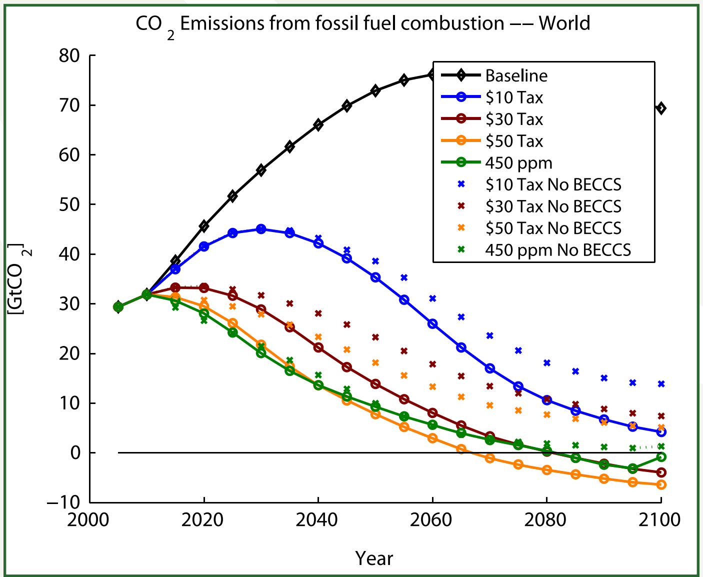
PCIC SCIENCE BRIEF: IS ATMOSPHERIC CARBON DIOXIDE REMOVAL A GAME CHANGER FOR CLIMATE CHANGE MITIGATION?

Recent work by Kriegler et al. (2013) in the journal *Climatic Change* finds that removing carbon dioxide from the atmosphere with a combination of biomass combustion and carbon capture, together with the storage of resulting carbon dioxide underground, can improve the feasibility and reduce the costs of achieving climate change goals.

Current global greenhouse gas emissions are tracking the upper range of the IPCC's scenarios. Climate model results suggest that this could lead to changes in the Earth's climate that would be larger than 2 °C (the range of global temperature change of these upper range scenarios is between 2.4 to 6.4 °C). Despite international consensus on the importance of climate change mitigation, primarily through the reduction of emissions, global emissions are currently increasing. Because of this, there is interest in developing methods for reducing the atmospheric concentration of greenhouse gases. These methods can be broadly broken into two categories: (1) biological methods, that aim to use biological organisms such as trees and algae to remove carbon, and (2) chemical methods, that involve using chemical reactions to reduce carbon dioxide concentrations.

Kriegler and colleagues examine one type of carbon dioxide reduction method, which involves using biomass for energy production and to produce biofuels, while capturing and storing the emissions. The overall strategy is as follows. As the biomass fuel source, such as corn, sugarcane or algae grows, it draws down atmospheric carbon dioxide. That carbon is released upon combustion, in a process that is potentially carbon neutral if a small enough amount of fossil fuel was is used for agricultural inputs and processing (tillage, fertilizer and pesticides, harvest transportation and processing). If the carbon from the combustion of the biomass is captured and stored, then the process, in principle, draws down more carbon than it releases and so the process acts as a carbon sink. This is known as Bioenergy with



Global CO_2 Emissions Projections, from Kriegler et al. (2013).
Carbon dioxide emissions under nine scenarios: a Baseline scenario with no policy to reduce carbon dioxide emissions, three taxation scenarios without Bioenergy with Carbon Capture and Storage (BECCS), three taxation scenarios with BECCS and two-scenarios in which carbon prices are set to limit atmospheric CO_2 equivalent greenhouse gas concentrations to 450 parts per million by the year 2100: one with BECCS and one without.

Carbon Capture and Storage, or BECCS.

The authors examine the effects of implementing this form of carbon dioxide reduction scheme, over the 21st century, on three sectors: energy, transportation and stationary, non-electric energy use (which is primarily heating). The computer model that they use to do this is one that represents global energy use, the economy and the Earth's climate system. Such models are called "Integrated Assessment Models."

