Introduction

The Carbon Mitigation Initiative (CMI) at Princeton University is a university-industry partnership sponsored by BP that began in 2000. The goal of the initiative is to lead the way to a compelling and sustainable solution to the carbon and climate change problem. 2015 concludes the first 15 years of the CMI program and marks the transition to the second renewal that will carry the program forward through 2020.

Interaction between Princeton and BP this year has been more extensive than in previous years. At BP’s request, Princeton researchers spent several days in conversations with senior BP leaders, first in London in May and then in Houston in September. The two-day CMI annual meeting in Princeton attracted more BP participation than in any prior year. There were numerous teleconferences.

This thread of high-level and close interaction continues into 2016 as preparations are underway for Princeton to host the CMI annual meeting at BP’s headquarters in London—the first time in CMI’s 16-year history that the meeting has not been in Princeton. Holding the annual meeting in London creates opportunities for deeper involvement of BP with Princeton’s program and suggests an increased determination on BP’s part to pay attention to climate change.

The hallmark of CMI’s research is connectivity across science, technology, and policy to offer an integrated assessment of Earth system science, carbon mitigation options, and societal responses. A major component of the next five years is a concerted effort to enhance integration and outreach and to provide sound information about climate science that will enable effective public policy discussions.

The CMI program currently includes approximately 14 lead faculty and more than 50 research staff and students at Princeton. In 2015, CMI was restructured to form three research work groups: Science, Technology, and Integration and Outreach.

**CMI Science** focuses on how terrestrial vegetation and the oceans soak up carbon and thereby determine the fraction of the carbon dioxide (CO$_2$) emitted into the atmosphere that actually stays there (the fraction is about one-half). CMI science increasingly features close collaboration with Princeton’s neighbor, the Geophysical Fluid Dynamics Laboratory (GFDL) of the US Department of Commerce. A recent and growing component of CMI addresses climate variability and departures from the historical frequency of extreme events, such as heat waves, droughts, and hurricanes.

**CMI Technology** studies energy conversion in conjunction with CO$_2$ capture and storage. Capture studies include both biological and fossil fuel inputs. Storage studies emphasize leakage pathways and now also investigate storage in shales. A program on advanced batteries has begun.

**CMI Integration and Outreach** introduces new conceptual frameworks that are useful for climate change policy. One effort seeks to make the emerging statistical analyses of extreme
events more accessible. A second effort focuses on improving the risk-assessment framework for the current scientific understanding of sea level rise. A third explores the value for climate policy analysis of adding a new component to traditional carbon accounting that tracks “committed emissions,” i.e., the future emissions that are likely to result when a power plant, vehicle, or addition to infrastructure is placed into service.

In this report, each of the PIs or teams of PIs has chosen to feature one research highlight from 2015 and has provided context for the work. These highlights are supplemented by a complete list of the year's publications.

For more information, visit us at CMI’s website - http://cmi.princeton.edu - or email us at cmi@princeton.edu.
CMI Science

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Research Highlights – At a Glance

Stephen Pacala: Tropical forests represent a key terrestrial carbon sink, yet their levels of carbon storage have been challenging to estimate due to the multi-layered structure of tropical forest tree communities. The Pacala group has used data from Panama’s Barrow Colorado Island Rainforest to develop a model for investigating carbon storage in tropical forests with improved accuracy. Another challenge is understanding methane emissions from oil and gas infrastructure, due to the ephemeral nature of high-emitting sources. The Pacala group has created a new method for estimating methane emissions that combines systematic and biased sampling data with meteorological factors.

Jorge Sarmiento: Biological and geological processes occurring in the Southern Ocean around Antarctica have important impacts on global carbon and climate cycles. Recent modeling results show that the Southern Ocean acts as a key sink for atmospheric $\text{CO}_2$, thus mitigating global temperature increases caused by rising levels of $\text{CO}_2$. To examine the dynamics of these processes across space and time, Jorge Sarmiento is directing the world’s first large-scale deployment of robotic floats equipped with biogeochemical measurement instruments. The project will enable unprecedented observations of pH, biological productivity, carbon cycling, and phytoplankton dynamics in the Southern Ocean.

