Large and Long-Lasting Human-Caused Climate Change

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Summary
The carbon dioxide released into the air by human fossil-fuel burning will have large and long-lasting effects on climate and sea level, impacting humans and other living things in major, costly ways. The high scientific confidence in these conclusions is based on a "four-legged stool" of evidence: (i) understanding from fundamental sciences (physics, chemistry, biology); (ii) agreement among a range of models of different types implementing the scientific understanding and run by different groups; (iii) emergence of trends in recent observations; and (iv) confirmation from Earth's climate history. Major changes expected include increasing heat stress and decreasing cold stress, increasing variability in the water system (more droughts and floods), increasing strength of the strongest storms, and sea level rise. Some of these changes are already occurring, but human decisions will control how large they become. Because the estimated costs and impacts of a degree of warming increase as the temperature rises, timely actions can be economically beneficial. Uncertainties in these projections are notable but mostly on the "bad" side; a chance of highly damaging impacts of carbon dioxide is not balanced by an equal chance of similarly beneficial changes. Research to reduce uncertainties thus can be cost effective in guiding policies.

Current realities
The climate warming from the carbon dioxide (CO_2) released by burning fossil fuels was first estimated in 1896. Much of the modern physical interpretation rests on military research conducted at Hanscom Air Force Base after WWII, for purposes such as designing sensors for heat-seeking missiles targeting the infrared energy emitted by the hot engines of enemy bombers. Such sensors would not work well if designed for some wavelengths because most of the energy is quickly absorbed by complex molecules in the air including CO_2, which then collide with other molecules and transfer the energy, warming the whole atmosphere. This knowledge also applies to climate studies; the Earth maintains energy balance by absorbing sunlight and then sending infrared radiation to space, and some of this radiation is absorbed by CO_2.

Humans release much CO_2 (about 38,000 pounds per person per year in the United States; for reference, compare to about 1,000 pounds of household trash per person per year in the U.S.), and this CO_2 is warming the planet. This warming causes other changes that amplify the warming. In particular, warmer air picks up more water vapor, itself a greenhouse gas, from the vast oceans. Water vapor added directly to the air by fossil-fuel burning or other processes rains out in just over a week, whereas the CO_2 concentration, once raised, will remain elevated for tens of thousands of years; the only major way to raise water vapor notably is to raise temperature. Other changes in response to warming may amplify or reduce that warming, but the net is moderately strong amplification. This conclusion is based on physical understanding, and on consistent results when that physical understanding is implemented in simple and complex models of various types run by different groups in different countries with different funding sources. Projections of warming made with such models a few decades ago are now seen to be accurate. Also, when the models are run with estimated past changes in brightness of the sun, blocking of the sun by volcanic dust, CO_2, etc., those models skillfully reproduce past climate changes that are estimated from sedimentary records in ice cores, ocean sediments, etc. If there is a consistent problem with the models, the climate has changed more than simulated. Strong warming is likely to release CO_2 stored in cold soils and sea-floor sediments, amplifying and extending the warming; CO_2 ultimately is removed from the ocean-atmosphere system by reaction with rocks and formation of new fossil fuels over 100,000-year timescales.

Many climate changes from rising CO_2 and the resulting impacts can be projected with high confidence, although others are notably uncertain. More water in warmer air gives more-intense precipitation when conditions are favorable, promoting flooding. Warmer air can dry the land faster (hair dryers have heating elements for good reasons), and together with expansion of the subtropical dry zones is projected to increase drought in many regions. The greater energy available from a warmer ocean allows the strongest tropical cyclones to be even stronger. Warming decreases cold stress and increases heat stress on plants and animals. If we continue to release fossil-fuel CO_2 rapidly, rising heat stress could greatly reduce the ability of people to work outside in coming decades, and temperatures high enough to kill healthy people who are not working might begin to occur near the end of this century. Sea level will rise from melting of glacier ice and volume expansion of warming ocean water.

