the right underground conditions, the remains of those photosynthesizers will become fossil fuel deposits such as coal, oil, or natural gas. This underground carbon is effectively removed from the short term carbon cycle. It will return to the atmosphere slowly, over tens or hundreds of millions of years, if ever.



BILLIONS OF TONS OF CARBON IN AND OUT OF THE ATMOSPHERE PER YEAR.

UPSETTING THE BALANCE

There is another way that organic carbon (carbon found in living things) gets returned to the atmosphere: fire. When organic matter burns, it releases CO_2 and water vapor. This is as true for fossil fuels, which are just the geologically modified remains of ancient organisms, as it is for a wood fire in your fireplace. Normally there is a balance between the CO_2 that enters the atmosphere from sources such as decomposing organic matter, animal respiration, and wildfires, and the CO_2 taken out by photosynthesis. Sometimes one process slightly outpaces the other, but in the long run they even out.

For the past 10,000 years, this balance of intake and emission has kept the amount of carbon dioxide in the atmosphere constant. But by burning an ever-increasing amount of fossil fuels, we are putting our finger on the scale, tipping the balance toward CO_2 emission. When we mine fossil fuels and burn them for energy, we are taking carbon that would have taken millions and millions of years to reenter the atmosphere and putting it back there all at once. There is a finite amount of carbon dioxide that plants and other photosynthesizers can remove from the atmosphere in a year, and almost all of that photosynthetic capacity goes toward balancing out natural CO_2 emissions. Once the CO_2 emitted by animal respiration and organic decomposition has been accounted for, there's not enough photosynthetic capacity left to scrub all the extra CO_2 emitted by fossil fuel combustion. As a result, the amount of carbon dioxide in the atmosphere has increased steadily since the beginning of the Industrial Revolution, with CO_2 concentrations rising especially sharply in the latter half of the 20^{th} century.

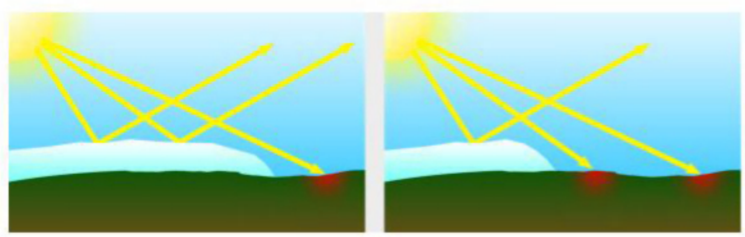
HUMAN CO_2 EMISSIONS

A ton of carbon dioxide has a volume of 136,324 gallons. In 2012, humans emitted 34.8 billion tons of CO_2 into the atmosphere,[5] a volume of 4.3 quadrillion gallons, or 3,912 cubic miles. That's enough CO_2 to fill Lake Mead, the 120-mile long, 489-foot deep reservoir formed by the Hoover Dam, once every seventeen hours, for a year. Since the Industrial Revolution, about 250 years ago, the amount of CO_2 in the atmosphere has increased 37%. Before 1750, one out of every 3,571 molecules in the atmosphere was a carbon dioxide molecule.[1] As of 2013, that number has risen to one out of every 2,500.[5] If one out of 2,500 molecules doesn't sound like a lot, consider that Venus's atmosphere is 96.5% carbon dioxide (or more than 96 out of every one hundred molecules), and its surface temperature is 863°F. An increase of a couple CO_2 molecules per thousand can have a significant effect on a planet's temperature. More CO_2 in the atmosphere means more opportunities for earth's infrared energy to be absorbed and reradiated back toward its surface. And we're seeing the effects: our planet is 1.3°F warmer than it was a century ago. By 2100, it could be another 3.2° to 7° warmer.[1]

IN 2011, HUMANS EMITTED ENOUGH CO_2 TO FILL LAKE MEAD, THE LARGEST RESERVOIR IN THE UNITED STATES, 515 TIMES.

OTHER SOURCES OF WARMING

Human CO_2 emissions are the driving force behind climate change, but as the earth gets warmer, it will trigger a number of self-reinforcing processes (vicious circles) that will intensify its effects. For example, he earth's surface only absorbs about 70% of the sunlight that falls on it. The amount of sunlight that gets absorbed depends on the color of the surface the light falls on. Dark colors absorb more light (and get hotter) than lighter colors. Snow and ice, which are white, reflect almost all the light that hits them, and the reflected light goes back into space without warming earth's surface. When snow or ice melts, it exposes the darker, more absorptive materials (rocks, dirt, water) beneath. With less snow on the ground due to climate change, earth will absorb more incoming energy from the sun, raising its temperature even further.