They find that, using their carbon dioxide reduction method, greater reductions in emissions are achieved than from taxes on carbon emissions alone (see figure) and that the mitigation costs to reach certain target

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emissions are reduced. The authors note that this can potentially balance the costs between current and future generations, such that the costs of mitigation will not rise dramatically for those living at the end of the 21st century. They also find that their carbon dioxide reduction method still plays a smaller role in overall emissions reduction than do direct measures, such as regulation and taxation. In the first half of the 21st century, the authors find that the electricity sector has the strongest reaction to an increasing carbon price, but the lifespan of fossil fuel infrastructure acts as a limit to emissions reduction. Most of the emissions reductions from the BECCS strategy in the near-term come from the electricity sector, though BECCS, because it removes carbon dioxide from the atmosphere, also allows for longer overall fossil fuel use in the generation of energy.

Kriegler et al. note that the transportation sector is the hardest to decarbonize, with reductions coming from reduced use[1] and higher cost technologies not related to BECCS. Negative emissions in both the electric and stationary non-electric sectors come from hydrogen and biofuel produced from biomass with carbon capture and storage.

The authors note that their method is limited both by biomass supply and by subterranean storage, which they estimate at approximately 3.6 teratonnes[2]. Because biomass requires the use of land, the authors caution that it could potentially compete with land for food production, reduce biodiversity, and have additional emissions due to deforestation for land use change.

Methodology

The authors use the Refined Model of Investment and Technological Development (ReMIND) global integrated assessment model, which has three modules: a macro-economic module, an energy-system module and a climate module. It calculates trade in goods, primary energy carriers, emission allowances, demand in energy for transportation, electricity and heating, as well as a simple climate model. The model includes emissions of sulfur dioxide, which forms aerosols, and three greenhouse gases: carbon dioxide, nitrogen dioxide and methane. The model includes approximately 50 different ways that primary energy sources, such as solar, wind, uranium, coal and biomass can be converted to energy carriers, such as electricity, heat, hydrogen, solid fuels, gases and petrol. Several of these conversion routes use biofuels: biomass to gas for combustion, biomass to liquid fuel and biomass to hydrogen for use in the commercial, residential and transportation sectors.

Kriegler et al. worked from nine scenarios that describe emissions, policy and alternative energy over the 21st century: a baseline scenario, in which no climate policies are enacted and emissions increase until 2060 and decrease after 2060; a scenario in which a carbon price is enforced to limit the atmospheric concentration of greenhouse gases to the equivalent of 450 parts per million of carbon dioxide (carbon dioxide equivalent is often referred to as CO_2e) with BECCS; a similar scenario in which a carbon price is enforced to limit the atmospheric concentration of greenhouse gases to the equivalent of 450 parts per million of carbon dioxide without BECCS; three scenarios with taxes of $10, $30 and $50 per tonne of CO_2e emitted, starting at the year 2015 and raising by 5 % each year afterward; and three scenarios with these taxes and with the addition of biofuels and carbon capture. The authors assume that the cost of bioenergy will increase as use increases, with an upper bound of total production of 200 exajoules[3] per year. Kriegler and colleagues took the global subterranean storage capacity of carbon dioxide to be 3.67 teratonnes and the maximum injection rate of carbon dioxide into these geological formations to be roughly 18 billion tonnes of carbon dioxide per year.

Using these methods, the authors arrived at the conclusions above.

Kriegler, E., et al., 2013: Is atmospheric carbon dioxide removal a game changer for climate change mitigation? *Climatic Change*, **118**, 45-57, doi: 10.1007/s10584-012-0681-4.

1. For a recent discussion on the upper limits of emissions from oil due to geological limitations and declining production, see: Murray, J.W., 2013: Peak Oil and Energy Independence: Myth and Reality. *EOS*, **94**, 28, 245-246.
2. One teratonne is 1,000,000,000,000 tonnes and a tonne is 1000 kilograms or 2,204.6 pounds. For reference, an average skyscraper tower weighs on the order of a hundred thousand tonnes.
3. One Joule is the amount of energy expended in applying a force of one Newton for one meter (roughly, the energy expended in raising a plum or a small apple weighing 100 grams, by one meter, against gravity). An exajoule is 1,000,000,000,000,000,000 Joules. For reference, the human population of the world uses about 500 exajoules of energy per year.

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