The ongoing CO_2 release is human-caused, but nature has changed CO_2 in the past, affecting climate and living things greatly. In some cases, past extinctions or other impacts were discovered long before the cause from rising CO_2 was identified with confidence. For example, about 56 million years ago at the Paleocene-Eocene Thermal Maximum, nature released about as much CO_2 as humans might release and much more than we have released so far, likely from a large volcanic intrusion into oil-rich rocks. Despite the warming occurring at a slower rate than we are causing, it still led to dwarfing of large warm-blooded animals, migrations, ecosystem disruptions, and local and even global extinctions.

The costs of warming rise super-linearly. For example, sufficiently small sea level rise may cause only “nuisance flooding” that can be handled operationally; slightly greater rise may require much more expensive relocation or levees. Similar arguments apply for most impacts; a farmer facing a small warming can plant crops that prefer warmer temperatures, but no such solution is available when and where temperatures exceed the optimum for all known crops.

Uncertainties about the impacts of rising CO_2 are strongly skewed, with more-damaging impacts more likely than less-damaging or beneficial changes. Sea level rise, for example, is typically projected to be less than three feet by the year 2100, but a rise of as much as 20 feet remains possible. Because the costs rise super-linearly, the chance of a large rise is especially important. Many other aspects have a similar long tail of possible “bad” impacts. The beneficial increase in plant growth from rising CO_2 may be slightly greater or less than expected, but there is some chance that climate change will greatly reduce crop yields through heat, drought, flood, invasive pests, or in other ways. An analogy may be useful: building something valuable requires many tools but breaking can be done with only a hammer; simply raising CO_2 may break things, but causing highly beneficial outcomes is likely to require many additional interventions.

Scientific opportunities and challenges

Energy use provides many benefits to people, and increasing energy use can partially (but not fully) offset the damages caused by fossil-fuel use. The full scholarship shows, however, that efficiently shifting away from a fossil-fuel based economy over a few decades would have economic as well as environmental benefits. A shift must be made; fossil fuels accumulated over a few hundred million years are being burned over a few hundred years, with essentially no new ones being formed, so sustainable reliance on fossil fuels is not possible. Slowing or delaying the change by a few decades will cause climate shifts that make life harder for humans and a wide range of other life on Earth for very long times. Balancing the need for abundant energy now and in the near future with the clear benefits of moving toward a sustainable energy system represents a great societal challenge. Existing technologies will support the transition, but engineering and scientific improvements would make it easier. The optimal rate of shifting depends in part on whether warming will cause very damaging impacts, so improved knowledge of possible worst-case scenarios is important.

A working paper from the International Monetary Fund, together with a report from the International Energy Agency, recently found that full subsidies for fossil fuels in the U.S. and worldwide are quite large, and greatly exceed those for renewable energy. The damages to society from fossil fuel CO_2 are not included in the price of the fuels in most places, and this "social cost of carbon" might be interpreted as the potential profit from wise policies or from technological and engineering advances. The Congressional Budget Office recently found that, even if the benefits of avoiding climate change are ignored, a revenue-neutral tax swap that reduced certain taxes, such as the tax on wages, while raising the price of fossil fuels by this social cost of carbon would not harm the economy. If the benefits of avoiding climate change are included, such a policy can grow the economy compared to business as usual.

Policy issues

- Moving toward a rational carbon price is arguably the single most widely cited mechanism to slow global warming while helping the economy. Many economists favor internationally harmonized carbon prices to simplify otherwise complex global issues.

- The U.S. military has many current efforts in energy generation, storage, and efficient use affecting warfighting and readiness purposes, all of which likely have dual-use benefits. Expanding these, building on the historical successes of the U.S. military in identifying technological options and implementing practical programs that address rapidly changing military and societal needs, is likely to be highly beneficial to the nation.

- The "long tails" of highly damaging possible impacts from rising CO_2 greatly complicate planning. For example, officials cannot easily implement policies that efficiently address a most-likely sea level rise of two feet by late in this century when there remains some chance of a 20-foot rise. Targeted research specifically addressing the most damaging "worst-case" impacts could allow much more efficient decision-making.

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