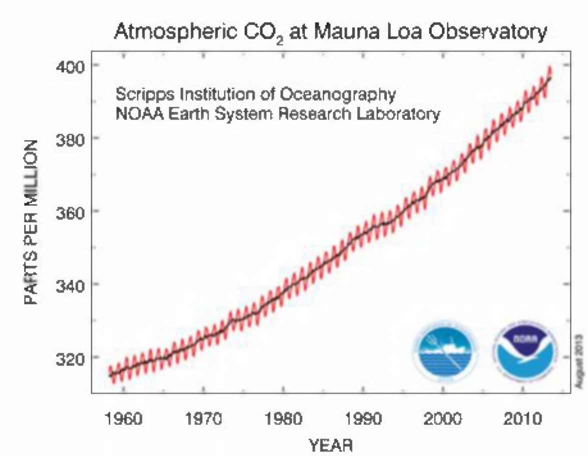


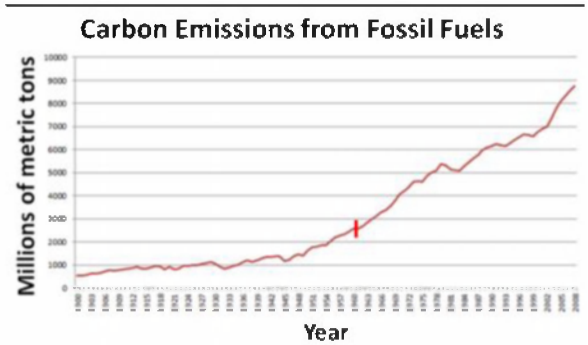
AS SNOW MELTS, IT EXPOSES THE DARKER GROUND BENEATH, WHICH ABSORBS MORE SUNLIGHT.

Another effect of warmer global temperatures will be the thawing of permanently frozen ground in places like Siberia and Alaska. This permafrost contains vast amounts of methane, another potent greenhouse gas. As the ice holding it in the ground begins to melt, the methane will escape into the atmosphere. As with CO_2, the more methane there is in the atmosphere, the stronger the greenhouse effect will become and the warmer earth will get.

ARE HUMANS CAUSING CLIMATE CHANGE?

We know that atmospheric carbon dioxide traps infrared energy from earth, and that the more CO_2 there is in the atmosphere, the warmer earth gets. We also know that atmospheric CO_2 levels have risen sharply in recent decades, reaching 400 parts per million (one out of every 2,500 molecules) in 2013.[5] Measurements of atmospheric composition taken at the Mauna Loa Observatory in Hawaii show that since 1960, the amount of CO_2 in the atmosphere has jumped from 320ppm to 400ppm.[6] CO_2 emissions from fossil fuel use have increased from 2.16 billion tons per year in 1900,[7] to over 34.8 billion tons per year in 2012.[5] As a result, earth is now 1.3°F warmer than it was at the beginning of the 20th century.[1]





ATMOSPHERIC CO_2 CONCENTRATION SINCE 1960 (TOP) AND CARBON EMISSIONS SINCE 1900 (BOTTOM). THE RED BAR ON THE BOTTOM GRAPH MARKS THE YEAR 1960.[6]

But can we be certain that human activities are responsible for that warming? Yes. There are no natural carbon dioxide sources that could account for this rapid increase in atmospheric CO_2. Volcanoes, which are one of the largest natural CO_2 emitters, only emit about 220 million tons of CO_2 per year.[8] In 2012, humans emitted 34.8 *billion* tons of carbon dioxide, more than 150 times as much CO_2 as volcanoes. And volcanic activity doesn't change much from millennium to millennium, so there's no reason to think that they are giving off more CO_2 now than in previous centuries. Earth's rising surface temperature isn't due to increased solar intensity, either. Satellite observations of the sun show that it hasn't been getting any hotter in recent decades.[9]

Climate scientists are nearly unanimous in their agreement that human CO_2 emissions are the driving force behind climate change. Over 97% of climate scientists say earth is warming, and that human activities are causing it.[10] As far as scientists are concerned, there is no debate about whether climate change is real, or whether we are causing it.