Michael Bender: Studies of ice cores from Greenland show that the Greenland ice sheet has persisted for at least 1 million years. This result puts limits on the sensitivity of the Greenland ice sheet to climate change, and provides a test for models of the ice sheet.
François Morel: Increasing concentrations of atmospheric $\text{CO}_2$ lead to higher concentrations of dissolved $\text{CO}_2$ in surface seawater. This results in ocean acidification, which may affect the growth of the photosynthetic phytoplankton that form the basis of marine food webs. The Morel group has conducted both field and laboratory experiments to examine the effects of acidification on phytoplankton productivity. The results will enable future assessments and predictions of how $\text{CO}_2$ concentration changes impact marine ecosystems.

Stephen Pacala and Elena Shevliakova: Beyond assessing effects of greenhouse gas emissions on trends in global temperature increases, research efforts led by Pacala and Shevliakova have advanced analysis of extreme precipitation from observations and climate model simulations, as well as improved representation of processes that affect climate extremes on regional scales, such as urbanization and dust emissions.
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Research Highlights – At a Glance

**Michael Celia:** The capture and belowground storage of carbon dioxide (CO$_2$) emissions from power plants and other sources has the potential to mitigate climate change by preventing the release of these emissions into the atmosphere. The presence of abandoned oil and gas wells in areas that are otherwise suitable for geological storage may compromise storage integrity. Both CO$_2$ and brine may leak out from old wells, potentially contaminating groundwater supplies and possibly leading to CO$_2$ leakage into the atmosphere. The Celia group has combined modeling approaches with empirical data collection to estimate the risks of leakage along abandoned wells in the Wabamun Lake area of Alberta, Canada.

**Howard Stone:** Climate changes involve atmospheric motions, ocean flows, and evolution of ice on land and in the sea. These dynamics are necessarily interrelated; insights into individual processes can help to illuminate poorly understood aspects of global climate dynamics, such as factors affecting the maintenance of sea ice cover in the Arctic basin. Sea ice cover can impact fresh water fluxes, local ecology, and ocean circulation. The Stone group is providing simplified models for understanding the movement of ice through narrow straits, which can affect flow and mixing in the ocean.

**Daniel Steingart:** Building more energy-efficient systems depends on the ability to optimize and regulate the performance of energy-storing batteries. The Steingart group has developed a new type of zinc material that overcomes many of the limitations of zinc storage batteries. This material may be useful for long-term energy storage in grid-scale and electric vehicle applications.
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Research Highlights – At a Glance

Robert Williams, Eric Larson, and Thomas Kreutz: Meeting current targets for reducing greenhouse gas emissions to mitigate climate change will require major changes in the makeup of the US electricity sector in the coming decades. A study by the Energy Systems Analysis group identifies incentives for carbon capture and storage (CCS) as a promising and economically viable approach to meeting emissions reduction goals. The study includes a thought experiment that analyzes how the contributions of different CCS technologies, along with shifts to renewable energy sources, could enable the US to achieve an 83% reduction in greenhouse gas emissions from power generation by 2050.

Michael Oppenheimer: To achieve incremental, near-term greenhouse gas emissions reductions, both governmental and private stakeholders can be encouraged to form partnerships driven by diverse political and economic incentives. These initiatives may take a variety of forms, and may serve to enhance the emissions reductions promised by existing international agreements.

Robert Socolow: A new academic field, Destiny Studies, should be created to foster coherent thinking about future time and the planetary vulnerabilities that will constrain what we are able to do. Today, when we make decisions that affect future generations, we are inconsistent and not guided by general principles. Notably, we are confused about future time—for example, we have difficulty distinguishing 500-year and 50-year time frames. Climate change and its solutions make particularly stringent demands on thinking about the future and are ripe for Destiny Studies.
Carbon Mitigation Initiative
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