WHY WE NEED TO DO SOMETHING ABOUT IT

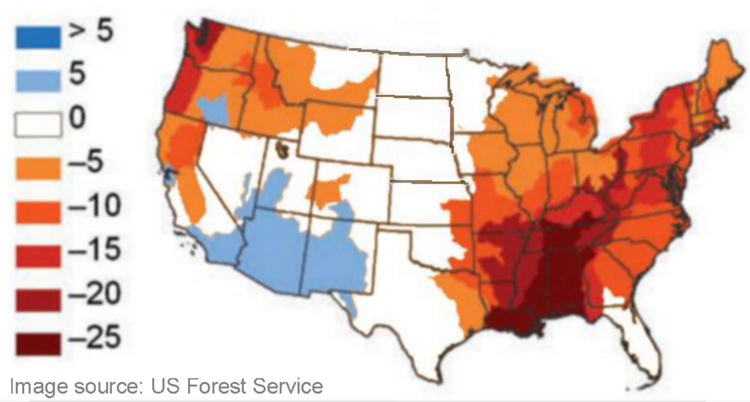
Once extra CO_2 gets into the atmosphere, it stays there for a long time. Most of the carbon dioxide that we emit today will still be there centuries from now. Even if we stopped burning fossil fuels right now, it would take the better part of a millennium for photosynthesis and other carbon-consuming processes to remove all our excess CO_2 from the atmosphere. For all practical purposes, the effects of climate change are permanent, and the more CO_2 we add to the atmosphere, the more severe those effects will be. It is true that the earth's climate could return to normal after a few thousand years, but most of us don't have a few thousand years to wait for things to get back to normal.

THE EFFECTS

WATER SUPPLIES

Water is our most important natural resource. Global surface temperatures affect the movement of air currents, the formation of high and low pressure systems, and the movement of water vapor around the atmosphere. All of these factors play a role in determining where, when, and how much it rains. Rising global temperatures will alter this system in many areas, potentially reducing the amount of water available to meet residents' agricultural, industrial, and recreational needs.

Climate change poses a serious risk to water supplies around the United States. Climate scientists predict that many parts of the country will see a reduction in annual rainfall by 2080.[11] Droughts are likely to become more common and more severe. Water stresses will lead to legal and economic conflicts as cities and states wrangle over how best to allocate diminished water supplies. This is already happening in the southeast, where Georgia and the city of Atlanta are locked in a legal battle with Florida and Alabama over how to divvy up the water in the Lake Lanier reservoir. Atlanta needs the water for its citizens to drink, while Alabama and Florida need it for agriculture, electrical generation, fishing, and recreation. A reduction in the region's annual precipitation would only sharpen the dispute over the reservoir's water. As some areas become drier due to climate change, we will see more of these intercity and interstate disagreements about water use. Inevitably, someone will wind up getting the short end of the stick.



PREDICTED CHANGE IN ANNUAL PRECIPITATION BETWEEN NOW AND 2080 (UNITS ARE CENTIMETERS). BLUE INDICATES AN INCREASE, ORANGE AND RED INDICATE A DECREASE.[9]

In the western states, where much of the land is arid to semi-arid, mountain snows are a crucial reservoir. As they melt throughout the spring and summer, they keep streams fed and the land relatively green, which reduces the risk of wildfires. However, as temperatures climb and the average year gets warmer, two threats to snow packs emerge. Warmer temperatures mean more rain and less snow in winter, and an early thaw in spring. Smaller, faster-melting snow packs will provide less water and disappear more quickly, leaving already dry areas even drier. This will increase the risk of wildfires, which threaten people's health and property, as well as decrease the inflow of water into reservoirs.

Even if you don't live in an area where climate change will strain your water supplies, the lack of water elsewhere in the country will still hit your pocketbook. Droughts, which will become more common in many areas, damage crops. Smaller crop yields mean higher food prices. A drought in the U.S. and Eastern Europe caused a 10% spike in world food prices in July 2012.[12] Overall food prices have since come down, but one year later U.S poultry and egg prices remained 5.5 and 6.9 percent higher, respectively, due to the drought.[13]

HUMAN HEALTH EFFECTS

Ozone is a good thing when it's way up in the atmosphere, where we can't breathe it, protecting earth from damaging UV light. Down at ground level, though, ozone is a nasty air pollutant that can aggravate asthma and heart conditions. Ground-level ozone (smog, basically) forms when nitrogen oxides react with certain chemicals, known as volatile organic compounds, in the presence of sunlight. Warmer temperatures increase the rate at which this reaction occurs, leading to increased ozone levels.[14, 15] As the world gets warmer, the conditions for smog formation will become more favorable.[15] If you live somewhere with a lot of cars or industrial activity, climate change will likely reduce your air quality.

SMOG OVER NEW YORK CITY

Rising temperatures will also increase the prevalence of some diseases. In some areas, climate change will increase the risk of flooding, either due to more overall rain, or more intense rain. Flooding can spread waterborne diseases such as *cryptosporidium*; or, if a sewage treatment plant overflows, *E. coli*. Animal-borne diseases such as West Nile virus will also expand their range. Mosquitos, which carry West Nile virus, need warm weather to survive. Currently, the disease is most common in the southeast, but as the earth warms up and summers get longer and more mosquito-friendly, it will push north, potentially infecting many more people.

ENVIRONMENTAL EFFECTS

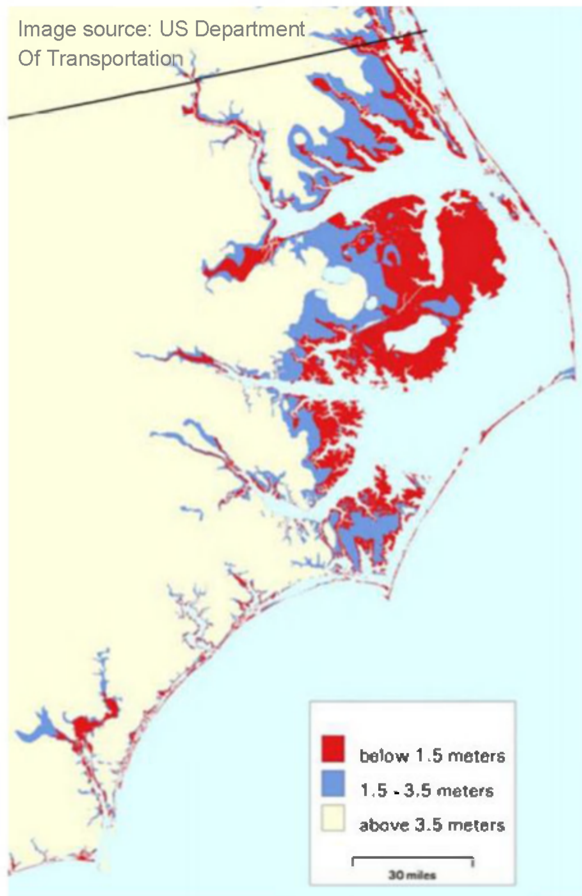
Obviously, humans won't be the only ones affected by climate change. A place's climate is one of the most important factors in determining what kinds of plants and animals can live there. As earth gets warmer, many species will have to move northward in order to keep within their comfort zones. For example, trout need cold water to survive and reproduce. Trout living in more southerly habitats will find it harder to get by as climate change warms the rivers and streams that these popular sport fish call home. In some places, they may disappear entirely, driven out by changes to their food sources and competition from invading warm-water fish. Climate change will cost us valuable recreational and economic opportunities as it reshapes habitats across the country, driving out local plants and animals and, in some cases, paving the way for unwanted species to move in and take their place.

Ocean acidification is another major problem associated with climate change. The oceans have actually absorbed a lot of the CO_2 that we've emitted. This has slowed the rate at which our excess CO_2 accumulates in the atmosphere, but at the cost of increasingly acidic ocean waters.[1] CO_2 in the air reacts with water to form carbonic acid. The more CO_2 the oceans absorb, the more carbonic acid they contain. Many marine organisms, including shellfish, corals, and some species of plankton, build their shells out of calcium carbonate, which is very susceptible to acids. As the oceans become more acidic, these organisms will have a harder time building their shells, which they need to survive. These species are economically important, either because people harvest them directly, or because they are part of an ecological community that supports other commercially valuable species. As they struggle to survive in our acidifying oceans, it will be a blow to many people's livelihoods.

SEA LEVEL RISE

For the many people living in coastal areas, sea level rise due to climate change is a real concern. The oceans are already seven inches higher than they were a century ago,[16] and climate scientists predict that they could rise by another one to five feet by 2100.[1, 17] As global temperatures rise, the Greenland ice sheet will continue to melt, releasing its store of frozen water into the oceans. The Greenland ice sheet contains more than 680,000 cubic miles of ice. If all of it were to melt, it would raise global sea levels by 23 feet.[1] In the short term, sea level rise won't be that dramatic, but if you live in a state like Delaware or Florida, which have an average elevation of only 60ft and 100ft above sea level, respectively, even a couple of feet are concerning. Higher sea levels pose a threat to coastal transportation infrastructure such as roads, tunnels, and, in cities like New York, subways systems. They will also increase coastal erosion, inundate wetlands and low-lying residential areas, and increase the risk of damaging storm surges.

These changes are largely imperceptible on a day-to-day basis. The oceans are only rising by fraction of an inch each year. But over a century, fractions of an inch can add up to a couple of feet. Climate change is the slow accumulation of small changes, until one day they turn into big ones.



ELEVATION ABOVE SEA LEVEL, NORTH CAROLINA. SEA LEVELS ARE PREDICTED TO RISE BY 0.3-1.5 METERS (1-5 FEET) BY 2100.

THE BOTTOM LINE

Climate change won't affect everyone the same way, but everyone will be affected in some way. If you live in Indiana, you don't have to worry about rising sea levels flooding your home, but you will have to worry about decreasing rainfall. Drought and high temperatures will stress crops on the Great Plains and put more pressure on the Ogallala aquifer. In the east, rising sea levels will threaten homes and infrastructure on the coast. Western states will experience more severe fire seasons. And everyone will have to reckon with climate change's economic effects. Adapting to climate change will cost a lot of money, which will be a major drag on the economy.

Given the expense and disruption of climate change, it makes sense for us to try to minimize its impact. Some of the effects are unavoidable—the CO_2 that we've already put in the atmosphere won't be going anywhere for a long time, and the 1.3°F of warming that we've already caused is here to stay—but so far they haven't been too severe. The really dramatic changes are still a few decades' worth of CO_2 away, and we can still avoid them if we start reducing or eliminating our CO_2 emissions now.

WHAT WE CAN DO

ALTERNATIVE ENERGIES

Human CO_2 emissions are the driving force behind climate change, and most of those emissions come from fossil fuels. We have sunk a lot of money into building our fossil fuel infrastructure, but fossil fuels are not the only way to power a modern economy. There are several alternative energy sources that not only emit no CO_2, but are also cost-competitive (or nearly so) with fossil fuels.

Solar: Earth's surface absorbs about 5.1 quintillion joules of energy from the sun every minute. In two hours, it absorbs more energy than the entire world used in 2012.[18] If we can harness even a tiny fraction of that energy, we would never need to burn fossil fuels again. Photovoltaic solar energy, which turns sunlight directly into electricity, is already a popular energy source. Solar thermal power plants use heat from the sun to drive steam turbines. By storing that heat in a medium such as molten salts, they can generate electricity even when the sun isn't shining.


Image source: National Renewable Energy Laboratory

Wind: Wind energy is another clean-energy option. In 2012, the U.S. produced 140 terawatt hours of wind power,[19] and could potentially produce much more. Depending on the area, wind energy output can have significant day-to-day variations, but when paired with other energy sources, such as solar or hydroelectric, it can be an important contributor to a clean, reliable energy supply.

Geothermal: Geothermal energy uses heat from within the earth's crust to generate electricity. While not as widely applicable as wind or solar, geothermal energy could be used in some places to supplement power from solar and wind energy.

No single alternative energy source will be able to replace fossil fuels. However, there are enough options available that, when used together, they can more than meet our energy needs. It will cost money to switch over to a clean energy economy, but the health benefits will offset some of the costs (fossil fuel combustion being responsible for the formation of harmful smog), and every dollar we spend reducing carbon emissions is a dollar we don't have to spend trying to adapt to climate change.

ENERGY CONSERVATION

Switching to clean energy is the big, dramatic step to combat climate change, but conserving energy, while not as flashy, is just as important. Many of our homes and buildings were built decades ago, with materials and techniques that just aren't as energy-efficient as the ones we have today. By making sure that new homes and buildings meet a minimum standard for energy efficiency, and retrofitting old ones to bring them up to code, we can reduce the amount of electricity needed to power them and thus the amount of fossil fuels we need to burn. This not only reduces the amount of CO_2 we emit; it also saves us money on our energy bills.

THE REAL PRICE OF FOSSIL FUELS

An external cost is basically when an economic activity—like manufacturing, transportation, or generating electricity—has a side effect that harms an uninvolved third party. Air pollution is a classic example of an external cost. Smog is harmful to human health, so a factory that emits smog-forming chemicals is imposing an external cost, in the form of increased rates of respiratory disease[20] and higher medical bills, on people who live nearby. In many cases, external costs are not factored into the price of a good or service.

At the moment, fossil fuels are among the world's cheapest energy sources.[21] But that's only because their price does not reflect the economic and environmental damage that climate change (of which CO_2 emissions from fossil fuel combustion are the primary driver) will cause. In other words, fossil fuels have huge external costs. Taking into account the damage that they do to human health and the environment, energy from coal and oil should be at least 50% more expensive than it is now.[22, 23] The underpricing of fossil gules gives them an unfair competitive advantage over other, non-CO_2-emitting energy sources. If we are to switch to a clean-energy economy and mitigate the effects of climate change, fossil fuels have to be fairly priced.

GETTING THE PRICE RIGHT

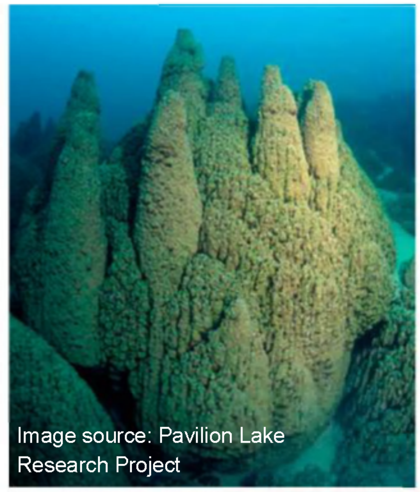
When it comes to bringing the price of fossil fuels in line with their real cost, there are two main options. The first is simply to tax carbon dioxide. The goal of a CO_2 tax would be to internalize the external costs of fossil fuels and eliminate their unfair market advantage. The second option, known as cap and trade, offers a more market-friendly option to reduce CO_2 emissions. In a cap and trade program, the government sets a limit on national CO_2 emissions. Companies that emit CO_2 must then purchase permits for their emissions (one permit usually being equal to a ton of CO_2), with the number of permits not to exceed the total emissions allowed by the national cap. Companies that manage to reduce their emissions can sell their excess permits to companies that are having a harder time bringing their emissions down. Over time, the cap gets smaller and smaller, with the goal being to eventually bring overall CO_2 emissions down to zero. And we know that cap and trade programs can work: In the U.S., a cap and trade program designed to reduce sulfur dioxide emissions has helped cut the nationwide occurrence of acid rain by close to 50% since 1990.[24]

CARBON SINKS

Cutting CO_2 emissions is crucial to mitigating climate change's effects. We can't eliminate all our emissions at once, though, so in the meantime there are steps we can take to help offset them. Plants are excellent carbon sinks: they pull CO_2 out of the air and incorporate it into their bodies. And long-lived plants, like trees, keep that CO_2 out of the atmosphere longer. By encouraging reforestation, we can help pull back some of our CO_2 emissions and slow down climate change, at least a little. Changing the way we grow our food can also help offset some of our emissions. Soils are important carbon reservoirs. Unfortunately, tilling soil reduces its ability to store carbon. Less intensive tilling, as well as other green agricultural practices, such as crop rotation, can help improve the amount of carbon that our soils can store.

THE BIOSPHERE

CAN LIFE CHANGE THE EARTH?



STRUCTURES FORMED BY PHOTOSYNTHESIZING BACTERIA.

Earth is huge: 24,000 miles around, its surface covered by 196 million square miles of continents, islands, oceans, and lakes. The forces that shape its surface—wind, rain, rivers, oceans, glaciers, volcanoes, earthquakes—are monumental. In comparison, human beings seem tiny. It's hard to imagine that our activities can change the way the natural world works. But living things, humans included, are more than just passengers on the earth. They play an important role in shaping its geologic and chemical systems. In the past, they have remade the earth in ways even more dramatic than we are today.

4.5 billion years ago, when the earth was first formed, there was no oxygen in the air.[25] Our planet's early atmosphere was an unbreathable mix of volcanic gasses—mostly nitrogen, carbon dioxide, and methane. The lack of oxygen in the atmosphere meant that, for a large part of our planet's history, only simple organisms like bacteria could survive on earth. But then, 2.4 billion years ago, the amount of oxygen in the atmosphere slowly began to creep up. Over the next two billion years, earth went from having an atmosphere with no oxygen in it, to having and atmosphere that was about 12% oxygen, enough for animals and other complex forms of life to start making their appearance.[25]

The source of the oxygen was not volcanoes, or the movement of earth's plates, or any other geologic force. It came from bacteria. Three billion years ago, a kind of photosynthesizing bacteria, known as cyanobacteria, appeared on earth.[25] Like modern plants, cyanobacteria use light from the sun to turn water and carbon dioxide into chemical energy. And, also like modern plants, cyanobacteria excrete or "breathe out" oxygen gas as a waste product. At first, all of the oxygen produced by the cyanobacteria went into the oceans. At the time, the oceans were rich in dissolved iron, which reacts with oxygen to form iron-oxide minerals like magnetite and hematite—rust, more or less. Once all that iron had been used up (when dissolved iron combines with oxygen, the resulting iron-oxides sink to the ocean floor), there was nowhere left for the oxygen to go except into the atmosphere. As the cyanobacteria continued to thrive, each year saw a little more oxygen in the atmosphere than the one before.

DROPS MAKE AN OCEAN

By itself, a single cyanobacterium would never have had much of an effect on earth's atmosphere. But over the course of a few billion years, the combined oxygen emission of millions upon millions of cyanobacteria caused perhaps the most important change in atmospheric chemistry in earth's history. Today, no single human being has the capacity to change the atmosphere. But seven billion people, each emitting a small amount of carbon dioxide, can have a profound effect on the way our planet works. But unlike the cyanobacteria before us, we have the knowledge and the insight to understand what we're doing, and to do something about it.

GAMBLING OUR FUTURE

WHY TAKE A BAD BET?

When we talk about climate change's effects, we're talking about what is likely to happen, not what is guaranteed to happen. Earth's climate is an extremely complicated system, and while climate scientists are sure about the broad outlines of climate change's effects—rising temperatures and sea levels, changes in the weather, increasing water stresses—we still don't know exactly how severe they will be. Climate change could be less serious than predicted, or (and this is the more likely possibility) much worse. The best case scenario is that things won't get any worse than they are today, which is extraordinarily unlikely.

We have nothing to gain by betting on business as usual, but an awful lot to lose: drought-damaged crops will cost money; fighting wildfires and rebuilding the homes they destroy will cost money; supplying water to cities and towns in regions where the rains fall less often than they used to will cost money; fighting back the rising oceans will cost money. In some cases, these costs will be prohibitive. We simply don't have the resources to remediate all of climate change's effects.

Climate scientists are 95% certain that climate change is happening, is human-caused, and will have major negative effects on both humans and the natural world.[1] Doing nothing to combat climate change is like ignoring an overloaded electrical outlet because, even though it's a mess of frayed, sparking wires, there's a small chance that it won't eventually start a fire. If you do nothing and it doesn't burn your house down, then you got lucky, but why take the risk? There's nothing to gain by not buying a decent power strip and some new appliances. It's a little bit of an investment, but far less expensive than the alternative. You can rebuild your house if it burns down—and we will be able to adapt, for the most part and at considerable expense, to climate change—but it's foolish to rebuild your house when you could have prevented it from burning down in the first place.

Except for the 1.3°F of warming that we've already caused, major climate disruption is not a foregone conclusion. We can prevent climate change from hitting us with its worst effects, but only if we start doing something about it now. We have the means—wind, solar, and geothermal power, energy efficient building materials and techniques—all we need now is the will. Earth's climate has been good to us. It's been pretty stable for the past 10,000 years, and that stability has allowed our civilizations to develop and thrive. If we let our fossil fuel use alter those climatic norms, we are leaving our children and grandchildren a less predictable, more unstable world. We have a responsibility to ensure that future generations have the same or better opportunities than we had; allowing climate change to happen would be an abdication of that responsibility. Let's not let the opportunity to stop climate change pass us by; let's do what needs to be done, embrace alternative energy and energy conservation, and leave the world as good and as livable a place as we found it.

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